ABB Review

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1 / 2009

Elements of productivity

Intelligent devices discover social networking
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The cogwheel is often used to symbolize productivity. Interlocked with other geared components, the wheels interact to advance the mechanism.

At ABB, productivity is the result of a multitude of innovations made by its dedicated work force, advancing ABB's offerings to provide efficient customer solutions. This issue of *ABB Review* takes a closer look at some of these "Elements of productivity."

The quest for the optimum

Throughout the history of industry, there has been one factor that has spurred on progress more than any other. That factor is productivity. From the invention of the first pump to advanced computer-based optimization methods, the key to the success of new ideas was that they permitted more to be achieved with less. This meant that consumers could, over time and measured in real terms, afford to buy more with less money. Luxuries restricted to a tiny minority not much more than a generation ago are now available to almost everybody in developed countries, with many developing countries rapidly catching up.

With industry and consumers expecting the trend towards higher productivity to continue, engineering companies are faced with the challenge of identifying and realizing further optimization potential. The solution often lies in taking a step back and looking at the bigger picture. Rather than optimizing every step individually, many modern optimization techniques look at a process as a whole, and sometimes even beyond it. They can, for example, take into account factors such as the volatility of fuel quality and price, the performance of maintenance and service practices or even improved data tracking and handling. All this would not be possible without the advanced processing capability of modern computer and control systems, able to handle numerous variables over large domains, and so solve optimization problems that would otherwise remain intractable.

Whether through a stunning example of how to improve the rolling of metal, or in a more general overview of progress in optimization algorithms, this edition of *ABB Review* brings you closer to the challenges and successes of real-world computer-based optimization tasks. But it is not in optimization and solving alone that information technology is making a difference: Who would have thought 10 years ago, that a technician would today be able to diagnose equipment and advise on maintenance without even visiting the factory? ABB's Remote Service makes this possible. In another article, *ABB Review* shows how the company is reducing paperwork while at the same time leveraging quality control through the computer-based tracking of production. And if you believed that so-called "Internet communities" were just about fun, you will be surprised to read how a spin-off of this idea is already leveraging production efficiency in real terms. Devices are able to form "social networks" and so facilitate maintenance.

This edition of *ABB Review* also features several stories of service and consulting successes, demonstrating how ABB's expertise has helped customers achieve higher levels of productivity. In a more fundamental look at the question of what reliability is really about, a thought-provoking analysis sets out to find the definition of that term that makes the greatest difference to overall production.

Robots have often been called "the extended arm of man." They are continuously advancing productivity by meeting ever-tightening demands on precision and efficiency. This edition of *ABB Review* dedicates two articles to robots.

Further technological breakthroughs discussed in this issue look at how ABB is keeping water clean or enabling gas to be shipped more efficiently.

The publication of this edition of *ABB Review* is timed to coincide with ABB Automation and Power World 2009, one of the company's greatest customer events. Readers visiting this event will doubtlessly recognize many technologies and products that have been covered in this and recent editions of the journal. Among the new products ABB is launching at the event is a caliper permitting the flatness of paper to be measured optically. We are proud to carry a report on this product on the very day of its launch.

Enjoy your reading.

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

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Perpetual pioneering

Service from afar

ABB's Remote Service concept is revolutionizing the robotics industry

Dominique Blanc

ABB robots are found in industrial applications everywhere – lifting, packing, grinding and welding, to name a few. Robust and tireless, they work around the clock and are critical to a company's productivity. Thus, keeping these robots in top shape is essential – any failure can lead to serious output consequences. But what happens when a robot malfunctions?

ABB's new Remote Service concept holds the answer: This approach enables a malfunctioning robot to alarm for help itself. An ABB service engineer then receives whole diagnostic information via wireless technology, analyzes the data on a Web site and responds with support in just minutes. This unique service is paying off for customers and ABB alike, and in the process is revolutionizing service thinking.

Every minute of production downtime can have financially disastrous consequences for a company. Traditional reactive service is no longer sufficient since on-site service engineer visits also demand great amounts of time and money. Thus, companies not only require faster help from the service organization when needed but they also want to avoid disturbances in production.

In 2006, ABB developed a new approach to better meet customer's expectations: Using the latest technologies to reach the robots at customer sites around the world, ABB could support them remotely in just minutes, thereby reducing the need for site visits. Thus the new Remote Service concept was quickly brought to fruition and was launched in mid-2007. Statistics show that by using the system the majority of production stoppages can be avoided.

Reactive maintenance

The hardware that makes ABB Remote Service possible consists of a communication unit, which has a function similar to that of an airplane's so-called black box 1. This "service box" is connected to the robot's control system and can read and transmit diagnostic information. The unit not only reads critical diagnostic information that enables immediate support in the event of a failure, but also makes it possible to monitor and analyze the robot's condition, thereby proactively detecting the need for maintenance.

If the robot breaks down, the service box immediately stores the status of the robot, its historical data (as log files), and diagnostic parameters such as temperature and power supply. Equipped with a built-in modem and using the GSM network, the box transmits the data to a central server for analysis and presentation on a dedicated Web site. Alerts are automatically sent to the nearest of ABB's 1,200 robot service engineers who then accesses the detailed data and error log to analyze the problem.

A remotely based ABB engineer can then quickly identify the exact fault, offering rapid customer support. For problems that cannot be solved remotely, the service engineer can arrange for quick delivery of spare parts and visit the site to repair the robot. Even if the engineer must make a site visit, service is faster, more efficient and performed to a higher standard than otherwise possible.

Remote Service enables engineers to "talk" to robots remotely and to utilize tools that enable smart, fast and automatic analysis. The system is based on a machine-to-machine (M2M) concept, which works automatically, requiring human input only for analysis and personalized customer recommendations. ABB was recognized for this innovative solution at the M2M United Conference in Chicago in 2008 Factbox.

Proactive maintenance

Remote Service also allows ABB engineers to monitor and detect potential problems in the robot system and opens up new possibilities for proactive maintenance.

Remote Service enables engineers to "talk" to robots remotely and to utilize tools that enable smart, fast and automatic analysis.

The service box regularly takes condition measurements. By monitoring key parameters over time, Remote Service can identify potential failures and when necessary notify both the end customer and the appropriate ABB engineer. The management and storage of full system backups is a very powerful service to help recover from critical situations caused, for example, by operator errors.

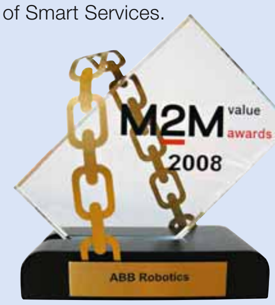
The first Remote Service installation took place in the automotive industry in the United States and quickly proved its value. The motherboard in a robot cabinet overheated and the rise in temperature triggered an alarm via Remote Service. Because of the alarm, engineers were able to replace a faulty fan, preventing a costly production shutdown.

MyRobot: 24-hour remote access

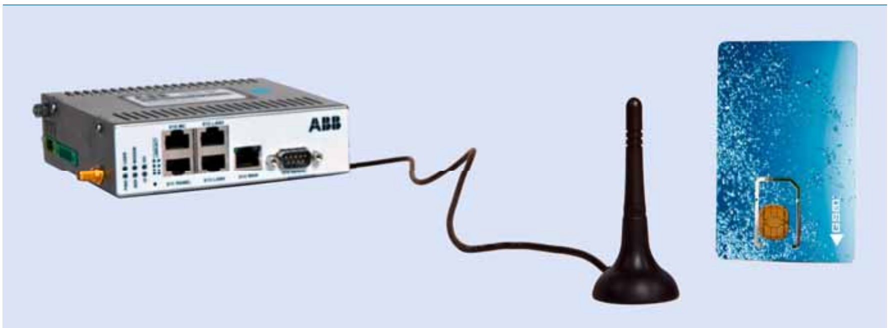
Having regular access to a robot's condition data is also essential to achieving lean production. At any time, from any location, customers can verify their robots' status and access maintenance information and performance reports simply by logging in to ABB's MyRobot Web site. The service enables customers to easily compare performances, identify bottlenecks or developing issues, and initiate the most

Factbox Award-winning solution

In June 2008, the innovative Remote Service solution won the Gold Value Chain award at the M2M United Conference in Chicago. The value chain award honors successful corporate adopters of M2M (machine–to-machine) technology and highlights the process of combining multiple technologies to deliver high-quality services to customers. ABB won in the category of Smart Services.



1 Remote Service "service box," antenna and GSM card



Partnership and productivity

appropriate and timely improvement activities. MyRobot contributes greatly to waste reduction and improved production outputs.

Case study: Tetley

Tetley GB Ltd is the world's second-largest manufacturer and distributor of tea. The company's manufacturing and distribution business is spread across 40 countries and sells over 60 branded tea bags. Tetley's UK tea production facility in Eaglescliffe, County Durham is the sole producer of Tetley tea bags 2.

2 Tetley factory in Eaglescliffe, County Durham

ABB offers a flexible choice of service agreements for both new and existing robot installations, which can help extend the mean time between failures, shorten the time to repair and lower the cost of automated production.

Robots in the plant's production line were tripping alarms and delaying the whole production cycle. The spurious alarms resulted in much unnecessary downtime that was spent resetting the robots in the hope that another breakdown could be avoided. Each time an alarm was tripped, several hours of production time was lost. "It was for this reason that we were keen to try out ABB's Remote Service agreement," said Colin Trevor, plant maintenance manager.

To prevent future disruptions caused by unplanned downtime, Tetley signed an ABB Response Package service agreement, which included installing a service box and system infrastructure into the robot control systems. Using the Remote Service solution, ABB remotely monitors and collects data on the "wear and tear" and productivity of the robotic cells; this data is then shared with the customer and contributes to smooth-running production cycles.

Higher production uptime

Since the implementation of Remote Service, Tetley has enjoyed greatly reduced robot downtime, with no further disruptions caused by unforeseen problems. "The Remote Service package has dramatically changed the plant," said Trevor. "We no longer have breakdown issues throughout the shift, helping us to achieve much longer periods of robot uptime. As we have learned, world-class manufacturing facilities need world-class support packages. Remote monitoring of our robots helps us to maintain machine uptime, prevent costly downtime and ensures my employees can be put to more valuable use."

Service access

Remote Service is available worldwide, connecting more than 500 robots. Companies that have up to 30 robots are often good candidates for the Remote Service offering, as they usually have neither the engineers nor the requisite skills to deal with robotics faults themselves. Larger companies are also enthusiastic about Remote Service, as the proactive services will improve the lifetime of their equipment and increase overall production uptime.

In today's competitive environment, business profitability often relies on demanding production schedules that do not always leave time for exhaustive or repeated equipment health checks. ABB's Remote Service agreements are designed to monitor its customers' robots to identify when problems are likely to occur and ensure that help is dispatched before the problem can escalate. In over 60 percent of ABB's service calls, its robots can be brought back online remotely, without further intervention.

ABB offers a flexible choice of service agreements for both new and existing robot installations, which helps extend the mean time between failures, shorten the time to repair and lower the total cost of ownership. With four new packages available – Support, Response, Maintenance and Warranty, each backed up by ABB's Remote Service technology – businesses can minimize the impact of unplanned downtime and achieve improved production-line efficiency.

The benefits of Remote Sevice are clear: improved availability, fewer service visits, lower maintenance costs and maximized total cost of ownership. This unique service sets ABB apart from its competitors and is the beginning of a revolution in service thinking. It provides ABB with a great opportunity to improve customer access to its expertise and develop more advanced services worldwide.

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Partners in technology

New challenges to a history of cooperation with customers

George A. Fodor, Sten Linder, Jan-Erik Ibstedt, Lennart Thegel, Fredrik Norlund, Håkan Wintzell, Jarl Sobel

ABB's predecessor companies, ASEA and BBC, were founded almost 120 years ago in a time when electromagnetism and Maxwell's equations were considered "rocket science." Since then several technological transitions have occurred and ABB has successfully outlived them all while many other companies vanished at some point along the way. This has been possible because of innovation and a willingness to learn from history. Understanding historical connections between products, technology and industrial economics is extremely important when planning future technologies and innovations.

These connections rely on information channels in companies and their existence cannot be underestimated if a company is to survive. An organization can acquire more information than any one individual, and the optimal use of this information depends on the existence and types of communication channels between those working in a company and the relevant people outside it.

Force Measurement, a division of ABB AB, has a long tradition of innovation. Thanks to strong ties with its customers, suppliers, research institutes and universities, Force Measurement provides state-of-the-art equipment for accurate and reliable measurement and control in a broad range of applications. At the same time, established principles such as Maxwell's equations continue to be applied in new and surprisingly innovative ways to produce products that promote long-term growth and increased competitiveness.

Partnership and productivity

Innovation is a key factor if companies and their customers are to survive what can only be called truly testing times. The target of innovation is to find and implement ideas that reshape industries, reinvent markets and redesign value chains, and many of these ideas come from innovative customers.

Key to successful innovation is communication or the types of information channels employed by firms [1, 2]. A global company like ABB, with offices and factories spanning 90 countries, faces many challenges in maintaining information channels. First of all, there are the internal challenges. Ideas need to be evaluated from many different perspectives to determine their overall impact on the market. Selecting the most effective ones requires expertise and teamwork from the various business, marketing and technology competence groups. Just as important are the channels of communication that exist between ABB, and its customers and suppliers.

The target of innovation is to find and implement ideas that reshape industries, reinvent markets and redesign value chains.

Many of ABB's customers come from countries that are gradually developing strong technology and scientific cultures thanks to major investments in very ambitious research programs. China and India, for example, are two such countries. In fact, the Chinese Academy of Sciences is currently conducting research projects in all state-of-the-art technologies. Countries in Africa and Eastern Europe are capitalizing on their pool of young talent to create a culture of technology development. Emerging markets, while welcome, mean stiffer competition, and competition to companies like ABB encourages even greater levels of innovation.

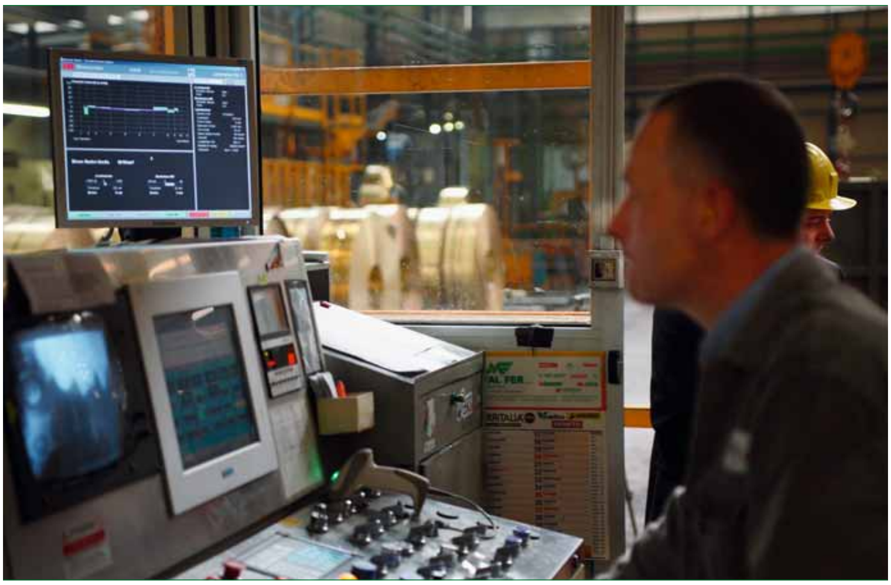
Many customers, similar stories

Backed by 120 years of technological development and experience, ABB continues to produce products and services in many automation, power generation and robotics fields, and the examples described in the following section illustrate this broad customer range.

High precision in Venice

From the 13th century, Venice traded in copper and bronze, which was used to manufacture coins and building details. Today, ILNOR SpA, a family-owned business established in 1961, continues the tradition of processing metals for use in various industries. The high-quality brass, bronze and copper strips it produces are used for products in the automotive, electric and electronic industries. However, the taste for aesthetical and high-quality products is centuries old in Venice, and ILNOR continues to uphold this tradition by constantly investing in technology that improves the quality of its products 1. The choice of the Stressometer 7.0 FSA from ABB was natural. Stressometer systems provide the advanced automated control system needed to produce the high-quality flat strip demanded by producers, and is evidence of ABB's dedication to detail and perfection, something that is well recognized and appreciated in this part of the old world.

1 ILNOR SpA in Venice constantly invests in quality improvements



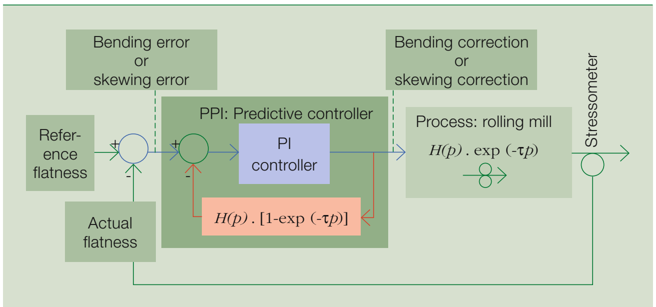
Building customer and internal knowledge networks help to raise business and people performance.

Venetian blinds from Sweden!

Alingsås, a small town in the southern part of Sweden, can trace its origins back to 1382. It is famous among light artists for its annual Lights in Alingsås festival. Alingsås is also well known as a manufacturer of high-quality Venetian blinds. In the Turnils factory, the production range varies over seven widths and six thickness ranges using three different alloys and 1,000 colors. The micron-precision thickness measurement system, better known as the Millmate Thickness Gauging (MTG) system, used in the rolling process is a unique force measurement product based on a proprietary new patented technology platform known as Pulsed Eddy Current (PEC) technology. This measurement system was developed out of a user need for more reliable and accurate thickness gauging. Though fundamentally based on the physics of electromagnetism, the existing technology had to be cleverly manipulated so it could be applied in an industrial setup. The system now in place in the factory can solve complicated Maxwell equations in a matter of milliseconds! High-precision electronics measure signals with a high degree of accuracy and within a time stability frame of picoseconds! A successful system depended on understanding the effects of induced currents in thin metal strips, and this was acquired through extensive laboratory work.

ABB has thus created an intelligent product and platform with superior accuracy and long-term stability. For customers, it is a cost-effective means for process improvement that will definitely withstand the test of time.

2 Classic versus predictive proportional-integral (PPI) control



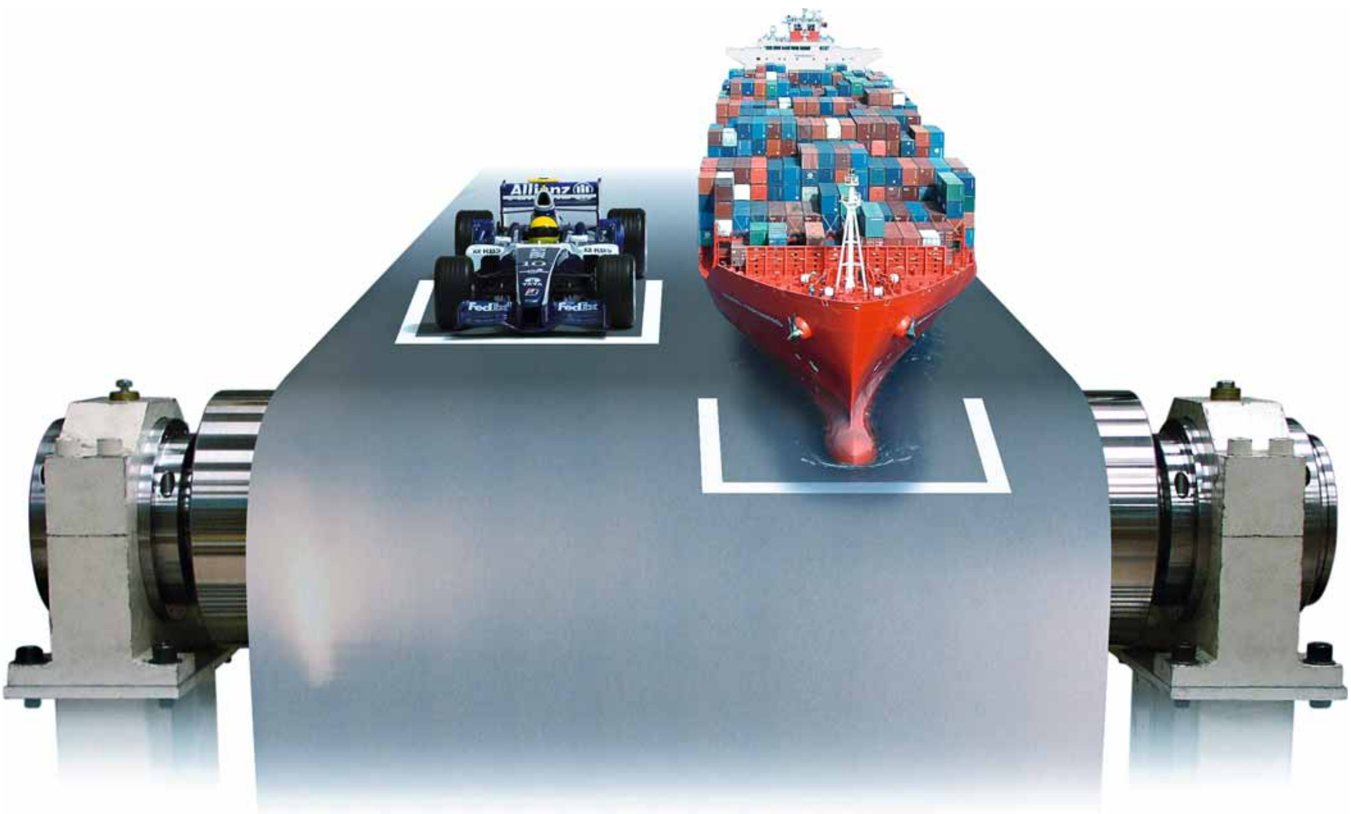
Excellence in China

Union Steel of Korea takes pride in describing itself as "a high technology steel producer."[1] ABB has contributed to this claim as several generations of its Stressometer Flatness Measurement systems can be found in one of Union Steel's daughter companies, the Wuxi Changjiang sheet metal plant in China[2]. Mr. Shen Zhong, the technical manager of the plant, describes the features of the different releases running in the mill: "The earlier version 4.0 has a more traditional industrial interface; the new version 6.0 has a modern human interface; more safety and more computing power. But all versions are excellent products."

Knowledge sharing with customers

Increasing globalization and competition are two of the main issues facing companies today. These challenges can be met through long-term collaboration when companies and customers share expertise and experiences with one another. Building a team consisting of reliable partners with proven track records is critical. However, creating and maintaining appropriate long-term communication channels is a challenge facing this form of collaboration. In particular, developing the necessary language translators and tools is costly and time consuming. For example, transferring specific technological knowledge via general-purpose Matlab or Mathematica syntax; process knowledge via IEC61131/IEC61499 languages; specifications via traditional mathematical formulae; or software design via UML (unified modeling language) takes years of education and experience.

The solution therefore lies in building customer and internal knowledge-sharing networks that enable employees, partners and customers to contribute and use knowledge by utilizing familiar tools. This not only enables a new combination of knowledge, but



Footnotes

[1] http://www.unionsteel.co.kr/eng/about/intro.asp, Retrieved December 2008.

[2] Together with its parent company, Union Steel of Korea, the the Wuxi Changjiang sheet metal plant in China takes pride in contributing "to make the world beautiful with steel." Steel is considered a fashionable art material and every year the plant supports design students in the creation of art with steel. Internationally, the Eiffel tower and pieces by Jack Howard-Potter are examples of steel artwork.

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information can be expressed in a more abstract and compact way. At the same time, business and people performance is raised and competitive power[3)] is increased because the technological and scientific experience a company has is being continuously enhanced.

The Torductor-S sensor ensures continuous and contactless high-speed torque measurements in the most demanding of mechanical conditions.

Successful cooperation between experts from ABB and its customers can make a difference. For example, when a plant expert identifies a problem or the possibility for some process improvement, models, simulations and optimization techniques available on high-end automation equipment can serve as real-time tools. Thus process improvements can be immediately carried out on the spot, something that was not possible in the not-too-distant past. In such a situation, the following steps are typically taken:

1) The problem is identified and isolated.
2) Experts create a model that illustrates the problem.
3) Simulations are performed with the model to determine the parameters of the problem in the simulation environment.
4) Optimization searches for so-called "indifference curves" that may provide a solution to the problem are begun. This is the (abstract) space of parameters that give an optimal solution to the problem. The solution is a specific point within this space.

Optimization techniques that might typically be used include Pareto, an internal point method, or the simplex method.

Consequences for high-end control equipment

This kind of cooperation between experts in control equipment and experts in plant processes is a means towards greater competitive power for all concerned. Additionally, quick modeling cycles and testing are an easy way of proposing and verifying new technologies and products. From a technological perspective, however, such modeling and testing can be done only when the equipment fulfills some design properties. These properties include [3]:

- *Component design*. The system should have software components that can be easily designed, connected and modified. The size (granularity) of these components is important to reach the correct balance between flexibility (ie, the number of components that can be connected and observed) and a manageable number of parameters (ie, the average number of parameters for each component versus how many connectors are needed for all components in an application).
- *Discrete and continuous state observers*. When connecting new components online, the active ones should take care of the process in a seamless fashion. A period of time exists between component switchover in which observers can identify the current state of the component removed while enforcing a corresponding state on the new component.
- *Mathematical, statistical and optimization library*. The system requires a powerful mathematical library that can be used to perform all the correlation, optimization and analysis functions. This is not a trivial task as there are few industrial-strength mathematical libraries available today.
- *Transparent communication*. Different sensor-based systems and control systems should work transparently. In other words both local and remote (ie, over the internet) interaction should be done in the same way. This is important for fast access to a remote plant by experts who might otherwise not be available locally. A steel company, for example, might have a team with expertise in plant parameter tuning. These experts should have the possibility to observe and tune plants around the globe in the same way.

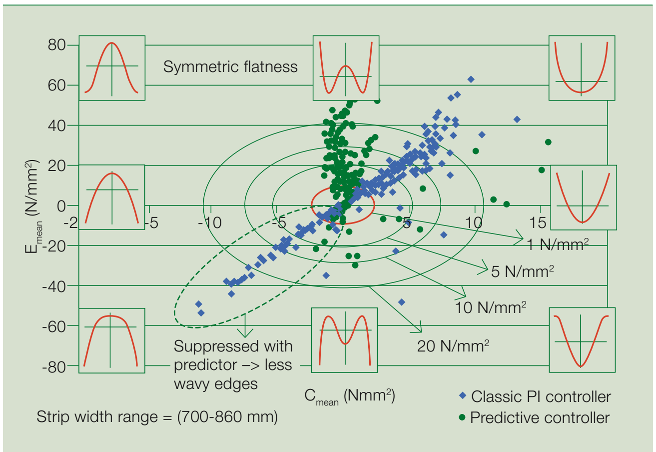
Successful collaborations

ABB is no stranger to long-term collaboration, and its willingness to share expertise and experiences with other

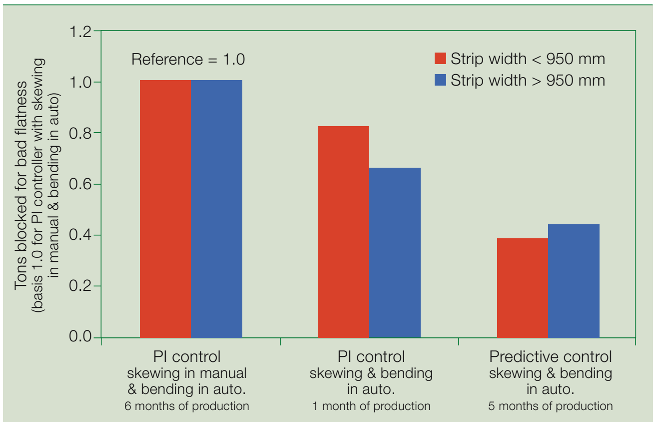
Footnote

[3)] In most cases, the companies and customers in collaboration will have complementary expertise and share a common goal of creating value for their customers.

3 Flatness distribution: versus PPI



4 Over a period of time PPI control leads to a reduction in downgraded material of about 50 percent



companies has proven very successful. One such collaboration involves the ArcelorMittal Research Center in Maizières, France.

Using ABB's Stressometer 7.0, which is designed for heavy matrix-oriented computations for dynamical systems via a component-based architecture, ArcelorMittal Research wanted to test a new adaptive-predictive control algorithm, and ABB experts were more than happy to participate. The idea was to add a predictive control loop to the classical proportional-integral (PI) control 2.

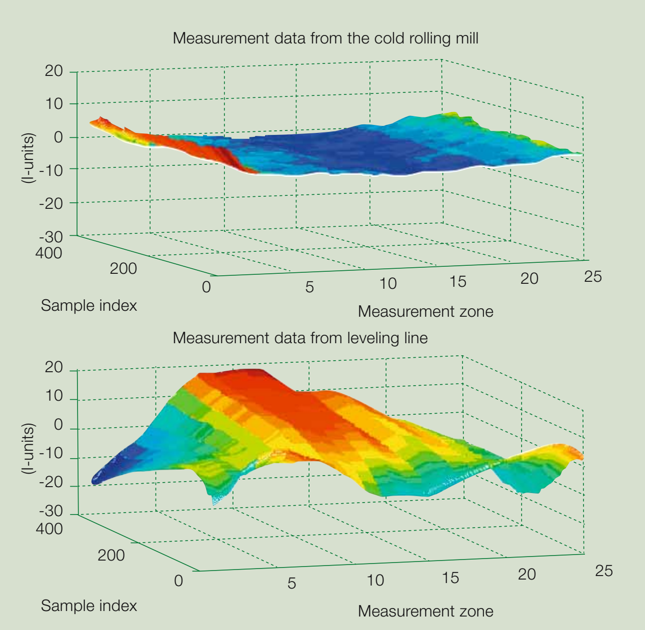
The resulting flatness distribution across actuators using traditional PI versus predictive proportional-integral (PPI) control is shown in 3. Besides some wavy edges along the strip (drawn with a dotted line), the overall difference isn't significant. However, after a test period of five months, the results clearly showed that PPI control leads to a reduction in downgraded material of about 50 percent [4] 4.

Customers with a thorough knowledge of post-rolling conditions can use ABB high-end control equipment to implement very effective post-rolling compensation methods of their own, as the following example illustrates.

> Cooperation between experts in control equipment and those in plant processes is a means towards greater competitive power.

Flatness is an essential property for industrial plants that use metal strips as the input material. Some processes used in the manufacturing of aluminum cans right up to aircrafts, for example, cannot be executed unless metal strips are of the highest quality. In other words, flatness quality is what ABB's customers are promising

5 Post-rolling flatness effects



6 Torque sensors for automotive applications

their customers. However, data from aluminum strip users indicate that although the strip might have had close to perfect flatness after cold rolling, heat and mechanical conditions during transportation combine to deteriorate the flatness profile.

In 2007, ABB experts together with experts from its customer, SAPA Heat Transfer in Finspång, Sweden, decided to analyze the difference between the flatness quality of a product at a customer site and the quality reached immediately after strip rolling. Based on an ABB patent, experts knew that if this difference was described mathematically, the problem could be identified and solved by using the Stressometer 7.0 Flatness Control equipment.

SAPA reproduced, as close as was possible, the thermal and mechanical conditions of post-processing using batch annealing. They found that the flatness did indeed deteriorate quite significantly 5. With the aid of statistical analysis and artificial neural network tools, these effects were identified and documented [5, 6]. This deterioration can now be compensated for using patented multi-dimensional statistical methods.

Torque sensors in F1 cars

How fast is fast enough when changing gears in a Formula One (F1) race? The answer goes through the ABB torque sensor used in the most prestigious competition race cars.

The design of the Torductor-S sensor ensures continuous and contactless high-speed torque measurements in the most demanding of mechanical conditions 6. It can withstand the temperature and vibration levels that exist in a typical racing car.

Working with the technical experts from the racing car industry was a very enriching experience for ABB's Force Measurement team. They witnessed firsthand how F1 engineers:

- Tuned a racing car's engine with the Torductor in the powertrain to achieve optimal performance
- Monitored wear and degradation of the engine during competition
- Monitored and controlled transients and oscillations due to backlash, wheelslip or from the road surface
- Performed condition and overload monitoring, misfiring detection and individual combustion sensing

Cylmate

There is a quiet but ongoing revolution in the design of large, slow-speed, two-stroke diesel engines, the type usually found on marine vessels. In fact more than 50 percent of all ordered vessels now have electronically controlled engines installed. In this

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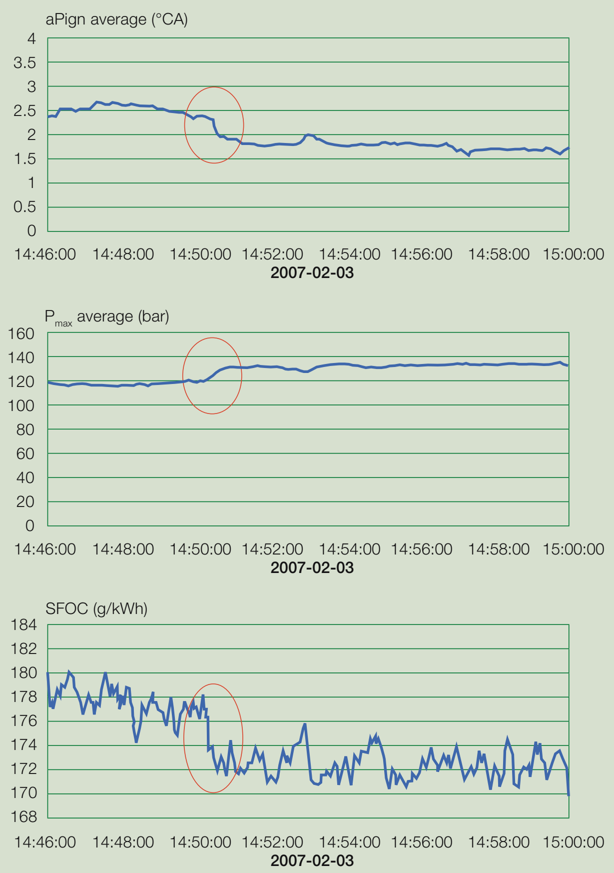
type of engine the mechanical cam has been replaced by electronics, and the combustion process can be automatically tuned by means of a closed-loop control function. Control is applied directly to the firing angle of each engine cylinder. There is a strong correlation between the maximum firing pressure, P_{max}, and specific fuel oil consumption (SFOC, g/kWh). Even small changes in the injection fuel angle (such as 0.5 degrees) can lead to a sizable fuel reduction [7]. As shown in 7, the relationship between P_{max} in the cylinder and SFOC changes when the timing of the fuel injection decreases by half a degree, ie, from a crank angle (CA) of 2.5 degrees to 2.0 degrees. The average value of P_{max} has increased from 120 to 130 bar. The 10 bar increase instantaneously reduces fuel consumption by 2.2 percent, from 177 to 173 g/kWh. Although this may seem small, when viewed as part of a bigger picture it makes quite an impact. According to a 2000 report on the study of greenhouse gas emissions from ships to the

7 The relationship between P_{max} and fuel consumption obtained at the Wärtsilä engine test center in Winterthur, Switzerland



ABB's Cylmate sensor can withstand high pressure and thermal shocks, and its controller can analyze and communicate the cylinder data.

International Maritime Organization (IMO), 138 million tons of bunker fuel was consumed by the global maritime industry in 1996. A saving of 2.2 percent is equivalent to about 3 million tons of bunker fuel, or $1.8 billion. For a typical 6,700 TEU vessel traveling from Rotterdam to Singapore, this would mean savings of about $60,000 plus decreased greenhouse emission effects.

The relationship between P_{max} and the CA is determined by a pressure sensor placed in the cylinder. Known as the ABB Cylmate sensor, it can withstand high pressure, a noxious environment and thermal shocks, and it can analyze and communicate the data during the time available between two cylinder firings. A paper describing how diesel engine performance was measured using the Cylmate engine pressure sensor and analysis equipment was awarded the CIMAC[4)] President's Award in June 2004 at the 24th World Congress of Combustion Engine Technology in Kyoto, Japan.

The importance of communication

Innovation is a key factor for ABB's future and the future of its customers. The sample results shown in this article highlight the importance of cooperating and communicating technological and scientifically relevant results with customers, suppliers, research centers or universities. Working with these enthusiastic groups of people is necessary both for survival and progress.

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Footnote

4) CIMAC stands for Conseil International des Machines à Combustion, and the President's Award is very prestigious in the engine industry.

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Data, not paper

Transforming shopfloor connectivity

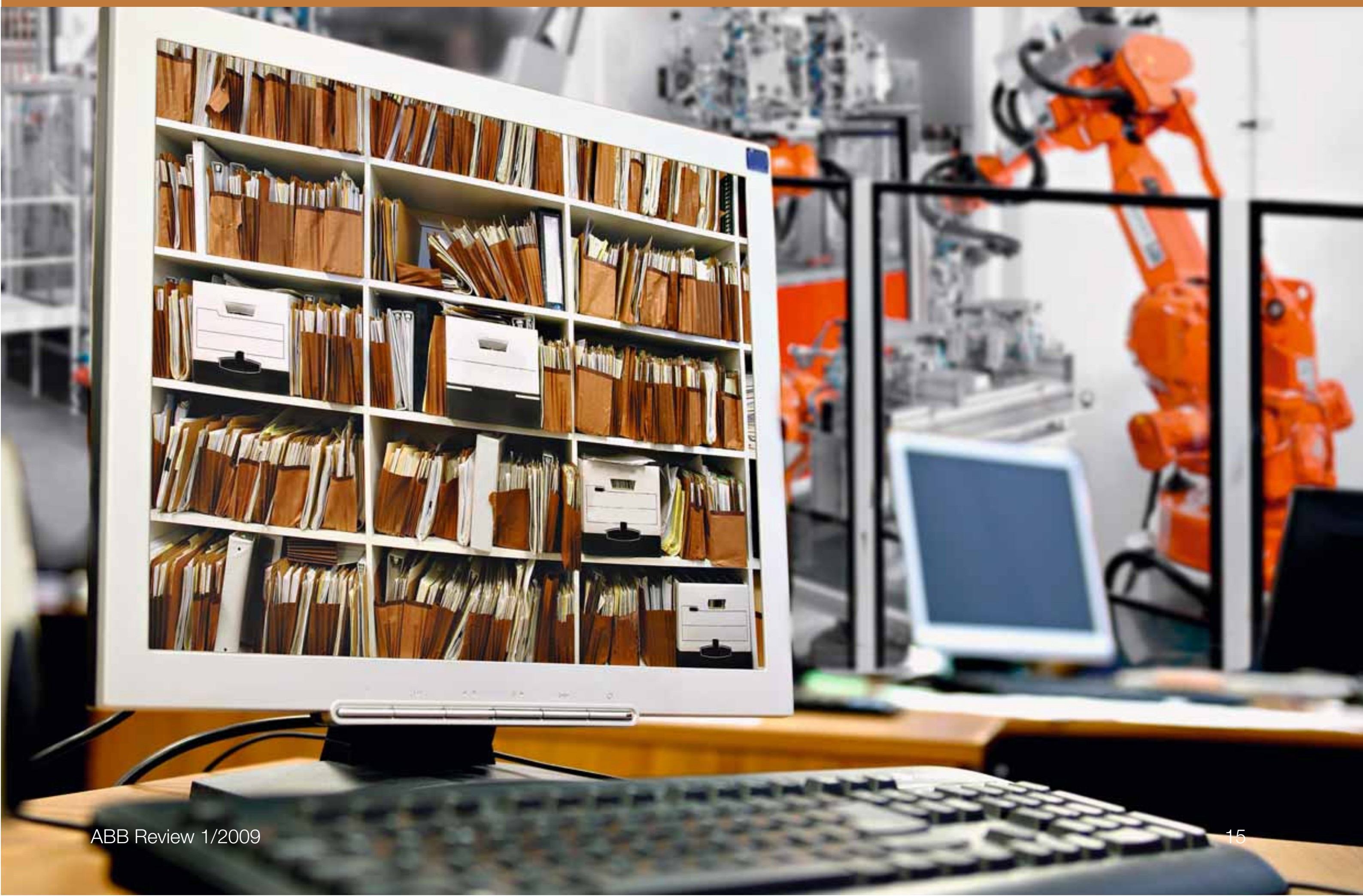
Sascha Stoeter, Dejan Milenovic

It has often been said that we are currently living in the Information Age. This is definitely true of manufacturing, where as a product passes through all steps from the release of the initial order to the delivery of the final product, it is accompanied by a dynamic mass of documentation. Production line personnel need to know exactly what steps are required and which parts or ingredients must be used. The results of individual actions may also be recorded for quality assurance and tracking.

In most cases, this process is strongly reliant on paper. Instructions are issued on paper; actions are recorded on paper; and even if data is eventually stored electronically, paper records must be transferred to a computer by hand. Not only is this time-consuming and error-prone, but it impedes the accessibility of up-to-date information.

ABB's cpmPlus Enterprise Connectivity software is changing all this and introducing truly paperless production: Records now follow the product in electronic form, and at every step, only those data are displayed that are directly relevant to that task. Ergonomics are leveraged and errors reduced.

The software is seeing successful use, for example, in ABB's own switchgear plant in Ratingen (Germany) and with the food manufacturer, Wander.



Partnership and productivity

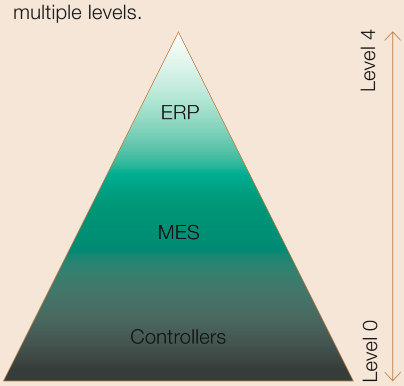
Connectivity is an important aspect of a manufacturing execution system (MES). It sits in the middle of the automation pyramid as defined by ISA-95 [1] Factbox 1, bridging the gap between enterprise resource planning (ERP) systems (level 4) and control systems (level 2 and lower). As such it offers level 3 functionality. A significant challenge in implementing this link lies in translating between different levels of information granularity: ERP systems concern themselves with time horizons of hours or longer, while controllers typically operate much faster than at minute rates.

ABB's cpmPlus Enterprise Connectivity (ECS) was initially marketed as Enterprise Connectivity Solutions [1]. It has become the centerpiece of the company's product suite for collaborative production management (CPM).

Factbox 1 The automation pyramid

The automation pyramid groups the devices and systems of a production environment into levels. Many different automation pyramids have been devised with a grouping criteria best suited for the domain. The most relevant to this work is the model used by the ISA-95 standard. Levels instill communication boundaries, as there should only be connections within a level or to neighboring levels. The pyramid shape indicates that there are many more devices in the lower levels than in the higher levels. Typically one ERP is on the highest level and a large number of controllers on the lowest. By placing systems and devices in this hierarchy, their relative degree of influence on production becomes visible.

As often happens with models, reality does not always adhere to them. Complex systems may provide functionality for the whole plant (eg, inventory) while also interacting with controllers, thus spanning multiple levels.



ERP: Enterprise resource planning
MES: Manufacturing execution system

Hand-written notes are a thing of the past – and with them the dangers of illegibility and errors in entering data into the ERP.

Going paperless

One important reason for introducing connectivity to the shopfloor is to achieve paperless production. Operational advantages and cost savings include:

- *Availability of real-time production data:* Management has comprehensive and up-to-date access to the status of the plant and production.
- *Contextual aids for operators:* Instead of forcing staff to flip through stacks of reference manuals and report cards, only information pertinent to the current product and production step is presented. This makes for a cleaner, safer, and more efficient work environment. Documentation can be updated easily and inexpensively by a central authority.
- *Elimination of transcription errors*: Information follows the semi-finished products from order to shipment in electronic form. Hand-written notes are a thing of the past – and with them the dangers of illegibility and errors in entering data into the ERP.
- *Wealth of new information:* Much more data can be recorded electronically with automated systems than with a traditional pen-and-paper approach. This benefits both the factory, for process optimization purposes, and the client, who can obtain more quality data on the purchased goods. Such record keeping may also be necessary to fulfill regulatory requirements.
- *Ease of access to historical data*: Electronic storage of data simplifies the tracing of material and limits potential recalls by helping identify contaminated or dangerous goods.

This can save a company both money and reputation.

In view of these benefits, what does a paperless ECS-equipped workplace look like? Changes are most pronounced on the shopfloor. In traditional manufacturing, instructions are taken from written records passed along with the product. With a paperless system, and if so configured, operators select the next unit of work from a graphical user interface that contains a prioritized list of upcoming tasks. Alternatively, this can be achieved by scanning a barcode. Such a check also helps verify whether the part is compatible with the current production step. Required assembly steps, support documentation and requested test values or mount options are subsequently displayed on a screen in the workplace 1.

Changes also occur on the operations level: Standard PCs are placed in offices, or software clients installed on existing computers. These are used to administrate the system, release orders and view reports. This improved accessibility of information provides manifold advantages: Sales staff gain better insight into the capacity available at factories and can negotiate orders accordingly; management can

1 The user interface consisting of a touch-screen monitor, a keyboard, and a wireless scanner for barcodes.

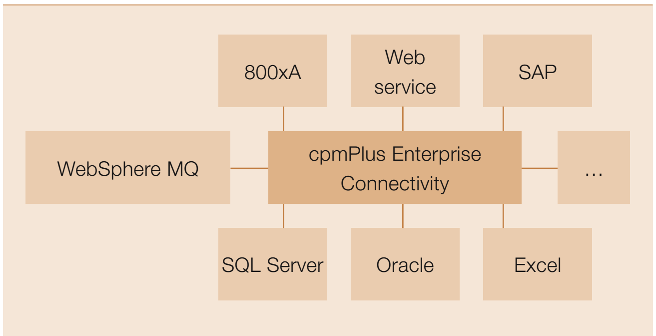
analyze the productivity and profitability in conjunction with the ERP system on a real-time basis; and maintenance crews can obtain detailed historic data on equipment and can schedule inspections appropriately.

ECS overview

ECS employs the ISA-95 standard to establish a common terminology for communications. Envisioned as the interface description between levels 3 and 4, it also provides an excellent basis for modeling enterprise connectivity. Furthermore, ISA-95 is extremely valuable when equipment suppliers and customers talk to one-another. Over the years, people in factories (and their consultants) have adopted their own terminology when talking about their infrastructure. A well-defined international standard simplifies the communication across different naming cultures.

Because ECS is resource-focused, it provides convenient ways of instructing personnel about their various roles, equipment, and material. Each modeling element within the system can be assigned properties of different types that hold run-time values of the processes. These resources can then be combined to yield segments, each of which represents a production step. By smartly transitioning from one segment to another along the workflow diagram and in accordance with the production requirements, orders become products.

2 ECS architecture with central connectivity service: Because of its openness, ECS can easily incorporate new external systems.



Code can be entered either traditionally with a text-based editor or using a graphical event editor.

ECS and integration

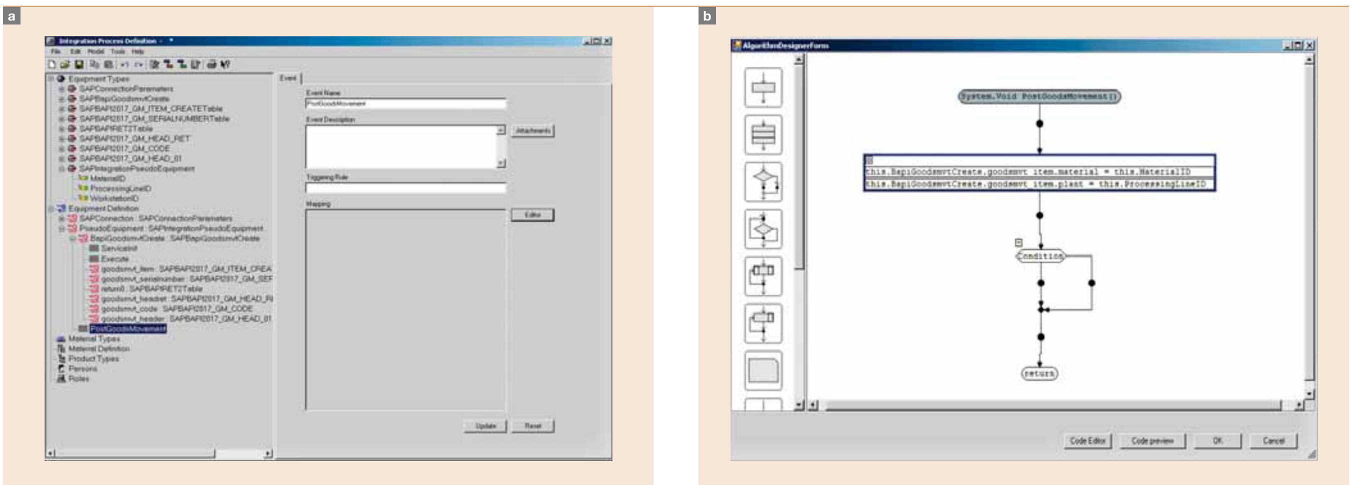
Architecturally, ECS sits at the center of the shopfloor communication system 2. It connects external systems such as ERPs with equipment and personnel. Information from connected systems is mapped to ISA-95 and made available within ABB's industrial automation platform, System 800xA. This tight coupling to 800xA means it is possible, for instance, to make selected ERP data available to OPC. This enables a seamless exchange of information between levels 2 and 4, and the ability to access enterprise data and functionality through the process graphics of 800xA.

Many connectivity systems tout interoperability with third-party products. What this often boils down to is an interface through which a connection can be facilitated. Development of this connection, however, is often left as an exercise to the customer or offered through an additional consulting contract. In stark contrast, ECS connects to the commonly used external systems by means of supplied adapters as part of its out of the box functionality. Such adapters exist for many standard scenarios, such as connectivity to SAP, WebSphere MQ, all common databases, and Web services. Further adapters can be dropped in using a plug-in architecture as required by the project. ECS connects all these systems seamlessly, translating between different data representations and rates as needed.

Once information exchange is established, the next natural step is to send commands from one system to another. A sales person can thus not only enter a new order into SAP, but also, hypothetically, directly start some aspects of production. More realistically, though, there are scenarios in which shopfloor conditions (ie, properties) have certain characteristics that automatically trigger actions:

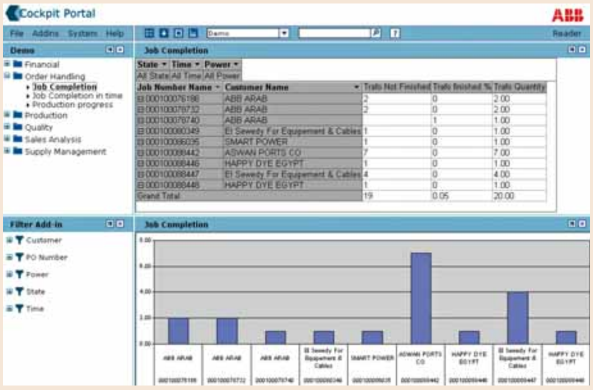
- A complex alarm condition involving properties from multiple sources

3 The Process Definition Tool is the primary modeling tool. It supports ISA-95 based resources and modeling of custom event code using both graphical and text-based editors.



Partnership and productivity

4 The Cockpit tool offers a simple graphical configuration to create advanced production reports.



5 A RESIBLOC transformer made in ABB's Brilon factory.

causes messages to be sent (eg, by SMS) to human operators, or immediate emergency shutdown procedures to be executed.
- The completion of a production step automatically starts the next.
- A mixer is automatically loaded with the right amount of ingredients from silos at the appropriate time.

The concept of "events" is offered by ECS to implement such behaviors. Such an event consists of custom code, whose execution can be started manually by an operator or through a Boolean expression over any combination of properties. By writing pithy events, an intelligent shopfloor connectivity solution can be created that is capable of relieving operators from tedious tasks as well as providing real-time supervision.

Tools

For engineers to benefit from a fruitful development environment, concepts must be translated into tools. ECS provides three such engineering tools.

Process Definition Tool (PDT)

PDT is the primary environment for creating models that represent a solution to a given shopfloor connectivity scenario 3. It is used to create this solution and then adapt it to new requirements at run-time. The left pane of the application window renders the current resources in multiple tree views. The right pane shows details for each modeling entity that can be manipulated by the engineers. Basic resources are modeled with this tool and their relationships set up. The engineer can include additional properties and custom code written in C# and Visual Basic, opening up the whole world of .NET. Code can be entered either in the traditional way with a text-based editor 3a or using a graphical event editor 3b. The latter allows the drawing of algorithms and provides immediate insight into the event's workflow. Event code makes it easy to create simple functionality and connectivity mappings. More complex functionality can be embedded using DLLs.

> ECS connects to the commonly used external systems as part of its out of the box functionality.

Admin tool

The Admin tool is used to configure a running ECS installation. It serves as an easy-to-use interface to the central SQL-server database. Using this tool, administrators maintain users and permissions, monitor the system and can view rudimentary reports.

Cockpit

The third tool, Cockpit, provides advanced reporting functionality 4. A large number of production data are collected continuously by ECS without the system needing to be specially configured. Cockpit uses this wealth of information and can relate it to additional sources (eg, historic data). The tool permits data to be presented graphically, making it easier to identify otherwise hidden correlations.

In its most recent release, 3.5, ECS gained a number of usability and engineering performance improvements, further speeding up project-realization time. Among them are single-button model redeployment with times that are cut down to mere seconds, model debugging support through Visual Studio, improved logging, and collaborative and simultaneous model creation by multiple engineers on different workstations. ECS 4.0, to be released in the first half of 2009, will no longer require System 800xA as a host environment, but a tight integration is still possible. A graphical workflow engine will provide a much simplified and more intuitive way of configuring the production processes. New projects can be started at an advanced state by using the ECS Template Repository that will be available to customers online. It offers ready-to-use integration

Factbox Acronyms

CPM	Collaborative production management
DLL	Dynamic link library
ERP	Enterprise resource planning
MES	Manufacturing execution system
OPC	(a connectivity standard for industrial automation)
SMS	Short message service
SQL	Structured query language (a database language)

models as starting points for new development efforts or learning best modeling practices.

Shared responsibilities

ECS is employed in numerous ABB factories and external companies. While project complexities vary, the path to a successful implementation is the same.

Operators embraced the new system because they were actively involved throughout the project.

After the initial contact, a team of ECS engineers visits the site for several days to interview the domain experts involved in the project. This is taken as input for the requirements document that specifies the complete system. Aside from a general overview, the document describes all system aspects in detail. Priorities are assigned to use cases to guide the project engineers during the implementation phase. Other use cases are marked as nice-to-have or for-future-extensions. Care is taken to clearly identify the system boundaries. The requirements document is verified with the customer.

Design and implementation of the solution are performed off-site. As pieces of the solution start to form a whole, and especially as user interfaces are added, the customer is again involved in the verification phase. Toward the end of the project, the focus shifts back to the customer site, as servers are installed and live tests are run.

The involvement of experts on both sides is a prerequisite for success, but certainly does not guarantee it. A system only proves valuable if it is accepted by its users. It is all too easy to forget that the little boxes in the documented model correspond to real people in the real world, and without their support, the implementation is likely to fail. In many ECS installations, operators embraced the new system because they were actively involved throughout the project. For instance, several factories held design competitions, open to all operators, to create workplace computer stations, such as shown in 1.

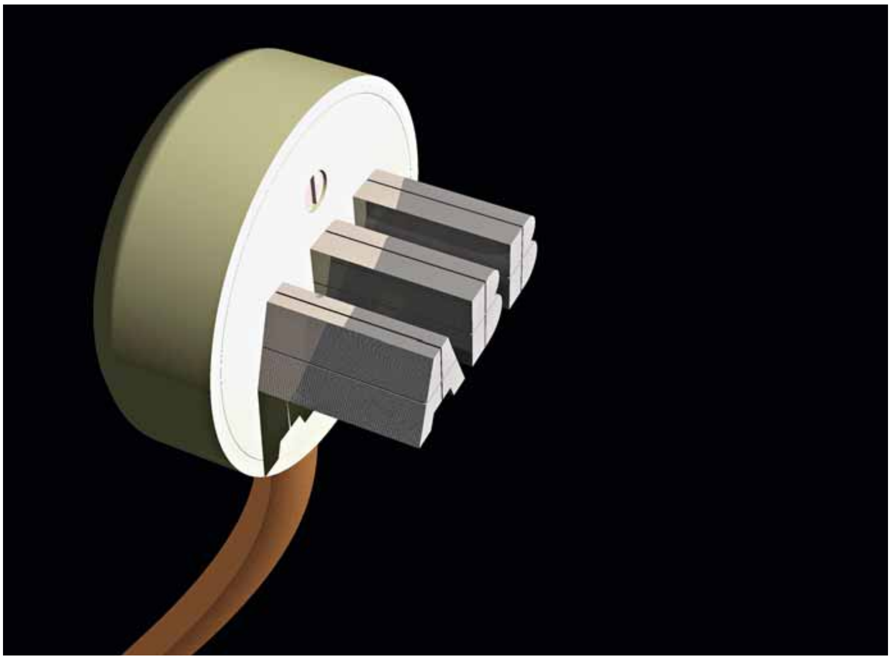
Benchmarking and application

A benchmarking exercise was carried out in ABB's transformer plant at Brilon in Germany 5. Multiple challenges that the product's flexibility elegantly handled included interfacing with an exotic ERP system and a scheduling application with flexible routing in the process workflow dependent on ERP-related constraints, integration of an existing document repository, and multi-lingual user interfaces to serve the multi-cultural workforce.

Another successful implementation was established with the Swiss food company, Wander, makers of the world-famous Ovomaltine (Ovaltine).

Several factories held design competitions, open to all operators, to create workplace computer stations.

The benefits of shopfloor connectivity shine with ABB's flexible cpmPlus Enterprise Connectivity solution. Coupled with its simple and straightforward configuration, customers can expect low engineering and maintenance costs, a high degree of flexibility allowing future system extensions, and reliable up-to-date information of the process state available at all levels of the enterprise.



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[1] ISA-95 Manufacturing Enterprise Systems Standards, http://www.isa.org/ (Feb 2009)

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Effective maintenance

Asset monitoring for a low-voltage Integrated Motor Control System (IMCS): a case study

Rajesh Tiwari, Jouni Seppala

When it comes to plant operation, no operator likes surprises. But in the fast-paced, round-the-clock world of manufacturing, how can one avoid encounters with the unexpected?

Keeping the health of plant equipment in check is fast becoming the key to avoiding these surprises, and thus the secret to a company's success. Substantial cost savings and productivity gains can be made by adopting a maintenance practice that is both predictive and proactive – in other words, condition-based.

A successful implementation of ABB's MNS *i*S system with asset monitoring technology was completed at a chemical company in Finland, helping improve its maintenance practices and achieve welcomed cost savings.

OMG Kokkola in Finland is the world's leading producer of cobalt-based specialty chemicals used primarily in batteries and hard metal cutting tools. Because of these extremely sensitive applications, the company's cobalt powders must meet very high-quality standards. Imagine the resulting disaster if a laptop battery exploded in an airplane!

To keep its systems current, OMG upgraded the automation system for its cobalt chemical line in 2006. One important part of this upgrade was the modernization of its low-voltage Motor Control Center (MCC). To enable full exploration of the maintenance improvement possibilities, the company chose ABB's MNS *i*S, an Integrated Motor Control System. Equipped with smart sensor measurement, MNS *i*S can measure current, voltage and temperature and provides a wealth of information. Most significantly, it enables the use of information for comprehensive condition-based maintenance practice.

At OMG, the use of sophisticated smart instruments and intelligent MCCs was quite common. There was a lot of information already available; however, it was not resulting in maintenance improvement as anticipated. The distinctive constraints were as follows:

- *Routing of information*. The information available through the smart equipment was routed through the distributed control system (DCS) controller – regardless of its relevance – thereby degrading the controller's performance and negatively impacting critical plant control applications. The role of the DCS controller needed to be focused on process control (rather than on information management).
- *Information relevance*. Information not related to process operation was being directed primarily to the process operators, who had little use for it.
- *Information utilization*. Site operators were lacking specific instructions about what actions to take and could not independently interpret the information for necessary corrective measures.

Information can only be meaningful when it is directed where it is valued, understood and utilized. A single unified environment that could present the right information to the right operator at the right time would be essential for the practical use of information at the site.

> Equipped with smart sensor measurement, MNS *i*S can measure current, voltage and temperature and provides a wealth of information.

OMG maintenance practice

The maintenance practice at OMG could be broadly classified into two categories: preventive and corrective.

Preventive maintenance

Preventive maintenance consists of regularly scheduled maintenance inspections during which a complete overhaul of all equipment is made, regardless of its true need. It is the most common maintenance for field instruments, motors, valves, pumps, etc, and serves as an insurance against potentially costly breakdowns during operation. The prevailing rationale for employing this inefficient maintenance method is the lack of factual data that quantifies the actual need for repair or maintenance of plant machinery, equipment and systems. Maintenance scheduling at OMG was often based on previous experience or on actual equipment failures. The most disturbing fact: Although maintenance occurred regularly, there was still no guarantee that the equipment would not break down between inspections.

Corrective maintenance

Corrective (or reactive) maintenance is performed only after a failure has occurred. It is normal in process dynamics that production may be interrupted by trips or overloading – while undesirable, these issues can be resolved. The challenge however is when the equipment itself breaks down and replacement parts are not immediately available.

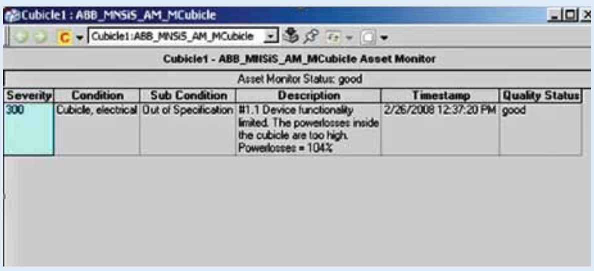
Asset monitoring for IMCS maintenance

Traditionally, LV constant-speed motors were not thought to greatly impact the overall plant availability; however, most of the plant shutdowns can be attributed to them. A trip on any such motor or a fault in the operating motor starter in the MCC was enough to halt a process. ABB's asset monitoring technology for MNS *i*S was deployed at OMG to explore the maintenance effectiveness possibilities in the area of low-voltage (LV) Integrated Motor Control Systems (IMCS).

Asset Monitor is a software component that gathers data from various sources, brings it into the context of the asset and evaluates the information 1. Conditions are assessed, possible degradation detected and remedies proposed. A fault report is subsequently delivered to personnel equipped to act upon the information.

1 Asset Monitor interface a and evaluation with possible cause of fault and suggested action b

a



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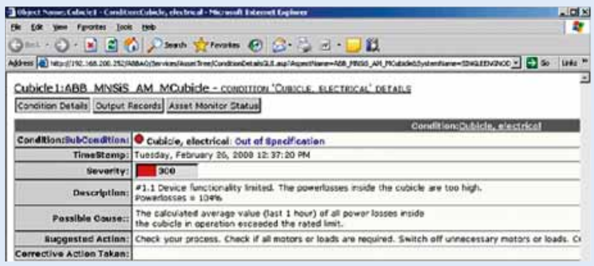


Partnership and productivity

Asset Monitor runs directly on the DCS platform, ABB's System 800xA, which is already available in the plant. The information collection and presentation is depicted in 2.

MNS *i*S provides a fieldbus interface for process-oriented data exchange and control to the DCS controller. All other electrical and maintenance-specific information is directly routed via an OPC[1] server, installed directly on the DCS operator station PC server. The asset monitoring workstation provides an exclusive workplace for maintenance purposes: Maintenance personnel can log in based on their specific roles (eg, technician) and view the pertinent information.

Inside the workplace there are four different structures through which to navigate. All structures serve as aids and their usage depends upon the operator's needs.

- Control structure: All IMCS in various electrical substations are shown and navigated through based on the communication structure.
- Location structure: This depicts the locations of all the IMCS in the plant.
- Asset structure: Here, the IMCS structure is divided into IMCS name followed by the grouping of motor starters based on the control schematics (eg, DOL, RDOL).
- Documentation structure: All the relevant IMCS documentation can be accessed through this structure.

Within these different navigation structures, there are several maintenance-oriented faceplates and display structures for all IMCS motor starters. These displays are accessible from all four navigation structures and are described in Factbox1.

ABB's asset monitoring technology for MNS *i*S was deployed at OMG to explore the maintenance effectiveness possibilities in the area of low-voltage Integrated Motor Control Systems.

IMCS motor-starter Asset Monitor

The motor-starter Asset Monitor gathers the actual usage data on motors, contactors and motor-starter contacts for condition-based monitoring, which are used to predict the necessary maintenance. The Asset Monitor distinguishes among equipment that is:

- Under continuous operation without switching
- Rarely operated or not used within a specified time
- Under capacity or over capacity for pertinent maintenance

The Asset Monitor also continuously evaluates all events, alarms and trips for specific maintenance and essential working issues. It groups these conditions into electrical, mechanical, operating and process-related categories. This categorization makes it possible to identify and direct the information to the appropriate maintenance operator, who can take the necessary action. These conditions are further categorized into subconditions with severity levels showing the degradation of asset performance for quick identification and operator action. The conditions, subconditions and severity levels are depicted in 3.

A right click on the conditions in Asset Monitor opens a new window with the fully analyzed problem or condition, and answers the following questions:

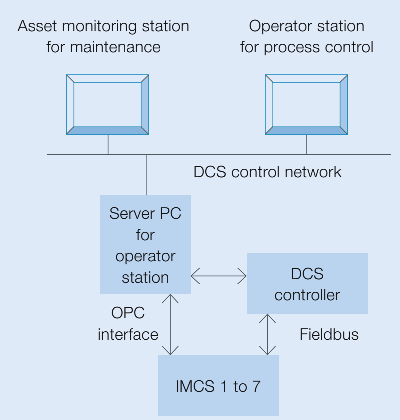
- What/where is the problem?
- What is the type and severity of the problem?
- How was the problem caused?
- Who is the appropriate operator to initiate action (ie, Is the issue operation- or maintenance-related)?
- What specific actions are needed to solve the problem?

If an emailing or SMS service is enabled, the fault report is directed to the right operator to initiate resolution of the problem.

Motor-starter maintenance faceplate

To support the electrical operator, a motor-starter faceplate depicting a single-line diagram of the motor starter is provided 4. The faceplate also contains all measured values and status information for online monitoring. In addition, it enables the resetting of

2 Information collection and presentation with Asset Monitor



Factbox 1 Maintenance-oriented faceplates and display structures for IMCS motor starters

- Event and alarm lists: displays a chronological list of all alarms and events
- Trend display for operation: shows logging of all three-phase currents, voltages and contact temperatures in all outgoing contacts in trend form
- Trend display for diagnostics: captures trip currents, thermal image tracking, "time to trip" should a motor run under overload conditions, and calculation of "time to reset," which is the cool-down time typical motors need after a thermal overload trip
- History logs: all logged values as stored data; these can be retrieved for data analysis at a later date
- Motor-starter Asset Monitor: evaluates all events, alarms and trips for specific maintenance and essential working issues, and is the most important functionality aspect of asset monitoring
- Motor-starter maintenance faceplate: a single-line representation of a motor starter in graphic form; provides a dynamic view of any fault within the motor starter; is well suited for electricians
- Asset viewer: provides an at-a-glance status of all motor starters in tree form

special maintenance-oriented fault conditions. These are:

- Too many thermal overload (TOL) alarms
- Too many TOL trips
- Too many start limitation alarms
- Too many start limitation trips
- Insertion cycles

Furthermore, Asset Monitor also supports national languages, and the asset monitoring software package uses the colors, symbols, nomenclature and layout specified by NAMUR[2] guidelines.

Asset-monitoring-based maintenance

The MNS *i*S IMCS provides a great amount of information and maintenance data. Asset monitoring software then puts this data into context for the maintenance operator. The IMCS, for example, is based on withdrawable motor-starter technology where the number of insertion cycles of motor starters does matter. When the number of insertions on a particular module reaches a set number of cycles, electrical contact maintenance is required. This ensures an optimum electrical contact connection and contact pressure for optimum motor-starter operation during the life cycle.

A similar condition-based monitoring is performed by continuously measuring the contact temperature for quality deterioration of the cable connection. Asset Monitor also performs operation supervision and identifies motors or equipment that have been in continuous operation to raise specific maintenance issues. It also checks that the motor starters are placed in a designated compartment after maintenance. Additionally, it performs a continuous check on all internal components, their consumption and lifetime calculation, and informs the operator about their health status, maintenance or replacement planning. All such conditions are constantly monitored and evaluated by Asset Monitor. The maintenance issues are categorized as electrical, mechanical, process and operation related, and are then directed to the appropriate maintenance team.

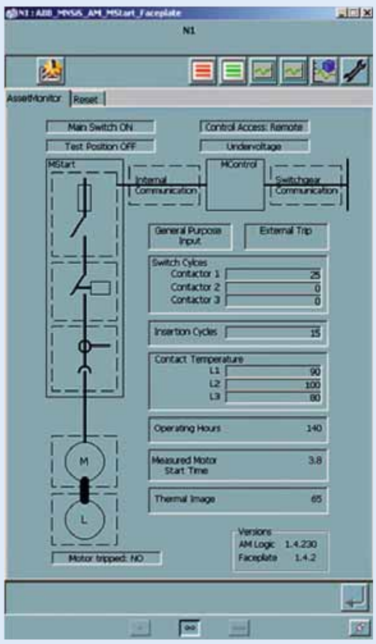
Asset Monitor is a software component that gathers data from various sources, brings it into the context of the asset and evaluates the information.

Just as operators are notified when maintenance is necessary, so are they warned when the conditions require proactive response. The warning criteria, the time delay before the trip occurs and the trip severity are all

3 Asset Monitor conditions and subconditions

Severity (condition)	Subcondition	Description
1 (Normal)	Normal	Motor is available; status is normal; asset functionality is fully available; no maintenance is required
2 (User-defined)	Failure	General-purpose input: the severity and the condition details "description," "possible cause" and "suggested action" are customer-defined; the icon depends on selected severity
100 (Low)	Maintenance required (soon)	Motor is available; status is maintenance required (soon); asset functionality fully available but maintenance required soon to avoid functional restrictions
250 (High)	Maintenance required (now)	Motor is available; status is maintenance required (now); asset functionality available but maintenance required now to avoid functional restrictions
400 (Outside IMCS)	Out of specification	Motor is still available; status is out of specification; asset functionality available but decreased due to operating conditions outside the specified limits
500 (Inside IMCS)	Out of specification	Motor is still available; status is out of specification; asset functionality available but decreased due to internal problems
750 (High; outside IMCS)	Function check	Motor has been stopped; operation is not possible; status is function check; asset functionality may be temporarily restricted due to ongoing work on the asset (eg, as local operation or maintenance)
900 (High; outside IMCS)	Failure	Motor has been stopped; status is failure; asset functionality lost due to malfunction of its peripherals or to operating conditions
1000 (High; inside IMCS)	Failure	Motor has been stopped; status is failure; asset functionality lost due to malfunction in the asset itself

4 Asset Monitor faceplate



Footnotes

1) OPC: OLE for Process Control, where OLE is Object Linking and Embedding

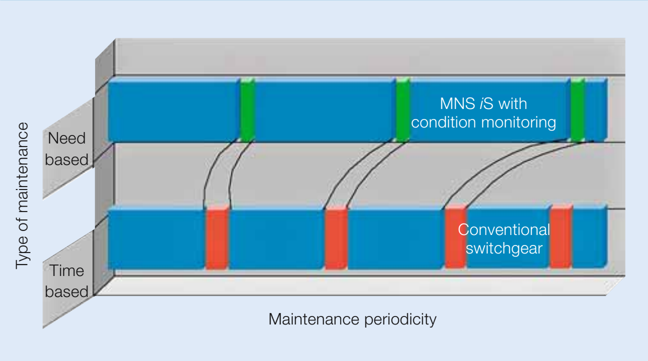
2) NAMUR is an international association of automation technology users in the process industry.

configurable on every fault, safety or motor-protection function. Most importantly, the thermal capacity is continuously tracked for all motors. If a motor is operating under overload conditions, then Asset Monitor dynamically calculates a precise time at which the motor may trip, notifying the monitoring operator and initiating a corrective action. When the trip is imminent, all measured values (including the trip current) are logged for post-analysis, and a detailed report is generated for faultfinding. These online working or maintenance issues are calculated on the basis of current, voltage and temperature measurements by the IMCS.

The motor-starter Asset Monitor gathers the actual usage data on motors, contactors and motor-starter contacts for condition-based monitoring, which are used to predict the necessary maintenance.

The IMCS also tracks general conditions that can be defined by the user. For example, when monitoring external conditions related to motors or process interlocks, the condition details, cause, severity level and suggested actions are user-defined.

5 Depiction of Asset Monitor's ability to complement but not replace traditional maintenance methods



OMG expectations and assessment

Asset monitoring provided an opportunity to improve the prevailing maintenance situation at OMG. The goals and results of the implementation follow.

Additions, modifications and usage

The main consideration in establishing the asset-monitoring program was maintaining the existing DCS structure and process control task. There was to be no additional programming in the DCS controller, and the process-control operation was to be undisturbed – ie, the system should not require modifications in order to work. The asset-monitoring program should be easy to acquire, easy to operate and accessible from day one.

This expectation was met. The information gathering from MNS *i*S was performed in real time and the data was directly routed to the operator without passing through the DCS process controller.

User-friendly system

OMG expected the maintenance information generated by Asset Monitor to be clear and user-friendly – working with the system should not require specific expertise.

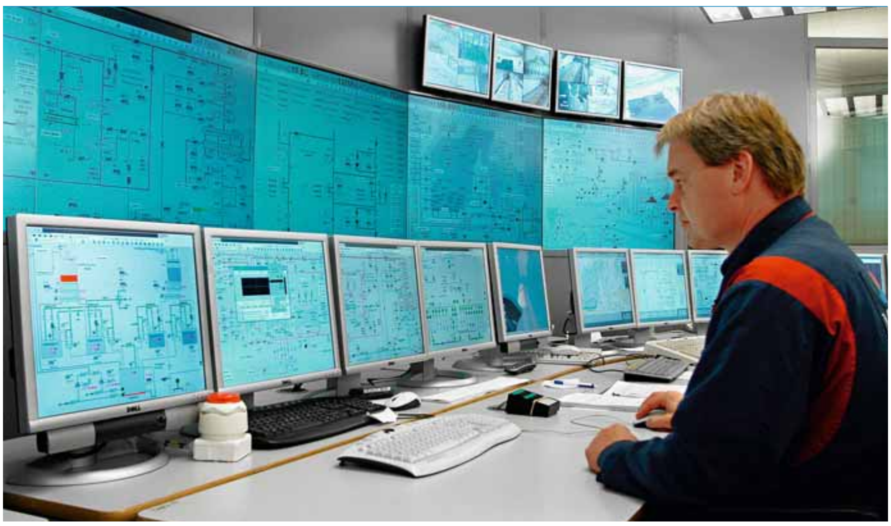
To become familiar with, adopt and utilize the system, training was necessary for the maintenance technicians. OMG found the system to be technician friendly.

Plant-wide maintenance workplace

OMG required that all maintenance activities for connected switchgears be performed on the same platform, with no switching of applications. The same platform was also to be extendable as a unified platform for plant-wide maintenance at a later date.

All MNS *i*S switchgears at the OMG site were connected to the asset monitoring platform. All other ABB-supplied plant equipment and process instruments can be connected to the same platform in the future. ABB offers generic Asset Monitors for third-party equipment but it would be necessary for OMG site personnel to configure them.

ABB's System 800xA in practice



The main consideration in establishing the asset-monitoring program was maintaining the existing DCS structure and process control task.

Maintenance practice improvement

The most important objective was that the asset-monitoring program should substantially reduce maintenance requirements and improve the IMCS performance. Asset monitoring cannot be interpreted as a substitute for the traditional preventive or reactive maintenance management methods at

Factbox Implementing Asset Monitor

The knowledge gained through the OMG implementation will well serve other companies looking to improve their maintenance efforts. Efficient utilization of the program requires a carefully constructed strategy and execution plan prior to its implementation.

1) Define objectives and execution plan. What is the desired outcome of the asset monitoring program? How should Asset Monitor solve the current plant maintenance issues? An execution plan detailing the resources, personnel and work model should be set. The identified team should have a stake in the program, and their training needs must be clearly identified and met.

2) Upper management involvement and support. Initial capital investment and resources are required to successfully launch the asset monitoring program. Upper management must fully support the implementation and commit the necessary resources, personnel and training.

3) Willing and prepared team. Existing maintenance practices and work cultures may need to be modified to adapt to the new way of working. The team should be willing to acquire new skills to make effective use of the program.

OMG. It can, however, be a valuable addition to a comprehensive, total plant maintenance program. 5 shows how asset monitoring can complement traditional maintenance practices.

Preventive maintenance is time based and is performed at regular intervals. Predictive maintenance must also be performed regularly, but the intervals are need based; ie, they can be shorter or longer. The duration of maintenance time differs, however – with preventive maintenance this can be comparatively longer as maintenance is performed on all equipment; with predictive maintenance this can be shorter as maintenance is performed only as needed. Most importantly, preventive maintenance is precautionary and is performed regularly, and yet it cannot always prevent a catastrophic shutdown when maintenance is required between two scheduled intervals. This is precisely where the online condition monitoring in Asset Monitor comes in, since the visualization of key plant information and asset performance are continuously under the radar of maintenance personnel.

Asset monitoring cannot eliminate reactive or fix-on-failure corrective maintenance. It can, however, effectively aid in warning operators of developing conditions so that corrective actions can be initiated before a breakdown occurs. When a trip or fault happens, Asset Monitor can help in quick identification of the problem, directing any technician through the fault-resolution process. Though it would not eliminate tripping or faults completely, asset monitoring would greatly reduce the mean time to repair (MTTR) in reactive maintenance.

A good predictor

The premise of ABB's Asset Monitor technology is that continuous monitoring of an asset's actual condition will ensure an accurate prediction of maintenance interval, thereby reducing the probability of asset failure between maintenance intervals, improving the availability and health of the asset, and increasing the overall availability of operating plants – all while reducing maintenance costs. It enables, in a sense, a condition-driven preventive maintenance program.

> Asset monitoring can be a valuable addition to a comprehensive, total plant maintenance program.

Additionally, Asset Monitor helps reduce spare parts inventory by providing ample time to order replacement parts. Prevention of unplanned failures and early detection of incipient asset problems can only increase the useful operating life of plant equipment. As the asset's consumption is also monitored, the tool can aid in deciding whether replacement of the asset is more viable than repairing it.

The DCS controllers are provided with only process-related data for process control and interlocking, making the process-control communication fast and pertinent. The controller can utilize this data for more effective and critical execution of process-control loops. And the different operators can access the information of interest and act on it directly. This setup also reduces the latent time between process and maintenance operators.

A well-implemented and exercised condition monitoring maintenance practice should enable a reduction in unnecessary maintenance and downtime, higher performance and lower maintenance costs. Most importantly, it should optimize all aspects of an asset's performance.

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Socially interactive devices

A device-centric approach to service: Have you talked to your device lately?

John DuBay

As well as being a source of information, the Internet allows people to interact on a social level. Social Internet-based environments have many powerful applications that can be utilized to service equipment (devices) in the industrial sector. In fact, as far as ABB is concerned, this environment is the next-generation approach to managing service intelligence.

Many Internet sites are presented as "communities" where people interact through various "spaces". Interaction in such environments is possible using Web 2.0 technologies, the term used to cover all of the latest Internet applications including blogs, RSS feeds, Wiki's, instant messaging, mashups and more. Many companies, however, are now beginning to see the value of Web 2.0 technologies and how they can be used to improve asset reliability. ABB believes that the applications used in social Internet-based environments can and will be used to manage Service Intelligence[1].

Social Internet-based environments have many powerful applications that can be utilized to service equipment (devices) in the industrial sector.

Giving devices a "voice" of their own

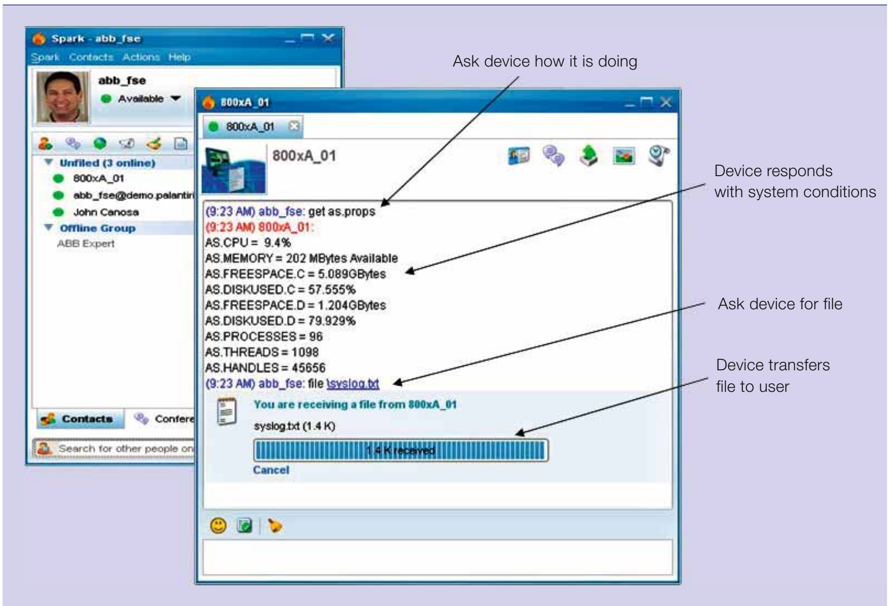
Remote intelligent device management (RIDM) refers to remotely installed equipment or systems – enabled through monitoring and diagnostic solutions – that use secure connectivity to make system health statuses available to a central monitoring service center to aid troubleshooting, and periodic and continuous maintenance. Expertise to on-site personnel is delivered via online connections, and device management solutions are provided by remotely delving into on-site devices. More specifically, ABB's remote capabilities allow access to:

- Process optimization experts
- A technical platform expertise center
- Added training and consulting
- Regional service call centers
- Project engineering support

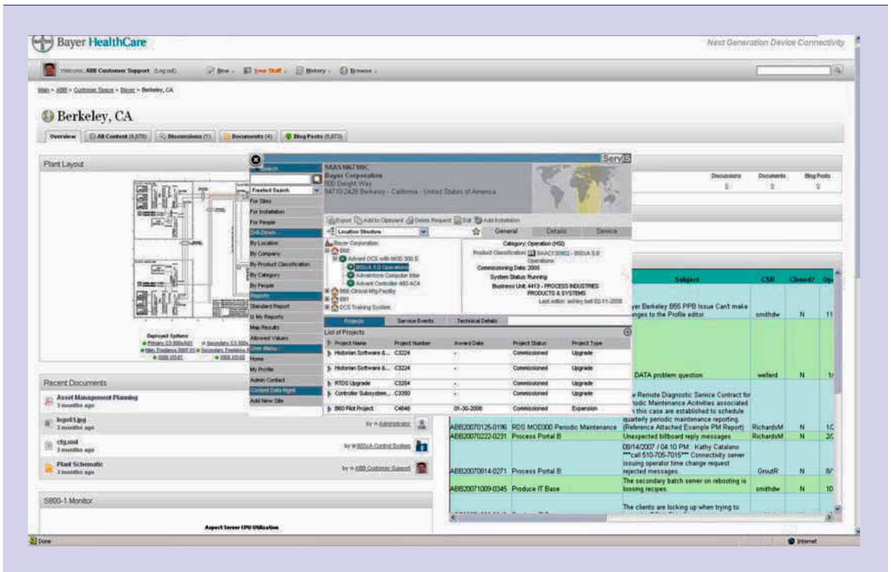
There is no doubt that RIDM increases overall equipment effectiveness (OEE). However, remote services are evolving rapidly and following paths first explored by online services such as FaceBook and MySpace. Additionally, many people now entering the workplace are members of what is commonly known as the Net Generation. "Net geners" were born in the 1980s and 1990s in a time when most of the digital devices (computers, Internet, iPods) were already available, and they are characterized by their high digital literacy. An environment like this is needed to entice younger-generation engineers to become involved in this field.

For its part, ABB wondered about the possibility of creating a type of "DeviceSpace" that could use next-generation Internet and enterprise-based technologies as an information platform. In other words, a device is thought of as a user that can generate content of value to a community. This possibility is gradually becoming a reality! By utilizing the connectivity already established for RIDM, ABB is developing a collaborative device community that will be able to personify a piece of equipment or system (device), thus enabling it to interact with end users and technical experts through collaborative chat sessions. For example, by using rich instant

1 An example of an instant messaging chat with ABB intelligent equipment



2 The customer space provides both customer- and site-specific information



Footnote

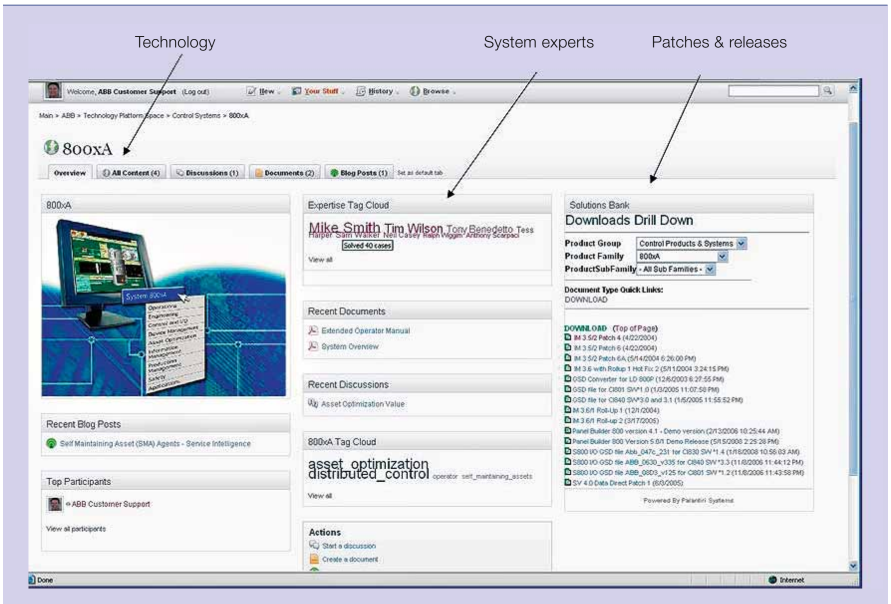
[1] Service Intelligence is a comprehensive term for all information, experts, diagnostic tools, business management and delivery mechanisms that support ABB products.

Partnership and productivity

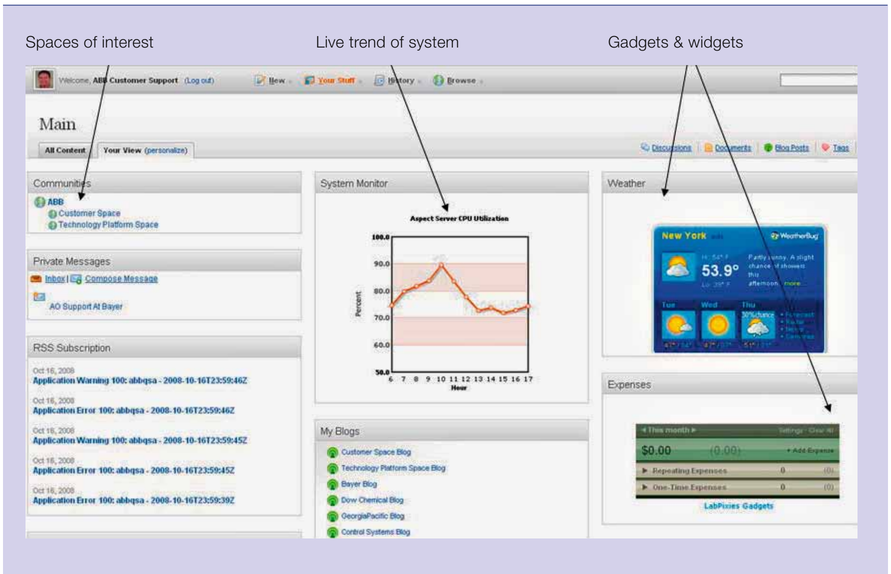
messaging, devices will provide real-time responses to requests for status, provide error log file uploads on demand and execute diagnostic routines, all within the same chat session 1. All chat sessions will then post a blog to the device's space, where it becomes a searchable and reusable nugget of service intelligence.

The ABB service community has two major spaces, the customer space and the technology space. The customer space provides both customer and site-specific information, which is fed from ABB-managed data sources 2. This information can be arranged into a customized view by the end user. The technology space provides a non-customer or site-specific environment where all specific technology platform service intelligence is organized and presented 3 4. Every space and page has standard WEB 2.0 technologies that enable users and devices to post blogs, populate tag clouds, subscribe to RSS feeds, navigate through mash-ups and build a real-time view of dashboards and gadgets. The reasons why this approach to managing service intelligence is superior to traditional methods are outlined in the Factbox.

3 The technology space provides a site-specific environment where all specific technology platform service intelligence is presented.



4 A typical service and support personnel page



Many companies are beginning to see the value of Web 2.0 technologies and their use in improving asset reliability.

ABB service solutions provide, among others, field resources, knowledge databases, service contracts, installed bases and software maintenance. With a device-centric community with spaces and pages, users can interact and collaborate with ABB in a manner that provides a "customer-defining moment,"[2)] reflecting ABB's commitment to supporting its technologies after commissioning.

The time is now ripe for building excellent relationships between devices and their human counterparts.

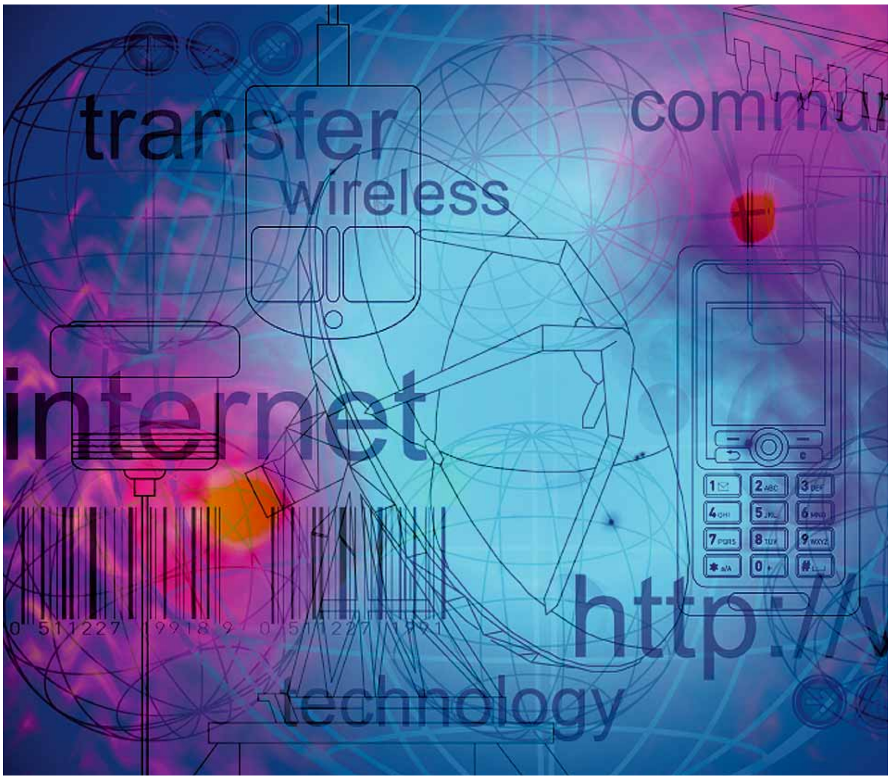
The traditional approach to trouble-shooting separates the interaction between technical support and the end user from the diagnostics performed by the service engineer. By enabling the device to engage in a collaborative chat session, problems are quickly and accurately resolved. More importantly, however, diagnostic approaches are captured and readily available for reuse.

ABB's collaborative device community will enable a piece of equipment or system to interact with end users and technical experts through collaborative chat sessions.

The Internet platform supporting these interactive communities has

Footnote

2) For ABB, a customer-defining moment is a measure of customer satisfaction.



proved itself to be readily accessible, scalable on a global basis, easy to use and the standard medium for presenting data. With mobile computing devices already Web enabled – and devices becoming increasingly connected and more intelligent – the time is ripe for building excellent relationships between devices and their human counterparts, ie, end users and manufacturers.

With its strategy of embedding services in its products, ABB can focus on asset performance management in a manner that optimizes availability, provides quality production, and extends the product life cycle. This in turn gives ABB's customers the benefit of lower total cost of ownership, thereby increasing their overall competitive advantage.

Factbox Why ABB's collaborative device community is superior to traditional methods for managing service intelligence

- The focus is on presenting information from existing sources instead of replacing existing databases or becoming yet another redundant receptacle of information. This allows for quicker deployment and less redundancy of data sources.
- Years of know-how and experience can be captured from experts nearing retirement and is stored in a way that can be readily searched and reused by the next generation of service engineers.
- Web 2.0 technologies provide an environment where the younger generation of technical support engineers can be more comfortable. This is a medium they are more likely to communicate in and one that allows them to interact with seasoned experts.
- Devices provide real-time feedback about their health and condition, as well as contributing to self diagnostics. This entices the device, customer and technical support to interact collaboratively, giving all participants the opportunity to learn from the experience and to better document the support session.
- Customers are directly involved in the problem-solving process.
- The environment provides a portal allowing customers to interact with databases such as ServIS*), an installed base management system. These customer interfaces contribute greatly to the accuracy of installed base information.
- Members are motivated to be innovative and collaborative, thus providing new approaches and best practices in an environment that is conducive to the reuse of these ideas.
- Hundreds of important data sources, each with separate logins, can be pulled into a single environment requiring only a single sign on. Furthermore, the interface to all this information is organized into a consolidated view or dashboard.
- Users can easily customize their own home pages to align with their job functions and responsibilities.
- Web 2.0 technologies are proven to be scalable to very large systems that span across the globe, providing harmonization to the approach a customer uses to interact with members and devices.

*) ServIS forms part of a traceability system that is used to keep track of Unigear switchboards and panels.

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The ladder to success

Risk-based inspection reduces costs

Bernhard O. Herzog, Paul Jackson

With today's rapid communications technologies and a highly interconnected world economy, changes in one part of the world rapidly disseminate to anotherr. Whether in times of fast economic growth or times of economic slowdown, companies able to make swift smart decisions that allow them to adapt to an ever-changing environment will succeed where others fail.

To make sound decisions that allow a company to capitalize on a rapidly growing economy or to weather a storm requires expertise, which may not always be available in-house.

ABB offers a consultancy service with expertise in the areas of maintenance and reliability, process safety, and industrial energy efficiency. ABB's consultants have a wide range of experience and a good track record, assisting industries with critically important decisions for their profitability and survival.

Consultants are frequently employed by companies seeking professional advice from experts with high levels of skill, experience and understanding in areas outside the scope of their normal daily business. For example, consultants may be employed to identify the optimal strategy by which a company could survive an economic downturn, or how a company should best renew its plant's equipment to maximize productivity, or identify what a company is required to do to comply with new regulations. Few companies can justify maintaining such specialized skills in-house, especially when the expertise is drawn upon relatively infrequently.

ABB provides expertise in the key service areas of maintenance and reliability, process safety and industrial energy efficiency.

The aim of ABB's consultancy service is to help clients to navigate through difficult decision-making processes and to increase their productivity, operational excellence and safety in a sustainable manner. ABB provides expertise in the key service areas of energy efficiency, process safety, reliability and maintenance. While all clients have their own specific aims, the main goal of the exercise is to achieve maximum performance from plant and equipment, at minimal cost.

An integral part of any ABB consulting project is knowledge transfer. By creating a mixed team of consultants and internal resources from the client's organization, ABB can work more effectively. By liaising directly with the people who work in the plant with a full understanding of what they hope to achieve, ABB can make a more time-efficient assessment of what needs to be done. The consultants can also gain a better understanding of the client's industry, allowing them to provide long-term solutions rather than quick fixes.

Equally, when the decisions have been made and it comes to applying new practices and processes, the ABB consultants are able to transfer expertise to the client's work force more efficiently by working in a mixed team and developing solutions together.

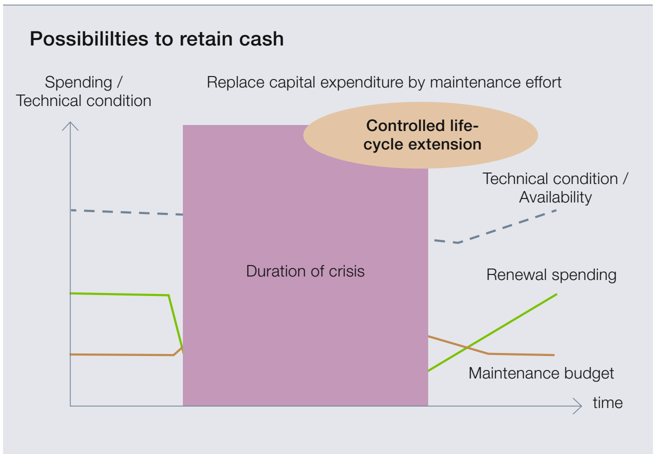
An additional advantage of such mixed teams is that, by providing some of the manpower needed to carry out surveys and assessments, a client is able to reduce the cost of the exercise.

Experience shows that simply installing the best products and superior systems is no guarantee for success. Each component and process must be finely tuned to achieve optimal productivity, reliability and cost effectiveness.

To achieve optimal performance, specialized knowledge is required not only of ABB's products and systems but also of equipment produced by other manufacturers, and of the applications in question. ABB has extensive knowledge of products and systems, as well as their applications in a range of industries – a significant advantage over smaller, stand-alone consultancies.

ABB can provide additional training for plant operators and maintenance staff, which can be a critical factor not just when new equipment has been installed, but also when improvements are to be made by implementing new processes or improved maintenance regimes.

1 Controlled life-cycle extension



During times of growth and ample liquidity, senior managers tend to focus on markets, revenues and the development of new products. Often, staff training, particularly in equipment maintenance, can be overlooked.

By working in a mixed team and developing solutions together, the ABB consultants are able to transfer expertise to the client's work force more efficiently.

When faced with an economic downturn, however, management's focus quickly shifts to the issue of curbing expenditure, wherever possible. Planned investments in new equipment are often the first victims of such cuts. This is understandable, since capital expenditure in one area could necessitate more drastic cuts elsewhere. However, simply blocking capital expenditure is not the answer. Such a blanket approach could lead to the breakdown of key equipment, leading to significant losses in productivity and expensive repairs, unless the potential risk of using aging equipment is countered by targeted and adequate measures in maintenance and diagnostics.

The most effective approach to optimizing productivity while minimizing cost is to simultaneously monitor levels of expenditure on new equipment, the cost of maintenance and the resulting performance, in terms of productivity.

If investments in new equipment are deemed inappropriate, adjustments may be needed in maintenance schedules and equipment-monitoring processes to avoid equipment breakdowns.

This approach of improving maintenance processes to extend the useful life of equipment is known as controlled life-cycle extension 1.

When capital expenditure is no longer an option, it falls to maintenance managers to implement the measures that will avoid breakdowns and safeguard productivity. Depending on the industry, special simulation, diagnostic and monitoring techniques are required, and a plant can stand or fall by the actions of its maintenance team.

ABB can provide inspection services, safety assessments, and reliability and integrity management.

ABB has extensive experience in maintenance optimization and strategic planning in a range of industries. ABB can provide inspection services, safety assessments, and reliability and integrity management[1)]. Such assessments can help determine the remaining lifespan of equipment and its future maintenance requirements, and can predict the point at which replacement becomes a necessity. In addition to providing its own engineers to perform these services, ABB is also able to help customers formulate their own controlled life-cycle extension schemes.

Risk-based inspection for BP

Over the last 25 years, ABB has been working on a risk-based inspection process known as RBI+© 2. The process is designed to identify critically important equipment and establish an appropriate inspection regime. The regime takes into account the risks associated with equipment failure and the impact that failure would have on the health and safety of personnel, the environment and business operations.

ABB's RBI+© methodology follows American Petroleum Industry recommended practices for risk-based inspection (RBI).

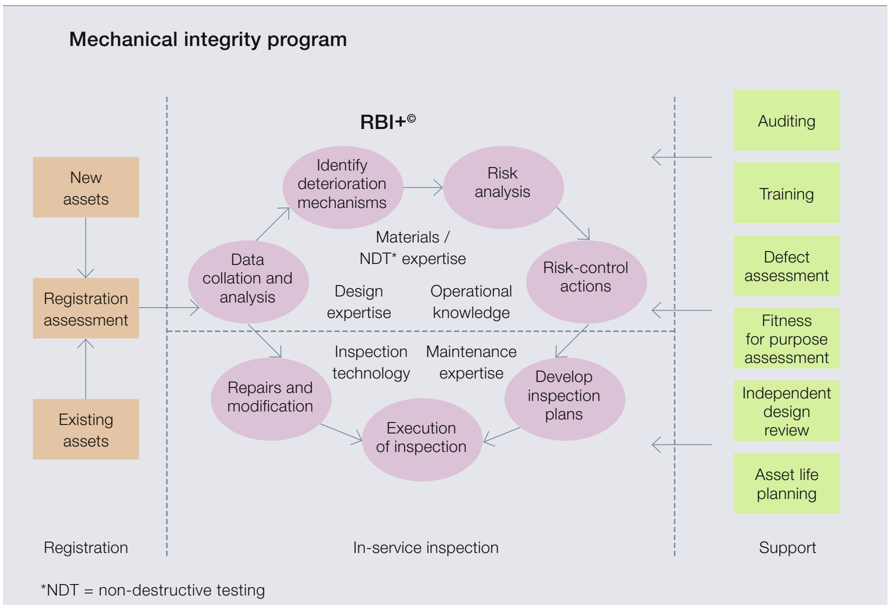
The approach can be applied to all types of equipment, including pressure systems, vessels, piping, pressure-relief systems, civil engineering structures and rotating machinery. The procedure identifies an optimum inspection plan based on risk analysis.

A long-term client of ABB, BP Exploration and Production operates a number of on-shore gas terminals in the United Kingdom, including one at Dimlington, in the northeast of England.

The terminal is 20 years old and processes natural gas from the North Sea, prior to feeding it into the UK's national gas transmission system. The Dimlington terminal plays a significant role in providing natural gas to the UK market.

In late 2007, ABB was contracted to carry out a risk-based inspection

2 Risk-based inspection process–RBI+©



review of all vessels and piping at the terminal, prioritizing equipment scheduled for inspection during the next planned shutdown period in the following summer.

The project involved personnel from both BP and ABB, with a wide range of competencies. It was based on ABB's RBI+© methodology, which determines the probability and consequences of equipment failure, in combination with BP's own corporate RBI procedure.

ABB's RBI+© methodology follows American Petroleum Industry recommended practices for risk-based inspection (RBI).

To date, over 70 pieces of equipment have been reviewed, including numerous pressure vessels and several piping systems. As a result of the RBI review, it was determined that 40 pressure vessels no longer require internal inspection, but can instead be examined using non-invasive techniques. Furthermore, it was found that the period between vessel inspections could be extended from seven to 10 years.

Based on these changes, BP conservatively estimates that it reduced its overall expenditure for 2008 by $770,000, including preparation costs to facilitate inspection (eg, scaffolding, cranes, cleaning equipment, fitting resource, stand-by men), and the inspection itself, representing a saving of 33 percent.

The change to non-invasive inspection for some items provides a number of significant benefits. Personnel are no longer required to enter the confined space inside a pressure vessel, and the environmental risks associated with cleaning effluent are also reduced. An additional advantage of the non-invasive inspection regime is that the plant can operate for longer as there are fewer inspections that need

Footnote

1) Integrity Management is the process used to ensure equipment is fit for purpose. Reliability ensures that equipment is available when needed.

to be carried out with the plant shut down. In addition, online inspections can be carried out to enable any necessary remedial work to be scheduled for the next appropriate shutdown period, thereby avoiding costly unexpected breakdowns.

ABB's consultancy service operates with some 600 staff based in the United Kingdom, United States, Canada, Mexico and Germany, executing projects in many of the major ABB markets.

In summary, the use of risk-based inspection methodology, built on the combined knowledge and expertise of specialists from BP and ABB, has realized a number of benefits. In particular, reducing the cost and duration of shutdown periods required to ensure the structural integrity of pressure system assets at the Dimlington gas terminal.

A similar approach is currently being used to determine inspection regimes for existing installations at BP's land-based gas terminals at the United Kingdom's central area transmission system (CATS), Seal Sands in the northeast of the country, and at the Sullom Voe terminal in the Shetland Islands. The RBI+© methodology will also be used to define inspection schedules for new plant equipment at both Sullom Voe and Dimlington.

Strengthening customer relations

By working with customers through service and maintenance contracts, ABB can help companies to weather the storm of an economic downturn by offering an alternative to capital investment in new equipment. Working in such close collaboration enables ABB to provide the solution that best fits the company's needs.

In some cases, a plant will ask ABB to take over entire maintenance services, in a Full Service contract. This relieves managers of critical responsibilities and allows them to concentrate on the core functions of their businesses. Full Service contracts often provide the best option for clients, both in terms of cost and in continuity of service. Using different firms to monitor different parts of a processing plant runs the risk that some pieces of equipment will be forgotten or treated in isolation when they form an integral part of a larger process.

ABB maintains a constant dialogue with its service clients, even if they undertake projects only once every few years. This allows changing needs to be assessed and schedules to be rearranged as needed.

ABB's consultancy service operates with some 600 staff based in the United Kingdom, United States, Canada, Mexico and Germany, executing projects in many of the major ABB markets. The main areas of expertise are maintenance and reliability, industrial energy efficiency and functional safety. ABB's consultancy service serves all process industries not only with respect to systems and equipment originating within ABB, but also with respect to the optimization of the design, configuration, operation and upkeep of just about all technical facilities and systems regardless of their origin.

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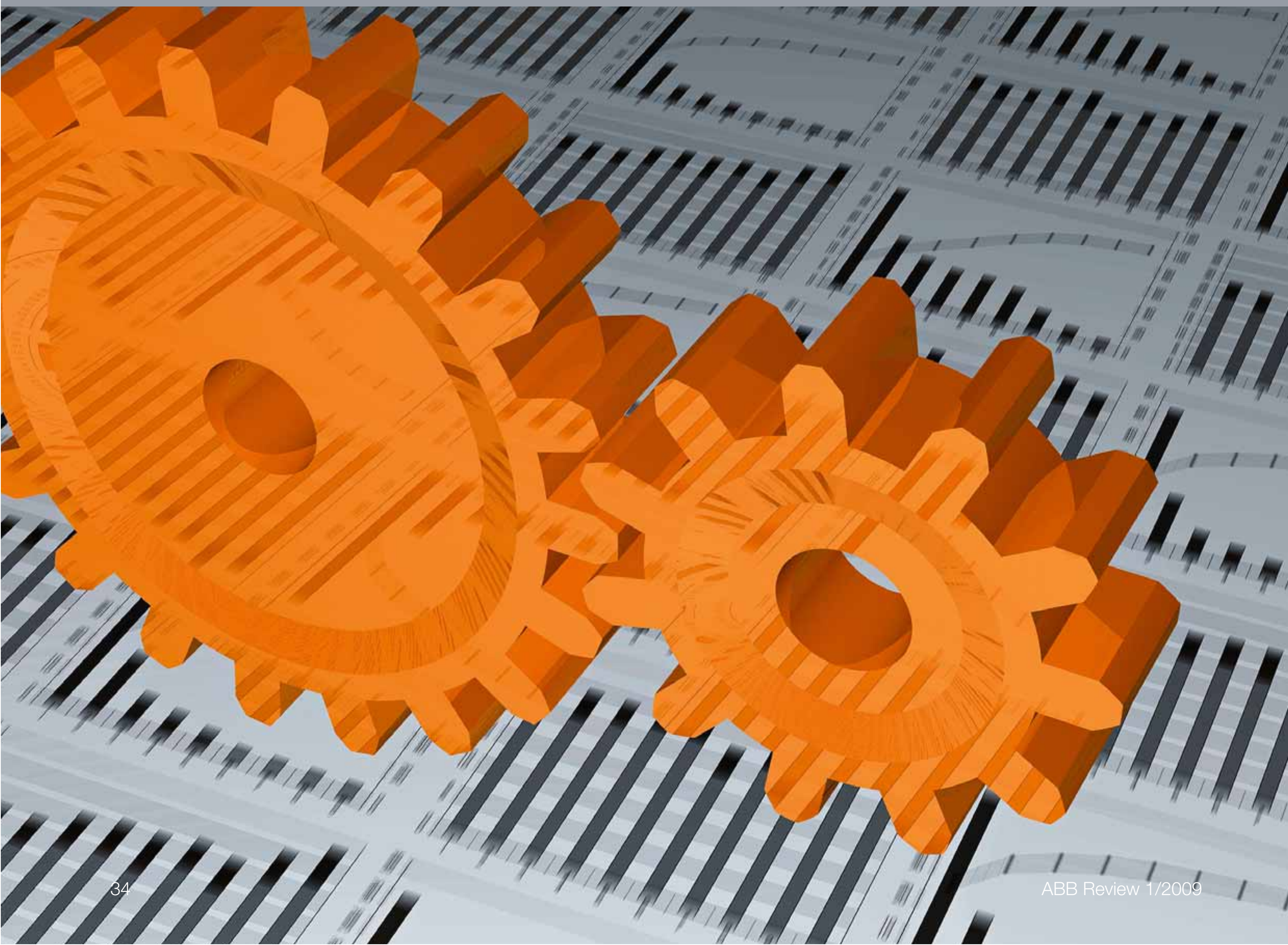
What is reliability?

Changing the reliability paradigm

Barry Kleine

Concepts used throughout the world to describe improvements to production throughput are often termed "reliability." But just what does the term really mean? What tasks that a plant's staff perform are considered "reliability" and how do these tasks actually improve the profitability of a company? Who, if anyone, should be involved in the reliability project?

If a plant decides to introduce a reliability plan, the actual steps agreed on are affected by the definitions used. One definition can lead the site in a totally different direction than another. It is therefore important to challenge and agree on the definition used. The absence of such a challenge may very well limit the potential of the improvements made.



This challenge is faced by ABB's manufacturing customers across the world. ABB is, however, also itself a manufacturer, and so often faces challenges and decisions similar to those of its customers. Within ABB, the refinement of these challenges has totally changed the direction the company's sites are taking – not only re-prioritizing what actions they take first, but aligning their sites through the adoption of common definitions to be able to better provide mutual support. The combined effects of these two principles have helped ABB achieve comfortable double-digit growth continuously over the last five years. In this article, *ABB Review* looks at some of the lessons learnt.

Paradigm 1:
Reliability means fewer breakdowns.

A common definition of reliability explains this in terms of equipment causing fewer breakdowns. Improving reliability is about having the ability to identify issues and repair equipment before the operations department notices anything is wrong. The operations department certainly appreciates the shift from unplanned stoppages to planned outages, but the maintenance actions thermselver still incur the cost of components and labor required to reinstate the equipment's functionality. There is therefore little overall benefit on the plant level. As a result of this definition, condition monitoring takes center stage, unplanned stoppages decrease, but frustratingly, maintenance costs and labor requirements changes little, if at all.

Further analysis of this situation shows that the equipment still needs to be replaced or repaired at the same frequency; so while production reliability does benefit, no practical equipment reliability has been achieved. Labor and material required for repairing the equipment stay largely unaffected, and any savings in reduced consequential damage is usually offset by in the additional inspections required. This shows that a more refined definition of reliability is required: one that not only includes reliability of production between shutdowns, but reliability of equipment – ie, less "need" for the shutdowns to fix the equipment. Maximizing the life of equipment not only means fewer breakdowns, but fewer required planned shutdowns, lower maintenance costs, lower labor requirements and lower required stores of spares.

In such a definition, the reliability concept should encompass actions that increment the current life being attained by the equipment (ie, actions such as lubrication, cleanliness, alignment, balancing, cleanliness) so increasing the mean time between failures (MTBF). It becomes apparent from this definition that actions such as condition monitoring are not related to reliability, but to the minimization of mean time to repair (MTTR).

New definition 1:
Reliability means less need for intervention.

Paradigm 2:
Reliability is used to determine equipment performance.

Site management teams are quite aware that equipment is not the only consideration for maintenance: Health and safety, environmental concerns, information management and planning and scheduling are just some of the other issues that need to be considered as part of normal business. When all the other aspects that need to be managed are taken into account in maintenance planning, it becomes apparent that reliability is not just the ability to maintain the functionality of equipment, but the requirement for all maintenance processes to function properly.

Actions such as condition monitoring are not related to reliability, but to the minimization of mean time to repair.

Every time a process needs intervention from employees, cost is incurred. Labor is valuable, so a lower labor requirement in any of these processes is desirable and this is achieved by making the process more reliable. Reliability therefore advances from referring just to equipment to referring to the entire business.

When it is realized that a task taking ten minutes a day adds up to one working week per year, it becomes more important that intervention is measured instead of just production impact. Ten minutes of avoidable attention a day is one week lost per year, which that person could be using to address other issues.

An ABB plant in Kinleith, New Zealand, for example, realized that the two engineers in one department did not both need to attend the half-hour

morning production meeting. The decision to rotate attendance meant half an hour a day of the engineers' time, or three weeks a year, was freed up. A five minute decision addressing a non-equipment issue created a lot of time for the engineers to progress other activities.

New definition 2:
Reliability can be used to determine performance of all activities.

Paradigm 3:
Reliability practices belong to the plant floor.

It is traditionally believed that reliability tasks are the responsibility of engineers and trades people. This may be the case when the term reliability relates only to equipment, including the relating tasks such as alignment, lubrication, precision maintenance, etc. Plant managers do not see how those tasks relate to their level.

When the reasons that initiatives do not get implemented are studied, however, it becomes apparent that it is the management of the initiative that causes most of the problems. Insufficient communication about what engineers are doing or why they are doing it reduces the buy-in of the other employees. Not creating enough time or not checking the quality of tasks can affect how fast a task can be completed. These initiatives must be driven by the managers on the site to ensure the organization is delivering all the support that the team members require to implement their tasks properly. Without senior management support and involvement, reliability initiatives will struggle.

New definition 3:
Reliability practices belong to the boardroom

Implementation of a reliability program on a site affects all personnel and starts with the business needs – production volume, costs, employee satisfaction, etc. The issues affecting these objectives need to be understood and prioritized.

The ABB loss-mapping processes show more than 1,500 issues that can cause loss of profit on a typical site. Which variables, therefore, in all the site losses will result in the largest profitability improvement?

Supposing a gearbox failed last night and caused 10 hours of downtime – the temptation is of course to investigate it, but how does that failure, which occurs every six years, compare to the most frequent type of equipment failure on the same site – for example motors? The most common reason that rotating equipment fails is bearings, so how much loss results from bearings compared to a specific equipment type? A gap in the site-planning process may result in each job taking 10 minutes longer than required, so how does this loss – which results in less work being done – compare to the production and cost loss from bearings? How does communication loss compare to planning loss, and if this is an issue, what actions are currently underway to address it?

When there is no way to compare the losses for the above examples, or the site has not tried comparing them, confusion and disagreement set in. Different people will have different passions and the result is multiple initiatives clashing for the same limited resources and money. When this happens, progress in all initiatives slows down.

The most common reason that rotating equipment fails is bearings, so how much loss results from bearings?

Once reliability is adopted as a measure of overall business loss, it becomes a lot easier to get management support for reliability initiatives. This support is critical for project success. By raising the definition of reliability, it is then easy to see how the lack of reliability of equipment or processes then contributes to the different key performance indicators (KPI) – eg, overall equipment effectiveness (OEE) or cost.

One of the key issues is the difficulty in defining a reliability problem. The first question asked is typically, "what is causing the gap in OEE or cost?" The first-level answer to this is usually easy to see, eg, it may be that availability is the reason OEE is low. The lower and more detailed the level at which a response is required, however, the more difficult providing that response gets – due to lack of data. A site will most likely be able to de-

scribe the most obvious availability losses, but is the most frequent equipment-type failure known? People typically focus on what they know, which is normally equipment failures, while missing the major contributors to loss such as the notoriously unreliable communication. For every ten minutes per day of unnecessary or inefficient communication, one week per year of labor is lost. How much improvement has that cost on a given site?

Before anything gets addressed on a site, it generally becomes apparent that the documentation of loss is unreliable. Improving failure codes and understanding what is slowing people down will give a far greater understanding of where focus should be directed.

Successful sites

The most successful sites are the ones with a systematic approach to improvement:

Start with a business need

Key financial variables that affect the site should be identified – these are the ones that will make the largest difference to the profit margin. It is important to understand clearly, for example, whether maintenance cost that needs to be decreased, or in fast the maintenance cost per unit produced. Many examples are available showing a reduction in spending that led to a loss several times that amount in lower production due to decreased reliability. The site strategy needs to emphasize the few variables where the focus should be kept.

> Improving reliability reduces both time and cost to repair.

Develop management support for the concept before it is started

Many processes are scheduled to be implemented on sites because other sites are doing it, or because someone believes they will add value. Unless the senior managers are sold on the fact that these processes are critical to achieving the objectives, little focus will be put on them and they will take many times longer than necessary to implement.

Excessive time to implement is a loss on a site as it means people are not available to work on other initiatives. It is for this reason that fewer initiatives should be implemented simultaneously, and the ones chosen should be the ones that the managers drive and show a personal interest in.

Establish how reliability can satisfy the business needs

As mentioned earlier, there is a distinct difference between reliability (reducing the need for intervention) and consequence minimization (fixing it faster). Many people are passionate about repairing, so focus can easily turn to these issues and reliability gets neglected. It is critical to understand that improving reliability reduces both time and cost to repair. Most other initiatives address only one or the other at a time.

> It is generally accepted that interest in an initiative will halve if no improvement is seen within three months

Select reliability improvements based on their ability to deliver quantifiable business benefits

Many good reliability topics are chosen, but when a given task is selected, often little or no data is provided in terms of a business case or the return on investment predicted. Reliability initiatives are best focused on the most frequent issues, as these are the ones that will give the fastest evidence of improvement. Addressing an issue that only occurs every five years will need another five years to see any benefit.

Sustain momentum by publishing improvements

It is generally accepted that interest in an initiative will halve if no improvement is seen within three months. As the results are observed, these need to be published across the site to maintain commitment, not only by the team members but also by senior management. Lack of evidence will result in people looking for alternative initiatives before the current ones gain traction.

Maintain quality

If a process is agreed upon, it is important to then follow the process. When things get busy, there is a tendency to try and shortcut the process – the consequence is lower results, fewer published improvements and a drop in interest. It is important in this area that managers show interest in the quality of work to maintain the standard. People always get the behavior they accept.

Reliability is one topic whose implementation falters due to not having enough time. Time is created, however, by understanding that a lot of the current tasks are not getting as many results as the reliability initiatives can achieve, and that some of the reliability initiatives being pursued are focused on issues with too long a payback. Time can be created simply by reprioritizing with respect to the business needs.

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Further reading

Cinder A. (2008). Making reliability sustainable. *ABB Review Special Report Process Automation Services & Capabilities*, 54–57.

Outperforming excellence

Full Service oil and gas site achieves cost reduction while improving client satisfaction

Richard M. Rockwood

The desire to do more with less is an ubiquitous but often elusive objective. However, the ability to achieve it often distinguishes failure from success. All businesses dream of finding the metaphoric Gordian knot: a rationalization step whose advantages by far outweigh costs. In reality, such measures are increasingly difficult to identify and businesses content themselves with minor adjustments whose advantages are often difficult to sustain.

In process industries, companies are facing intense pressure, either directly or indirectly, from global competition, and are adopting cost-cutting as a key corporate strategy. There is nothing inherently wrong with cost-cutting. However, to be meaningful in the long term, it must be combined with further strategic and sustainable steps that lead to what is termed "manufacturing excellence". A long history of failed initiatives based exclusively on cost-cutting demonstrates that this choice does little to improve the knowledge base or strengthen processes. Improvements in plant operations, equipment and process reliability, and hence ultimately operational excellence, remain elusive.

It can take great commitment to break out of this circle. *ABB Review* presents an example of sustainable improvements being implemented on a customer site.

In addition to cost-management pressures, organizations also face increasing demands for higher performance. Pressures to increase first-pass yield, attain higher levels of safety and environmental compliance pose unprecedented challenges to organizations the world over.

These and other pressures further combine with demands for higher levels of customer service and satisfaction. Consequently, many organizations are facing a difficult "sandwich effect" in which they are required to achieve more with fewer resources. This was exactly the challenge faced by ABB Full Service on an oil, gas, and petrochemical site in Argentina.

Since November 2006, ABB has been responsible for the electrical, instrumentation, and motor management for the Solvay Indupa site located outside Bahia Blanca, Argentina.

Customer satisfaction: a KPI

ABB, through its service-partnership offering, ABB Full Service®[1], can look back on a long history of delivering consistently high levels of customer service. ABB took on Solvay Indupa's challenge to deliver higher levels of customer satisfaction while seeking to maintain or reduce the manning, budgets, and other support resources. An important part of this challenge was demonstrating that client satisfaction does not have to be compromised when maintenance costs are reduced.

ABB Full Service uses a framework developed by ABB to deliver standard, repeatable approaches to improve operations at customer sites. This practice, common to all sites, is supported by common processes, site assessments, and knowledge sharing, with customer-satisfaction management, and people satisfaction being essential ingredients to its success 1.

> Many organizations are facing a difficult "sandwich effect" in which they are required to achieve more with fewer resources

This site-assessment process is not only effective in the ascertaining of current performance, but is also highly effective in developing forward-looking strategies.

Turning data into action

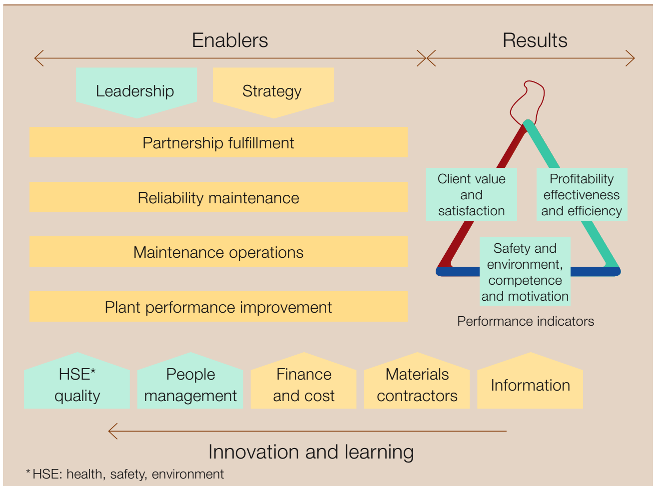
The customer satisfaction process was followed and implemented by the ABB Solvay site. Solvay participated in the ABB site-satisfaction survey process Factbox 1. The results of the survey were analyzed by ABB's team on the Solvay site and were used as the basis of a roadmap for future improvement initiatives.

While overall high marks were received, three key trends emerged as needs that Solvay looked to ABB to resolve. These needs were:
1) Form partnership practices with product units
2) Reduce maintenance costs
3) Continue to deliver equivalent if not better service delivery

Factbox 1 Customer satisfaction

The ultimate measure of a customer's satisfaction with site service is measured by how that customer feels about the value of the service being provided by ABB's site team. To objectively measure this, ABB has developed a global customer satisfaction survey assessment that provides valuable feedback to the site and the ABB management team. The tool is invaluable for the identification, measurement, and execution of action initiatives behind improvements. It identifies trends, shows performance levels against client expectations and tracks customer loyalty. The survey results assist ABB's site team in setting targets, managing actions to close any gaps, and then communicating improvement to the customer.

1 The site assessment process is an effective tool used to ascertain current performance and is also highly effective in developing forward-thinking strategies



2 The Solvay Indupa site located outside Bahia Blanca, Argentina, showing the different areas

Footnotes

[1] For further background on ABB Full Service, see also "Outsourced maintenance" on pages 79–83 of *ABB Review Special Report Process Automation Services & Capabilities* (2008).

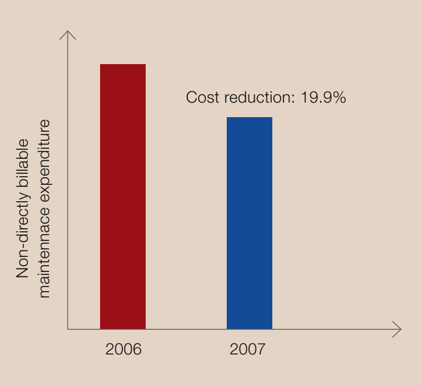
Maintenance for productivity

Attempting to fulfill the above three needs would stagger many organizations. However, the ABB Solvay team rose to the challenge. ABB carefully evaluated what Solvay was saying, analyzed how all these needs could be addressed and then developed an action plan to ultimately not only meet these needs but also exceed them.

Creating partnership practices

ABB drew on the extensive knowledge of individuals within its organization to understand how the first need, that of creating partnership practices with production, could best be accomplished.

3 The plant's maintenance budget was reduced by almost 20 percent



Factbox 2 Improvement methodology

1) Review budget data and conduct benchmarking analysis
2) Classify parts as A,B or C:
   - "A" the most expensive
   - "B" next most expensive
   - "C" most common and least expensive
3) Create short- and long-term goals
4) Short-term
   - Storeroom clean-up…5S*)
   - Part count and location accuracy audit
   - Clean-up part descriptions in SAP
5) Long-term
   - Select parts based on a balance between cost and process, safety, and environmental criticality
   - Continue to drive for equipment standardization

*) The 5S concept is discussed in **Factbox 3**

Although, at first sight, taking such a step may not sound too innovative, it is far easier said than done. In order to get closer to the production areas and to build and strengthen partnerships, ABB reorganized its on-site presence, assigning supervisors to each of the site's major production areas. On the Solvay site, these were the three areas, Cloro, PVC and CVM 2.

> The maintenance budget was reduced by 19.9 percent. Furthermore, this adjustment did not have any negative or adverse impact on the delivery of maintenance services.

Beyond the organizational chart

Reorganizations, as a tactical approach, are nothing new. However, ABB went a step further and arranged that ABB supervisors attend beginning and end-of-shift meetings at the customer size. This partnering became part of the supervisor's job expectations and resulted in the development of the weekly practices of work identification and agreement of the prioritization of upcoming maintenance work. This was reinforced through the use of weekly work schedules.

ABB's proactivity in creating partnership practices had an effect that no one could forsee at the time but that would have a profound positive impact on furthering ABB's relationship with Solvay.

Operational improvements

As a result of this collaboration, the ABB supervisors began to become intimately aware of the challenges facing their Solvay counterparts. During feedback sections, it was communicated to ABB's Supervisors that Solvay was looking to the company to help it with cost reduction.

Getting started

It is not uncommon that when faced with a challenge, some organizations never progress beyond the analysis stage leading to the classic phenomenon of paralysis due to over-analysis. However, ABB reviewed the maintenance budget and soon came to realize that spare part expenditures represented between 35 and 40 percent of the overall maintenance budget. Drawing upon ABB's vast global experience network in site management, ABB benchmarked the site against the best of ABB's other involvements, clearly revealing that there was room for improvement.

Standard processes yield quick results

Using a standard process model **Factbox 2**, the ABB team efficiently organized for action and followed a logical step-by-step process improvement methodology.

Tools improve results

To improve the delivery of results, the

4 Monthly tracking of customer satisfaction revealed that customer satisfaction not only approached, but actually exceeded the mutually agreed target levels

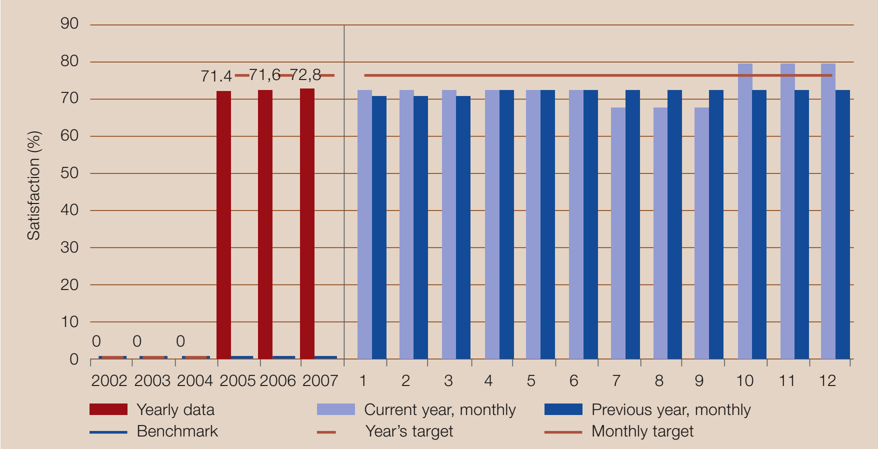


ABB site team leveraged the site's Computerized Maintenance Management System (CMMS) SAP-PM. SAP was used to "drill down" and generate reports that provided data on spare-part issues, inventory turns, stock outs and frequency of use. Additionally, significant value was derived from an inventory cross-reference report that searched for parts used on common equipment and also parts that might not have originally been set up correctly in the SAP system.

Some organizations never progress beyond the analysis stage leading to the classic phenomenon of paralysis due to over-analysis.

ABB also used process-mapping techniques to analyze external repair and rebuild cycle time and identify bottlenecks. Thus, through the application of lean maintenance techniques, the ABB site was able to quantify lead times and repair cycle times. This provided insight into external repair and rebuild processes that functioned well, but also highlighted those that were disconnected or dysfunctional.

Going back to the solid foundation laid through partnership practices with Solvay's production supervision, ABB's supervisors held monthly progress meetings and data review meetings to obtain clarification, support and understanding regarding which parts should be retained and which ones should be further reviewed. This critical step made sure that Solvay supervisors supported the findings and results as they were proactively involved in the inventory classification process.

The ABB team then divided the approach into several "sub-tasks" that were more manageable and offered improved project and progress tracking. The result was a greater surfacing of and focus on the parts that really mattered. In particular, the team used Pareto charts[2] to identify the 80 percent of problem parts affected by 20 percent of the causes[3]. A simple Pareto bar chart thus highlighted the relative contribution of each part or component to the total problem. This provided the team a valuable tool to focus and leverage on the critical few, which allowed energies to be channeled into those areas representing the biggest impact. These could be tracked by part-related KPI's.

Positive results achieved

As a result of the inventory improvement project, the maintenance budget was reduced by 19.9 percent 3. Furthermore, this adjustment did not have any negative or adverse impact on the delivery of maintenance services.

Customer satisfaction exceeds target

After successfully reducing the maintenance budget by almost 20 percent, monthly tracking of customer satisfaction revealed that customer satisfaction not only approached, but actually exceeded the mutually agreed target levels 4.

The trending of monthly maintenance costs shows that a steady management of these costs on a monthly basis has been achieved, and that there is little variation around the monthly target 5.

Continuous improvement is a marathon and not a sprint.

The way forward

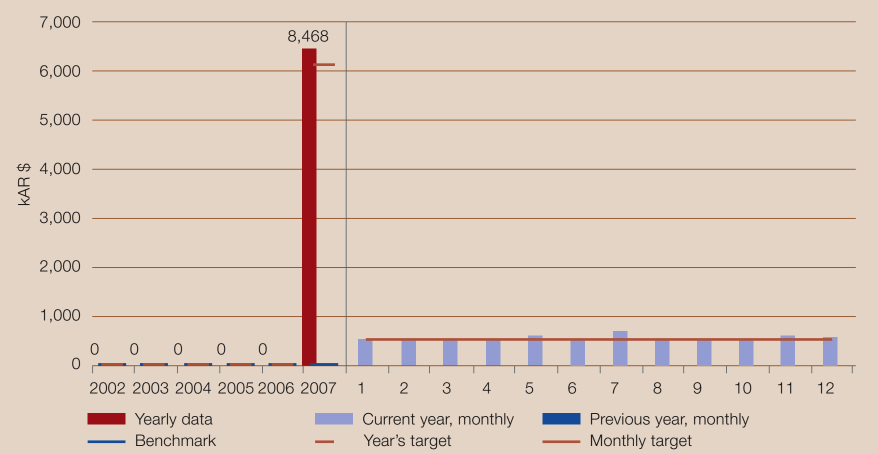
Not resting on the laurels of its success, the site is now poised to take performance to higher levels with a focus on equipment reliability. It has been said that "equipment doesn't fail, components fail." With that in mind, ABB configured SAP to deliver specific reports that allow the "drilling down" into specific data to yield additional opportunities for continuous improvement. The focus area was again driven by the customer satisfaction survey which highlighted addi-

Footnotes

[2] Pareto charts are bar charts in which the values being plotted are arranged in descending order, and an ascending curve is traced showing their cumulative value. Pareto charts are used in quality assurance and often used to illustrate the 80–20 Rule.

[3] The 80–20 Rule states that in many situations, about 80 percent of effects are due to 20 percent of causes.

5 Monthly maintenance costs could be sustainably reduced, and show little variation around the monthly target



Factbox 3 The 5S concept

5S is a tool contained within the Continuous Improvement methodology (Kaizen). Kaizen is a Japanese word literally meaning change for the better. 5S is comprised of the following elements:

1) Sort (Seiketsu)...remove unnecessary items
2) Straighten (Seiri)...organize
3) Scrub (Seiso)...clean
4) Standardize (Seiton)...develop standard routines
5) Spread (Shitsuke)... continue 5S initiative and carry to other areas

ABB's site manager, Duilio Magi

"Achieving results year after year requires excellent communication, cooperation, and a talented, skilled team of professionals. We have those vital components here at the ABB Solvay site."

tional areas for ABB to deliver initiatives to improve client site satisfaction.

"Bad actor or culprit" equipment was identified 6. Such equipment excessively consumes both labor hours and spare parts used in the repair and maintenance of that equipment. The hypothesis being applied is that equipment consuming more labor hours and spare parts than allocated or budgeted is also likely to have a low reliability or a high failure rate. This process provides an excellent entry point into equipment life-cycle cost-management practices. It is anticipated that this will provide another value-adding service delivery to Solvay.

6 ABB engineers apply the lessons learned from the inventory improvement initiative to pinpoint equipment that causes excessive costs

Recognized for leading practices
The Solvay site recently completed the site-assessment process. Among many notable achievements, the site received specific recognition for the way it has developed site improvements and cataloged these into an improvement library. This serves an added benefit by providing objective examples of the added value received by the client as a result of ABB's management of the site.

Not resting on the laurels of its success, the site is now poised to take performance to higher levels with a focus on equipment reliability.

ABB's Solvay site documents and retains each improvement initiative in a library that functions not only as a reference for further improvement initiatives but also serves as a reminder of the numerous benefits being delivered by ABB to Solvay.

Great achievements
It has been said that continuous improvement is a marathon and not a sprint. The ABB Solvay site is an example of the benefits that can be obtained through analyzing the client-satisfaction survey, forming close partnership practices with the customer and then creating a plan of action to address those opportunities that the survey shed light upon.

These initiatives are then sustained through the effective use of key performance indicators, which ensure that the performance gains are monitored. The analysis also revealed how a passion for delivering client value drives additional continuous improvement opportunities for attaining operational excellence. These deliver sustainable client value and thereby further underscore the importance of creating lasting partnership practices between the site and ABB.

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Rolling models

Adaptive setup models for cold rolling mills

Frank Feldmann, Mark Gerdau, Andreas Vollmer

Cold rolling mills are an important part of the production of metal sheet. In these plants, the metal is incrementally deformed by rolls in a number of passes to obtain the required surface and material properties and thickness.

To remain competitive, producers of flat rolled products are continually seeking to maintain and improve product quality, mill flexibility and productivity. Such steps require a deeper understanding of, and greater control over what happens inside the process.

ABB has developed a portfolio of models that help customers optimize their mills. In this article, *ABB Review* looks at the company's solutions for adaptive setup models.

Maintenance for productivity

Improvements in product quality mainly focus on finding ways to decrease tolerances in thickness and flatness and improve surface quality. Furthermore, mill flexibility must be increased to satisfy the growing demand for product variety, while high productivity (in both throughput and yield) is a prerequisite for remaining competitive in the global economy.

From the automation point of view, these demands translate into, among others, the following requirements:
- Reliable and modern automation control system
- Reliable sensors and actors
- Adaptive setup model for pass schedule[1)] and preset calculation
- Advanced technology control solutions
- Intuitive visualization, operation and diagnosis system and concept

Factbox 1 lists some of the applications that the models designed by ABB provide for.

To reach these goals, a mathematical model is used to calculate the pass-schedule and the mill preset 1. Based on the coil- and roll-data, scheduling uses reduction and tension tables that are derived from both practical experience and mathematical submodels, and predicts the behavior of the process on the basis of these. The model essentially consists of four parts: the work-hardening curve of the material (the flow-stress model), a roll-gap friction model, the roll-gap model (providing rolling load, drive torque, forward slip and strip temperature), and the mill model (providing the references for the strip-flatness actuators and the roll-gap positions).

Measured values are collected and filtered during each pass, and then compared with the corresponding predicted values. Adaptive parameters are calculated to bring the predictions into agreement with the measured values.

The rolling model consists of a package of various sub-models that are closely connected to each other and mainly based on physical principles.

The main sub-models are:
- Pass scheduling (Calculates the number of passes and related strip thickness distribution)
- Preset (Calculates all necessary preset values)
- Adaption model (Adapts the model by measurements)

Setup- and adaption-reports are generated for every coil and are stored to the database for further analysis and offline tuning of the model.

Pass-scheduling calculation

The task of the pass schedule calculation is to identify a suitable distribution of the reductions over several passes for given coil data (material grade, strip width, start and finish gauges). First, the boundary within which the optimal path must lie is defined by calculating the maximum reductions, pass by pass from the initial gauge forwards, and then again from the final gauge backwards 2. Then, taking into account the boundary conditions set by the mill and standard practice limits, a reduction path is sought that comes closest to meeting the chosen criterion. This can, for example, be a simple minimization of rolling time, or the achieve-

Footnote

[1)] A pass is one deformation step consisting of the different phases threading, rolling at constant speed, deceleration and tailout of the strip through the mill. A pass schedule is a series of values for the pass, such as thickness, speeds and forces presets.

Factbox 1 ABB and rolling mills

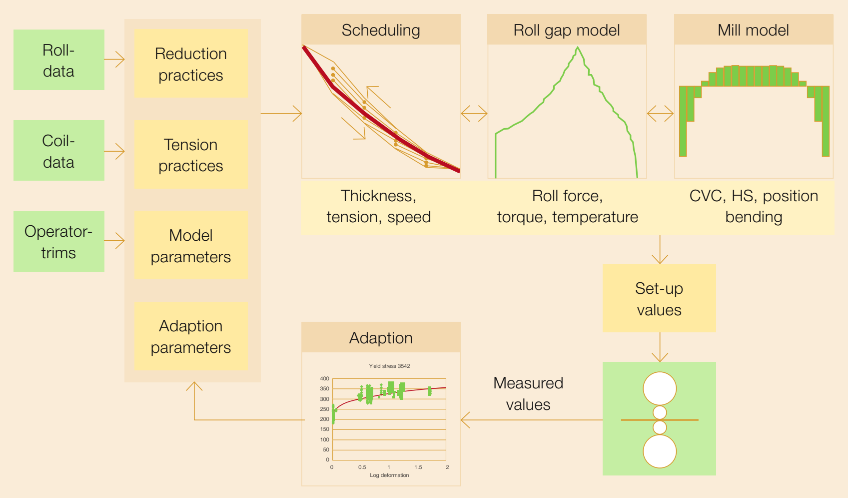
Rolling mill applications covered by ABB include:
- Single and multistand Mills
- Cluster and Sendzimir[*)] Mills
- Inline and continuous rolling mills
- Reversing and non-reversing
- Reduction, skin-pass, double cold reduction (DCR) and foil rolling
- Steel, stainless, aluminium, copper and brass for a wide range of end products

The task of the rolling model is to supply the appropriate setup-values to the level 1 open control system (OCS). The most important goals of the preset model are:
- Optimization of strip quality regarding off-gauge length, surface and flatness
- Optimization of throughput by faster threading, acceleration and maximum speed
- Ensuring that preset values remain within material and mill limitations
- Avoiding strip breaks, roll marking and threading stops
- Provision of stable rolling conditions
- Minimization of operator interventions

Footnote

[*)] A Sendzimir mill is a mill with small diameter work rolls, each backed up by two rolls of larger diameter which are in turn jointly backed up by a cluster of three rolls. This mill configuration is often used for height-strength- and stainless steel.

1 Interaction of data and functions in the rolling-mill process



ment of the same rolling loads for all passes.

The standard practice limits referred to above are process-boundary conditions that are defined in tables according to the product group, and may specify, for example, maximum reductions, coiling tensions in the first and last passes and so on.

The distribution of reduction per pass can be optimized according to several criteria. Criteria relating to high throughput or strip quality (eg, flatness and strip surface) may sometimes be contradictory. Schedules can be generated to fulfill demands for reduction and force limits as well as reduction and force trends (eg, constant reduction per pass or declining specific roll force per pass). Schedules can be optimized to gain the maximum rolling speed by equalizing the required motor power of all passes or stands. This can be achieved by changing the reduction or the tension distribution.

To meet operational requirements such as, for example, the charging and discharging of the coil on a certain side of the mill, an odd or even number of passes can be enforced. A fixed reduction in the final pass can be also configured. During the rolling of a pass, a recalculation correcting the subsequent passes can be performed when, eg, an intermediate thickness was not reached or the material appeared to be harder than estimated.

An essential element of the pass-schedule calculation is a roll-gap model based on physical laws. Besides entry and exit gauges and tensions, such a model also requires as entry data the resistance to deformation of the material, and the characteristics of the friction between rolls and strip. The resistance to deformation is described in the form of a flow-stress curve, which is in turn based on the results of tensile tests on samples of strip at each stage of rolling. The major influences on the roll-bite friction conditions are considered to be the roll roughness and the rolling speed. The effect of friction variations on the rolling load can be most clearly seen with mild steel and light gauges 3.

Preset model

After a pass schedule has been determined, the preset calculates the remaining set-up values. Sometimes the schedule data (eg thicknesses, tensions) are taken from a pass-schedule table or delivered by an external system (PPS, ERP, Level 3).

Required strip related input data for the preset calculation are:

- Entry thickness, width, entry temperature
- Hot rolling thickness or last annealing thickness
- Material grade, annealing type
- Strip profile, outer coil diameter
- Exit target thickness (for reduction mills) or exit target elongation (for skin pass mills)

The actual roll data such as roll diameter, crown, taper, length and texture are also important for a precise calculation.

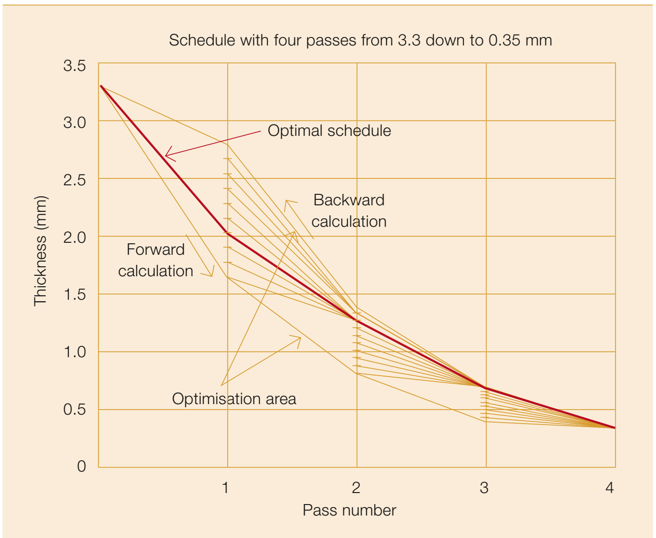
General parameters such as mill and drive limits, standard practices, adaption coefficients, yield stress and friction values are stored locally on the Level 2 (MES) system. The different sub-models are closely connected to each other 4, with the outputs of one model being available for use as inputs for other models.

The preset calculation function produces set-up values for threading-, rolling- and unthreading conditions, of all required passes. The calculated values are fed to the different control functions on Level 1 (OCS). The main

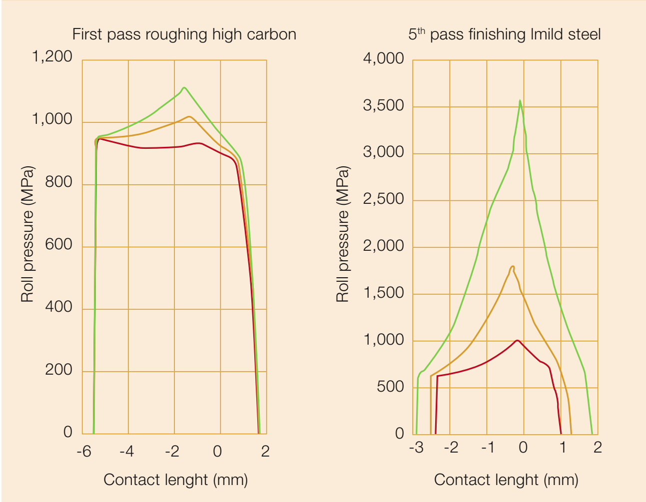
Factbox 2 Main values transferred from preset calculation to OCS Level 1

- Entry, intermediate and exit thickness
- Rolling speed
- Entry, intermediate and exit tensions
- Rolling force
- Roll gap position
- Rolling torque
- Flatness actuators (bending and shifting)
- Cooling quantity

2 The procedure used for calculating the pass schedule



3 Influence of different friction coefficients (μ=0.03, 0.05, 0.07) on the rolling load



Maintenance for productivity

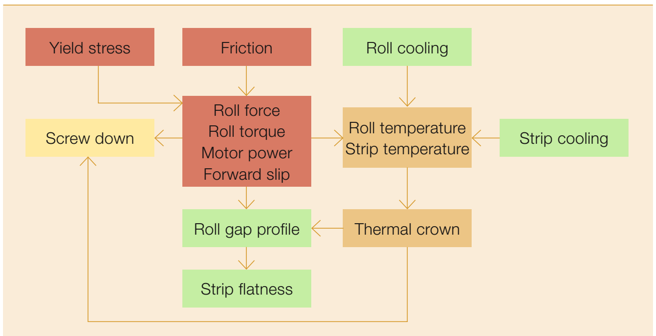
preset values transferred are listed in Factbox 2.

The scheduling and preset calculation is activated automatically when:

- The coil data was available the first time (plausibility check)
- The coil gets the state "next coil" or when the next coil is mounted to the pay-off reel
- The adaption of the previous coil is finished
- By manual request of the operator

The calculated preset values can be viewed by the operator. After possible modifications via the operator trim values and final check, the operator transfers the preset values to the level 1 and threading of the coil can be initiated. The state of the coil changes from "next coil" to "current coil". Preset values for that coil can only be changed when the mill is stopped. The operator can view the set points of the current coil and can prepare the set points for the next coil.

4 Interaction of sub-models in the rolling mill model



The different sub-models are closely connected to each other, with the outputs of one model being available for use as inputs for other models.

Key preset model components

The rolling model uses several sub models as components:

Tension model

The tension model is based on the determination of the specific tensions. These are calculated on the basis of strip thickness and yield stress of the material and the tension practice. Particularly, the first pay-off reel and last coiling tension depend on the pre-treatment and the post-treatment of the cold rolled coil. Rolling with inadequate tensions cause eg, coil slipping, unstable rolling and sticking during batch annealing.

When tensions can exceed the maximum values of the coiler or pay-off reel, they must be limited. When bridles are used, the ratio between pay-off reel/entry tension and exit/coiler tension is also limited.

Speed model

The maximum rolling speed is limited by the following restrictions:

- Maximum power of drives (mill drive, pay off reel/coiler drive)
- Maximum drive speed considering gear box ratio
- Maximum exit strip temperature
- Quality related speed limitation

The speed model reduces the speed until all of these limitations are satisfied.

Roll-gap model

The roll-gap model is further differentiated into a model for reduction mills and for skin pass / temper mills / foil mills.

For reductions of more than about five percent and a larger ratio between the mean gauge und contact length, a roll-gap model based on the classical circular arc theory of Ford, Ellis and Bland is used. This approach considers the plastic and elastic deformation of the strip in the roll gap. The deformed roll radius is calculated by the Hitchcock equation.

For skin-pass and foil rolling configurations (smaller reduction and ratio between the mean gauge und contact length), an online model is used that is tuned using a non-circular arc model based on the theory of Fleck and Johnson. The model calculates the roll force and torque, forward slip, deformation and friction energy. It uses the yield stress and friction model. Process disturbances are compensated by adaption coefficients.

The yield stress of a defined product is calculated on the basis of deformation, deformation rate and strip temperature. A product can be defined by a combination of properties such as material group, material grade or pretreatment (eg, type of annealing). The material-grade specific parameters need to be determined in close cooperation with the customer.

The friction coefficient is calculated on the basis of work-roll roughness/texture, speed and pass number.

Rolling with inadequate tensions cause eg, coil slipping, unstable rolling and sticking during batch annealing.

Strip temperature model

The purpose of the strip temperature model is to predict the temperature of the strip at all stages of the rolling process. The strip temperature is used for the yield-stress model and for the pass-schedule calculation. Factors affecting the strip temperature are the strip temperature at entrance, air cooling, heat extraction by the coolant pool, heat generation in the roll gap and heat exchange with the work roll.

If there is a separate strip cooling, the strip coolant flow needs to be calculated in such a way that the exit strip temperature stays below a defined maximum in order to avoid the occurrence of paper mark defects on the strip surface (stainless steel) or fire ignition (aluminum) due to an excessive temperature of the strip during coiling. If the calculated coiling temperature in one pass exceeds the safety limit with the maximum allowable oil flow, the rolling speed distribution over all passes is decreased accordingly.

Roll temperature and thermal expansion model

This two-dimensional transient model, which runs continuously, calculates the thermal state of the work during and after rolling. The finite-difference technique is used to calculate the temperature distribution in the work roll, balancing the heat flows into and out of the roll. The external heat flows from the strip to the roll and from the roll to the coolant, the backup roll and the air are represented by suitable heat-transfer coefficients. The spatial thermal expansion of the roll is then calculated from the resulting temperature distribution. The heat-input rate and the distribution of cooling effect across the roll are taken from the strip temperature and the roll cooling model.

Flatness model

The flatness model calculates the preset values of the flatness actuators to achieve the desired roll gap profile and flatness. A finite difference model takes into account the profile of incoming strip, roll force, strip width, roll diameter, grinding, deflection flattening and thermal expansion of rolls.

This thermal aspect is especially important when using a work roll of large diameter and small cooling efficiency combined with high heat input form the roll gap (eg, in aluminum mills). Depending on the type of mill, the profile model calculates the preset value for bending force of work and intermediate roll and axial shifting positioning of rolls.

This two-dimensional transient model, which runs continuously, calculates the thermal state of the work during and after rolling.

Roll gap position model

To permit a mill to be threaded in a stable manner, the roll-gap position of the loaded roll gap for a desired strip gauge has to be known. This model calculates the roll-gap position taking into account the stand modulus as a nonlinear function of the roll-force, strip-width and backup-roll-diameter. The thermal expansion of the work- and backup-roll and adaptation coefficients also influence the roll gap position.

Sensitivity model

The sensitivity model calculates the finite differences of the process inputs

to the outputs. These can then be used for the calculation of the feed forward and feed back controller parameters of gauge, tension and flatness control. This enables a constant quality for different products at all rolling phases.

The speed feed forward parameter, eg, describes the interdependency of speed and force. The bending feed forward parameter describes the dependency of force on bending. Both feed forward controls attenuate disturbances during acceleration and deceleration and are an important support of the gauge and flatness feedback control.

ABB's Preset model solutions for cold rolling mills play an important part in the improvement of product quality and productivity.

Adaption model

One problem encountered in mathematical modeling is that although the physical correlations within the process may be known, parameters are frequently unknown and may even be subject to change. The parameters of the cold-rolling process, for instance, yield stress, friction, heat transfer coefficients, etc, which are not all known and vary with time. This often leads to inaccurate predictions.

In order to improve the prediction capability of the preset model, an online model adaption for updating coefficients and parameters is performed which considers variations of material and mill behavior.

During rolling, measured data (if sensors are available: eg, entry and exit strip thickness, entry and exit strip tensions, entry and exit speed, rolling speed, rolling force, bending force, shifting and roll gap position) is acquired in a time-based cycle ("Input variables" in 5). After a plausibility check and filtering and estimation of unmeasured values, the recalculation ("Rolling model" in 5) and adaption for different rolling phases is started for the current coil to provide the adaption coefficients and parameters so that set-up calculation of the next pass can be calculated with an improved accuracy.

The adaption procedure learns from the differences between calculated and measured variables. The learning speed is configurable with a learning gain.

Short term adaption (fast learning speed) is performed from pass to pass and long term adaption (slow learning speed) from coil to coil and for a series of similar coils. Changes of product-classification (material class, width, gauge, etc), roll changes and long downtimes are taken into account 6.

An advanced roll model for mills

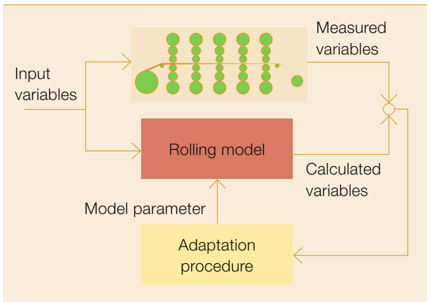
ABB's Preset model solutions for cold rolling mills play an important part in the improvement of product quality and productivity.

Main customer advantages are summarized in Factbox 3.

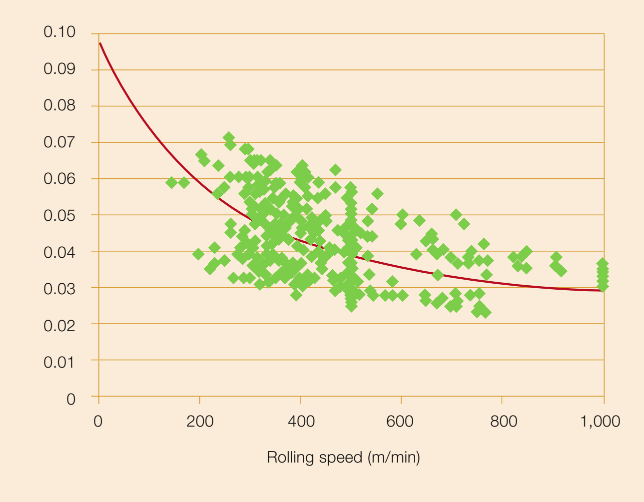
Factbox 3 Customer advantages

- Supports operator and production planer with automated set-point references
- Stabilizes rolling conditions with respect to the mill and process limitations
- Minimizes threading, tail-out and reversing times
- Reduces off gauge length at strip head and tail (in a recent revamped tandem cold rolling mill in average over the complete product range by 60 percent)
- Minimizes strip breaks, downtimes and roll damages
- Indirect improvement of strip surface quality
- Optimizes through-put rates (up to 4–6 percent, depending on mill and level of optimization)

5 Adaptation in a rolling model (the example is of a tandem cold mill)



6 Friction adaption with multiple passes



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Doing more with less

The drive for greater productivity

Trond Haugen, Edgar Jellum, Michal Orkisz

Oil and gas are valuable and finite resources in a world of increasing demand. Dwindling oil and gas reserves mean the days of accessing easy hydrocarbons are all but over. With the downturn in the economy, many companies are trying to boost productivity by implementing cost-saving measures, increasing work efficiency and by being more environmentally friendly. Indeed striving to improve productivity and eco-efficiency may be the only sustainable path through what are increasingly volatile markets. Success partly depends on redefining cooperation and partnerships, and by using technology as the enabler.

With capital, hydrocarbon reserves, human resources and energy severely limited, ABB has been working closely with customers to develop and deliver technologies and services that support a vision of integrated operations (IO). IO brings the problem to the experts who can then effectively support the operations of multiple assets from an operations center.

Maintenance for productivity

With mature, marginal and remote oil fields, arctic and deep sea locations, not to mention politically unstable regions, global warming and a shortage of qualified people, extracting the oil needed to satisfy an increasingly oil-thirsty world is becoming more and more difficult. Because companies now have to tighten their belts, the fact of doing more with less is not so much a cliché as it is a fact that has to be cleverly managed if companies are to weather the current financial storm.

In a world of limited resources, ABB offers technologies and services that help improve productivity and provide efficient operation and maintenance.

In a world of limited resources – and limited cash flow – ABB offers technologies and services that actually help improve productivity and provide efficient operation and maintenance. These solutions support the vision of integrated operations (IO)[1], which is defined as a set of solutions designed to increase efficiency, enhance recovery and lower operational costs in a time of declining oil output and rising demand.

Remote access and collaboration

An important part of IO is the information and communications technology (ICT) infrastructure and applications that enable multidisciplinary teams to effectively and remotely support the operations of multiple assets from an operations center.

Even though the concept of remote access and collaboration is more or less mainstream in office environments, in the management of power networks, home computing and entertainment, it was met with a healthy dose of skepticism in relation to the operation and service of oil and gas facilities. Failures can result in serious injury or even loss of life, spills or emissions into the environment and of course substantial financial losses. The targets of improved productivity, and the health, safety and environmental (HSE) impact had to be verified by extensive research and development, piloting and step-by-step roll-out to establish trust and evaluate the benefits. A continuous research and development effort, much of which is carried out in cooperation with Statoil-Hydro and various universities, ensures a constant flow of new IO technologies.

Supporting operations from an operations center enables the definition of new work processes that will increase recovery and daily production, reduce costs and improve HSE performance. To achieve this, technology plays a vital supporting role. As a key service and technology provider for implementing IO, ABB has also exploited the same technologies to improve its own performance.

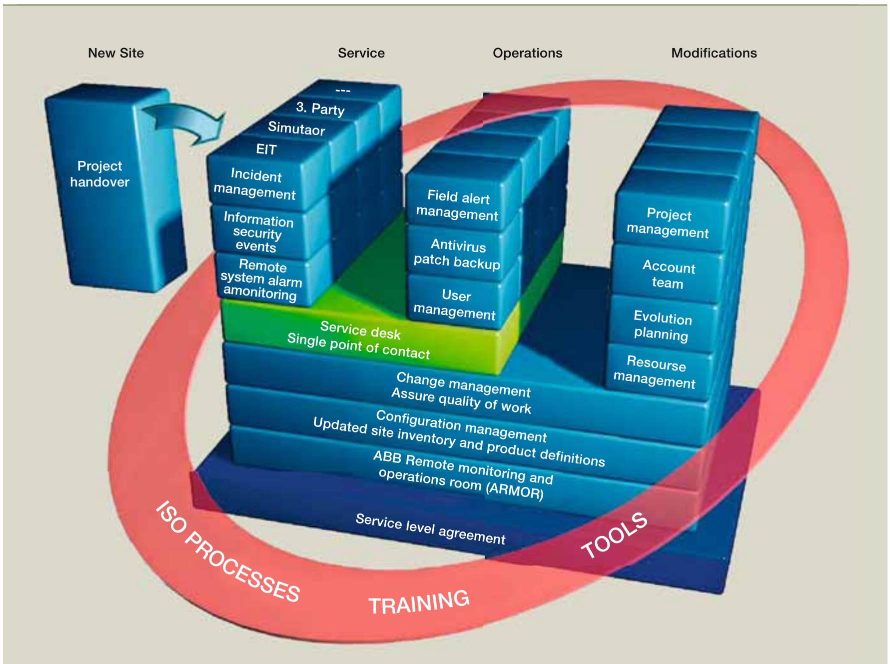
In recent years, automation and information technology in the oil & gas industry has advanced at a rapid rate. These advancements have in turn fundamentally changed the way ABB interacts with its oil and gas customers, and services their assets. In much the same way as customers organize work more efficiently and safely, ABB has developed the Service Environment™ to enable it to utilize expertise and deliveries from various ABB product and service groups, as well as customer resources and third-party supply partners.

ABB Service Environment™

Where is expert help when you need it? Often it is found within an organization, or with system suppliers and third-party vendors.

Traditionally, the expert has always had to travel to the site to solve the problem. What if the facility could be remotely accessed! This approach would not only slash the time and expense – not to mention the emissions – spent on traveling, but when a problem occurs, experts from anywhere in the world can be "on-site" in a matter of minutes rather than days. Sophisticated condition-monitoring and diagnostic tools combined with secure remote access solve the practical aspects of the logistical problem with faraway experts. It can be said

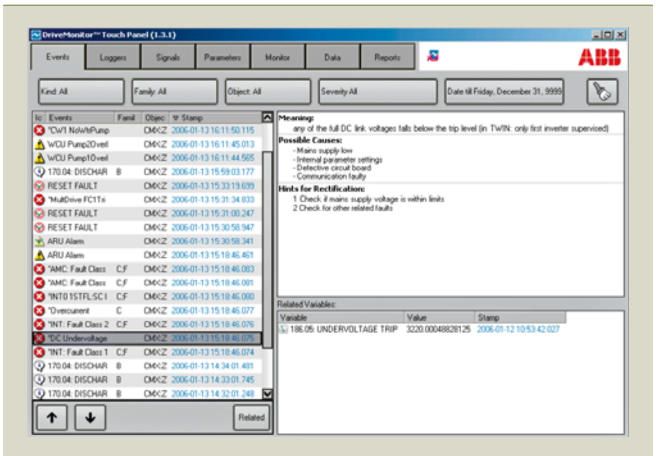
1 ABB's Service Environment™ has emerged from demands in the oil & gas industry and offers a comprehensive range of services that support the requirements of an integrated operations (IO) vision.



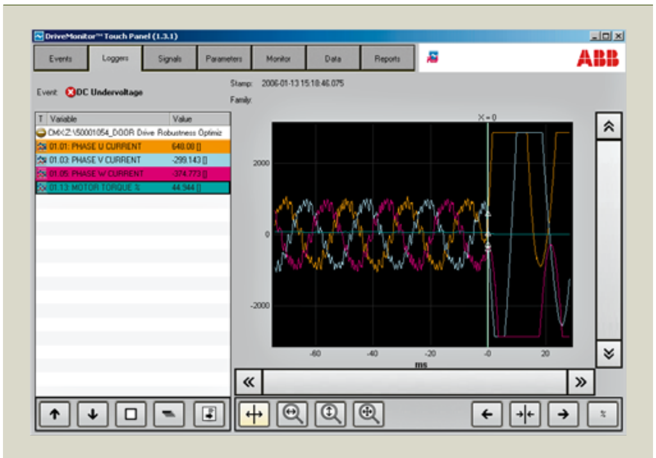
Footnote

[1] Statoil defines integrated operations (IO) as "collaboration across disciplines, companies, and organizational and geographical boundaries, made possible by real-time data and new work processes, in order to reach safer and better decisions – faster." www.isa.org/intech/20080401 (retrieved December 2008)

2 A DriveMonitor™ touch panel screenshot. The events list displayed includes alarms, sensitive parameter change notifications and application-specific diagnostic messages.



3 By selecting the "Loggers" tab, all relevant signals sampled at a high frequency prior to and after the selected event will be displayed.



that a timely, safe and consistent response to service requests requires the proper organization of people, work processes and procedures.

ABB's Service Environment provides such a solution. It has been developed for the oil & gas industry to support the vision of IO 1. The technical foundation of this framework is the ICT infrastructure and procedures that provide:

- Data security and integration
- User authentication (physical access and log-on)
- Remote access to ABB and third-party systems in the customer plant
- Collaboration tools to connect the customer, ABB and third-party experts

All remote work carried out on customer systems is done from a dedicated work environment called ARMOR™ (ABB Remote Monitoring and Operations Room), the cornerstone of the ICT infrastructure. A remote job is initiated by a service request that can be:

- Manually initiated by the customer
- Initiated on a time scheduled basis
- Automatically initiated by an alarm generated in a condition-monitoring system from ABB or third-party vendors

The service desk, which is part of the ABB Service Environment, provides a single point of contact for all service requests. From here the requests are routed to the right expert team, which is then ready to mobilize within a specified time. The safety and quality of the work performed by each of the service teams is ensured by an integral set of Service Environment work procedures that comply with the HSE regulations used in the oil & gas industry. All changes made to the system under service are logged and retained by the Service Environment configuration management and change management systems.

> ABB's Service Environment™ has been developed for the oil & gas industry to support the vision of integrated operations (IO).

Procedures and a code of conduct play a fundamental role in the daily operation of the Service Environment and ARMOR, in particular to ensure that remote operation in no way feels detached from the real plant. ARMOR is similar to an embassy in the sense that although hosted by ABB, the moment someone steps inside, the rules and regulations of the particular company and site apply.

Asset management applications for condition and performance monitoring, problem analysis and diagnosis can greatly improve the productivity of a company's local operation. Opening these applications up to remote access and collaboration, either by embedding them into the Service Environment or as standalone, further increases their value.

As a leader in power and automation, many of ABB's asset management tools have been developed based on experience from its core technology areas. One such example is DriveMonitor™, an intelligent monitoring and diagnostics system for medium-voltage drives that allows secure access to the drive from any location in the world.

VSDs and DriveMonitor™

Variable-speed drive systems (VSDSs) are fast becoming the prime mover of choice in the oil & gas industry. When compared with gas turbines, their main benefits include increased availability, better energy efficiency and operational flexibility, as well as improved HSE. A VSDS can be designed to run continuously for up to five years without scheduled maintenance. While they are crucial to an operation, VSDSs in general require little attention. However, failing rotating machinery may cause substantial production losses, and can impact the environment because of flaring. Additionally, limited attention translates into limited experience and therefore few certified experts.

ABB's award-winning tool, DriveMonitor captures, stores and visualizes the comprehensive information available in a VSDS. It offers a structured work

Maintenance for productivity

flow for condition monitoring, fault analysis and rectification. The comprehensive information available in an ABB variable-speed drive (VSD) combined with the diagnostic capabilities of DriveMonitor and the competence of certified experts mean the time needed to make repairs is drastically reduced. In general competence is available but normally not on-site, and definitely not in the middle of the night! With DriveMonitor connected to a fleet of VSDSs – either stand-alone or as a component of the Service Environment – expert assistance can immediately be brought on-line from any location within the company or as part of a service agreement with ABB. As opposed to heavy rotating machinery, VSDS repair is normally fast and straightforward once the problem is identified.

Factbox Improvement methodology

The “TAIL – Integrated Operations” project began in January 2006. The assigned targets of the project included:

- Increasing daily production by at least 5 percent by reducing production losses caused by operational failure, maintenance stops, and inadequate equipment performance.
- Reducing operating, construction, and maintenance costs by 30 percent.
- Reducing the number of unwanted incidents relating to health, safety, and the environment by 50 percent.
- Extending the lifetime of Statoil’s oil and gas fields.

Source: www.isa.org/intech/20080401 (Retrieved December 2008)

DriveMonitorTM, an award winning tool, provides the means to capture, store and visualize the comprehensive information available in a VSDS.

As part of the TAIL IO research and development cooperation with StatoilHydro **Factbox**, DriveMonitor has been installed on a compressor at the Kollsnes gas processing and pipeline compression plant. More specifically, it has been integrated into the StatoilHydro ICT infrastructure and tested for a set of remote access use cases. DriveMonitor, and the workflows it enables, captures the very idea of IO: it enables the efficient use of scarce resources irrespective of whether they are inside the company, or from technology or third-party vendors regardless of location. More specifically, it captures and organizes information that can be accessed from literally anywhere in a controlled and safe manner. Experts in remote locations can support and cooperate with site personnel.

The following key requirements are fulfilled by DriveMonitor:

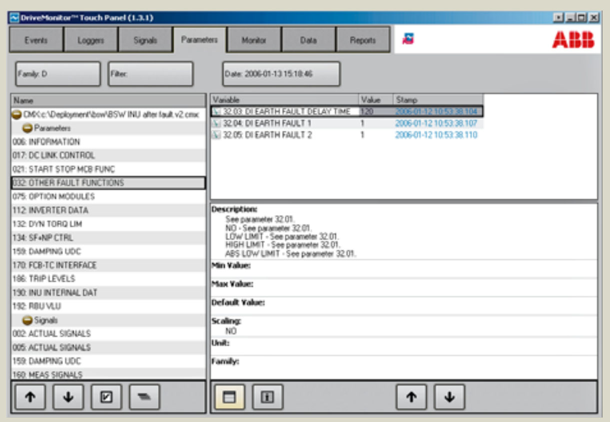
1) Tracking and storing the history of a VSDS as a basis for faster fault rectification; improved diagnostics, cooperation, and remote expert access and support; and collecting and storing alarms and events, operational data, as well as parameter and configuration changes.
2) Organization, cross-referencing and presentation of the information so that changes and problems can be identified and located.
3) Guidance and support for different levels of expertise: Site maintenance personnel; ABB local support personnel; and ABB Drives factory experts.

All events are stored together with the logs of measured values and other VSDS data that relate to a particular event. This data can then be retained for the entire life of the VSD. Access to the VSDS history is a valuable source of information for efficient analysis and fault diagnosis.

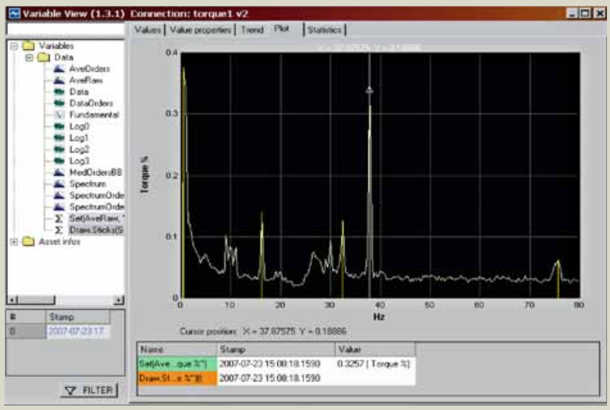
The user interface is organized to allow for easy navigation between the different views, which in turn provide structured support for condition monitoring, diagnostics and reporting. DriveMonitor comes with predefined settings and information that match different ABB VSD models. This ensures to-the-point expert advice concerning the different event types, sensible trigger criteria and the selection of data for retrieval, as well as the correct grouping and descriptions related to the drive parameters. In addition to the default settings, data capture and analysis can be freely customized with regard to trigger criteria and data selection. DriveMonitor can capture and store any information

4 The “Signals” tab will show a selection of relevant signals from the time a fault was reset.

5 The “Parameters” tab shows the relevant groups of parameters related to the selected event.



6 DriveMonitor™ also includes a general set of advanced mathematical and statistical tools.



available in the VSD control system, discrete events and analog data. Furthermore, all VSD parameters can be viewed together with information detailing when a parameter was changed.

The tab highlighted in the screenshot in 2 displays an event list which includes drive faults and alarms, sensitive parameter change notifications and application-specific diagnostic messages. By selecting an alarm or fault in the list, the user is presented with a description of the problem, a list of possible causes and hints for rectifying the problem.

The information presented in the three consecutive tabs is filtered according to the selected event. The second tab (Loggers) will display relevant signals sampled at a high frequency prior to and after the selected event 3. The Signals tab will show a selection of relevant signals from the time a fault was reset 4. This can be used to verify that fault rectification has had the desired effect.

The fourth tab (Parameters) shows the relevant groups of parameters that may relate to the selected event 5. Each parameter has a time tag showing when it received its current value. The tab view Monitor allows for the ad-hoc capture and storage of data. The user can freely select from all the available signals in the VSD control system.

Access to DriveMonitor

The VSD is a critical component and must be protected against malicious and mistaken access. DriveMonitor controls access to the information provided by the VSD control system. Those granted remote access will only be able to view the available data. If remote personnel want to change VSD parameters or modify the DriveMonitor configuration, access rights for one specific session must be explicitly obtained from authorized personnel within the customer safe access zone.

Individual oil and gas companies have typically deployed different architectures and tools for collaboration. Consequently, ABB makes its tools with added flexibility, thus enabling them to interface with the most common solutions. DriveMonitor has been field tested with different customers who also work with other collaboration tools such as Citrix, Microsoft Live-Meeting, VNC and IBM Lotus Sametime.

ABB's Service Environment™ and DriveMonitor™ allow problems to be solved faster and with fewer resources.

VSD as an instrument

In addition to providing monitoring and diagnostic capability tailored to the vital VSD, DriveMonitor also includes a general set of advanced mathematical and statistical tools 6. When used in combination with the valuable and detailed information supplied by the VSD, condition and performance monitoring of the motor, the equipment and even the process can be carried out without having to introduce additional instrumentation. This means an ABB VSD control system will have instant access to fast sampled data. Furthermore the drive's accurate dynamic model of the motor will provide additional calculated data such as motor torque.

DriveMonitor has the flexibility to read data from sources other than a VSD – such as a process control system – thereby allowing more comprehensive analysis of interactions between different subsystems, ie, the VSDS and the process.

Better access to service drives productivity

ABB's Service Environment and DriveMonitor help bring the problem to the expert rather than the expert to the problem. In doing so, problems can be solved faster and with fewer resources. In some situations they can even be avoided altogether! This lowers the overall cost of engaging an expert. Thirty minutes of collaborative expert assistance or quality assurance of a job rarely performed by site personnel can prevent errors. This type of approach will not only engage site personnel, but it will also increase their competence under the guidance of qualified experts. Similarly, a number of other services can be delivered on a continuous and proactive basis, ie, control loop performance and equipment condition can be monitored on a regular basis with limited effort.

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Simply the best

New trends in optimization to maximize productivity

Margret Bauer, Guido Sand, Iiro Harjunkoski, Alexander Horch

source: ThyssenKrupp

In April 2008, around 50 leading experts from industry and academia gathered to discuss the future trends of optimization in production management and manufacturing execution systems (MES). Presentations were made by 16 speakers focusing on the optimization of MES in the process industries. Among the topics covered were applications of mathematical optimization in industry and the experience and evaluation of modeling tools and optimization software.

Every year the German Operations Research society (GOR) organizes joint workshops with industry. In April 2008, ABB hosted the 80th such workshop entitled "Optimization in Manufacturing Execution Systems."[1] The main message of the workshop was that optimization is a fast growing area with an increasing number of applications in the process industries. Production companies and automation system vendors alike are under increasing pressure to raise production yield and run plants at maximum productivity.

What is meant by "optimization"?

A traveling salesman planning his route between 20 customers at 20 different sites provides a classic example of an optimization problem. Planning a route would be easy enough, but planning the best route would be a different matter. Optimization experts could be consulted, but only if a clear definition of "best" could be established. Would the "best" route be the fastest route or the shortest route? Or would it be the route that allowed the salesman to stay in his favorite hotel?

The decision hinges on the saleman's[2] definition of "best" and on what aspects of his route he would "optimize" for. Daily life is full of such optimization challenges: What is the quickest way of traveling between Frankfurt and Berlin? Which method will be most productive over a particular timeframe? How can the salesman spend more time with his family? One way to solve these challenges is through a process of continuous improvement. This involves finding a solution, which is then subjected to a series of refinements to provide a better solution. This technique is often used to refine production processes with the aim of increasing productivity.

Continuous improvement is good – it will find a better solution – but optimization would be better. Optimization finds the best solution! In its mathematical sense, "optimization" is the process of finding the best of all possible solutions. Therefore, the set of all possible solutions can be represented by a formal model describing the aim of the exercise (the objective), the decision variables and the constraints.

Interest in mathematical optimization has intensified in recent decades as computers have become more powerful and sophisticated new algorithms have been developed.

Mathematical optimization means finding the minimum or maximum of the objective function by choosing the values for a set of decision variables, while satisfying the constraints. For any specified objective, there may be local and global optima 1. In mathematical optimization, it is not enough simply to move closer to the optimal point, as done in process improvement. In mathematical optimization, the aim is to find the best solution point globally.

The optimization world

Mathematical optimization is a well-defined technology based upon a formal representation of the optimization problem. In order to solve a real-world problem using mathematical optimization, three key steps are necessary 2.

1) Problem identification
2) Modeling, ie, expressing the problem in mathematical terms
3) The development of appropriate algorithms to solve the problem

For industrial applications, once established, the solution to the problem will be implemented in the production environment. Optimization solutions are part of the MES layer (for more details see "The automation pyramid" factbox on page 16 of this issue) that sits on top of the automation system and also communicates with enterprise resources planning systems. Successful implementation requires real-time capabilities, online configurability, connectivity and reliability 3a.

Optimization problems

Production planning and scheduling is an area in which there are many applications for optimization 3b. In

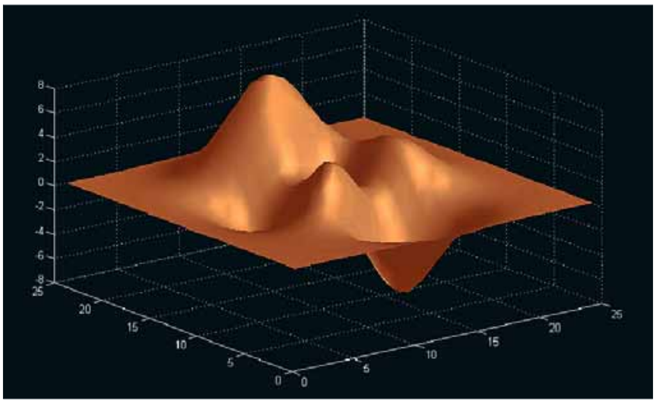
Footnotes

1) The workshop was jointly organized and hosted by Dr. Guido Sand, Scientist at ABB Corporate Research, and Prof. Josef Kallrath, head of the GOR working group. For the set of presentation slides contact guido.sand@de.abb.com.

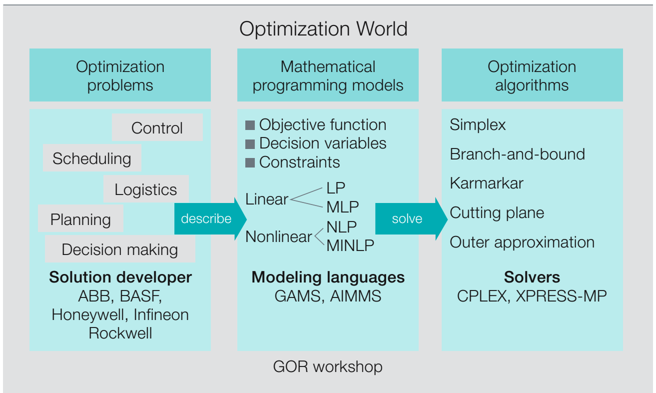
2) The "traveling salesman problem" is a classical problem in mathematical optimization.

3) The solution developers, modeling languages and solvers named here were presented at the workshop. There are others which are not named here.

1 Optimization objective as a function of two variables



2 The key elements of mathematical optimization[3]



planning and scheduling, the task is to allocate scarce resources to tasks over a specified period of time. In the production environment, resources comprise energy, raw materials, process equipment and manpower. Mathematical optimization can be used to determine the best use of these resources under given production constraints. For example, energy consumption and cost can be minimized by optimizing the energy efficiency of equipment and shifting energy-intensive operations to periods of low consumption when cheaper electricity tariffs are available 3c.

Although many industrial problems have been analyzed and improved solutions have been developed, in many areas the best solution has not yet been found and the optimization potential remains untapped. Problems that are often addressed manually include the following:
- Production scheduling (in terms of both volume and product type)
- Machine scheduling for each batch of products
- Capacity allocation (manpower and resource planning)

Interest in mathematical optimization has intensified in recent decades as computers have become more powerful and sophisticated new algorithms have been developed.

Modeling the optimization problem

When expressing an optimization problem in mathematical terms, the first step is to define the problem clearly. Is the aim to maximize throughput or to minimize energy consumption? Or are both variables important? Once the objective has been clarified (not always an easy task), the next step is to identify the decision variables, the choices that can be made. For example, can an energy-intensive production process be shifted to take advantage of cheaper electricity tariffs? What equipment is available and which machines would be best suited to the task in hand? Can raw material be purchased from different suppliers? When these questions have been answered, the constraints of the problem can be defined.

With each problem that needs to be solved comes a different set of considerations. A process might rely on the use of limited resources, such as raw materials, processing capacity, or even storage capacity for the final product. All processes are limited by bottlenecks, but it is not always easy to identify where these bottlenecks are.

3 Table of speakers participating in the meeting

	Topic	Speaker	Affiliation
a	Requirements on sustainable MES solutions and technologies in process industry of process industries	Ansgar Münnemann	BASF, Germany
b	Overview of planning and scheduling for enterprise-wide optimization	Ignacio Grossmann	Carnegie Mellon University, USA
c	On the relevance of optimization for the growing requirements on energy efficiency with cases studies	Bazmi Husain	ABB, Sweden
d	Manufacturing – Is there a role for algebraic modeling systems?	Jan-Henrik Jagla	GAMS, Germany
e	Optimizing manufacturing processes and planning with AIMMS	Frans de Rooij	AIMMS, Netherlands
f	Integrated manufacturing planning, batching, and scheduling, with ILOG plant PowerOps	Julien Briton	ILOG, France
g	Solving hard production planning and scheduling problems using Xpress-MP	Oliver Bastert	Fair Isaac, Germany
h	Production Optimization – requirements for sustainable Success	Alexander Horch	ABB, Germany
i	Oil & gas supply chain optimization	Marco Fahl	Honeywell, Germany
j	Advanced process control and optimization in the modern industry	Eduardo Gallestey	ABB, Switzerland
k	Unattended operation of water supply and optimization of pump schedules	Jan Poland	ABB, Switzerland
l	Chance constrained model predictive control for building energy management	Manfred Morari	ETH Zürich, Switzerland
m	Non-anticipative scheduling in semiconductor manufacturing systems involving setups	Hermann Gold	Infineon Technologies, Germany
n	The challenge of increasing complexity in production optimization	Iiro Harjunkoski	ABB, Germany
o	Integration of manufacturing optimization according to ISA 95	Thomas Schulz	Rockwell Automation, Germany
p	Uncertainty-conscious production scheduling	Sebastian Engell	TU Dortmund, Germany

When expressing an optimization problem in mathematical terms, the first step is to define the problem clearly.

Objective functions and their relationship with decision variables and constraints are expressed by mathematical equalities and inequalities[4]. The complete formulation is referred to as a "mathematical program," where the term program is used differently to the common notion[5]. Mathematical programs are of different types, depending on the nature of the formulation. If all equations, ie, the objective and all constraints, can be formulated using only linear terms with continuous variables, the optimization is referred to as linear programming. The formulation of a linear program (LP) is as follows:

Footnotes

[4] Equality is a proposition stating that two terms are equal ie, an equation. Inequality is a proposition stating the relative size, order, or difference of two objects ie, greater than (>),less than (<), or not equal to (≠).

[5] The term "mathematical program" does not refer to a computer program but is simply a synonym for a formal optimization model. Correspondingly, the term "mathematical programming" is a synonym for solving the mathematical program, ie, for mathematical optimization.

$$\text{maximize } c^T x$$
$$\text{subject to } Ax \le b$$

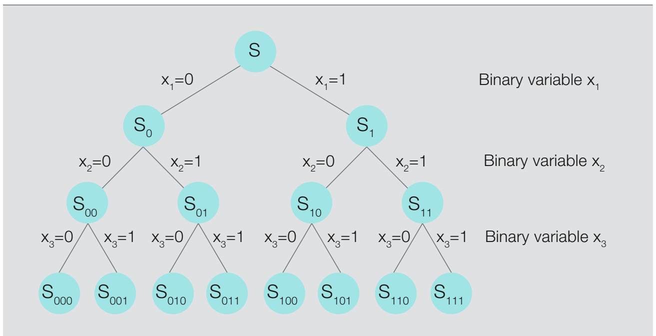
where x is a vector of variables, c and b are known parameter vectors and A is a matrix of known parameters. $c^T x$ is the objective function and $Ax \le b$ represent the constraints[6].

If any equation comprises a nonlinear term, for example a product of two decision variables ($x_1 \cdot x_2$), then the problem is referred to as a nonlinear program (NLP).

In many cases, the decisions to be made are binary and answer yes/no questions: "Shall I visit customer x today: yes/no?" Also, many variables are integers (whole numbers): A carpenter can manufacture only a whole number of tables, never a fraction of a table. In this case, the problem would be a mixed-integer linear program (MILP) or a mixed-integer nonlinear program (MINLP).

Most modeling languages for mathematical programs were developed for operations research, but have found increasing use in engineering applications. Two dedicated modeling languages for optimization problems are GAMS and AIMMS. The roots of these modeling tools are in economic optimization 3d, but there is increasing interest in their use in engineering applications. Current software includes debugging, profiling and data analysis features 3e. The modeling systems provide interfaces to a number of standard solvers for the different types of mathematical programs.

5 Binary search tree for solving mixed-integer linear programs



Finding the optimal solution

Finding the optimal solution to a problem can be very difficult, particularly if there are large numbers of variables to be considered and if the problem is highly complex. Generally, even large LPs can be solved in a relatively short time because the best solution lies at the constraints or at intersections of the constraints. For example, the throughput of a process may be limited by an output-flow rate. This means that the maximum throughput will be exactly equal to the limiting output flow rate. Finding the solution to NLPs, however, can be more challenging, especially if the problem is non-convex[7] 4. In these cases, more complex algorithms must be applied or the problem must be divided into convex sub-problems.

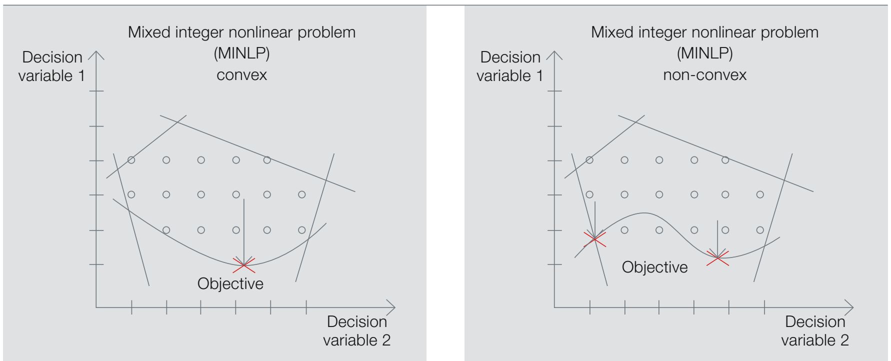
A standard method to solve mixed-integer problems (MILPs or MINLPs) is to apply branch-and-bound algorithms.

Discrete decisions can also complicate an optimization problem as the number of possible solutions grows exponentially with the number of choices to be made. The production sequence of three products, A, B and C, which are all manufactured by the same machine, can be produced 3! (factorial)= 1*2*3 = 6 different sequences (ie, ABC, ACB, BAC, BCA, CAB and CBA). Normally, to manufacture 100 different products, several machines would be needed. Manufacturing just twenty products on one machine would result in 20! different sequences – a number with 18 digits – and it is clear that not even a super computer could try all combinations within a reasonable time. If a computer was able to test one million combinations per second, it would need 77,000 years to try 20! combinations and find the best solution. This sequencing problem is very similar to the traveling salesman problem stated above: The number of possible traveling routes is also 20!

A standard method to solve mixed-integer problems (MILPs or MINLPs) is to apply branch-and-bound algorithms. Branch-and-bound algorithms can be used to solve a sequence of LPs or NLPs and are capable of finding an optimal solution by examining only a fraction of the possible solutions and eliminating whole branches of the search tree 5.

There are many solvers available, such as ILOG CPLEX, which can deal with very large optimization problems using multiple CPUs in parallel processes 3f. Xpress-MP Optimizer is noted for its ability to solve numerically difficult or unstable problems, which is often applied in the process industries 3g. Because these sophisticated algorithms are still very expensive, in the range of several thousand dollars each, optimization as a service that can be purchased on demand, may

4 Optimization problem types – convex and non-convex nonlinear programming problems



Footnotes

[6] As each equality constraint can equivalently be represented by two inequality constraints, the formulation covers both equality and inequality constraints.

[7] When the problem is described by a function that forms a non-convex curve on a graph.

become a popular option 3h. The US government already provides a website (NEOS) onto which optimization problems in GAMS or AMPL can be uploaded and solutions retrieved in real time. This may not be viable for all applications, but is a good way to test and verify problems before investing in expensive solvers[8].

Applications

Real-world optimization problems are usually hard to solve. The problem type is often nonlinear and/or contains binary variables. The performance of standard tools is often insufficient, necessitating the development of engineered solutions. Engineered mathematical programming uses carefully designed optimization models and intelligent solution strategies, often based on problem decomposition. When designing such a solution, the optimization core ie, formulating and implementing the problem, often contributes no more than 10 to 15 percent of the engineering effort. Problem understanding, idea development, discussion with customers, testing, documentation, marketing, and so on, constitutes the remaining effort. During the GOR workshop, this opinion was shared by speakers presenting optimization application solutions – both from inside and outside ABB. The applications introduced included supply chain management in liquefied natural gas plants 3i, economic process optimization and scheduling in minerals 3j, optimization of pump schedules in pump stations 3k, online optimization for building energy management 3l and batch scheduling in semiconductor plants 3m.

In the following, three very successful ABB optimization solutions, published previously and discussed at the GOR workshop, are shown in the context of mathematical optimization.

> The US government provides a website (NEOS) onto which optimization problems in GAMS or AMPL can be uploaded and solutions retrieved in real time.

Copper plant scheduling and optimization

In copper production, the ore is purified in several consecutive stages. During this process, it is transferred between stages in ladles using cranes. Large copper plants have parallel processing lines for the stages that would otherwise create bottlenecks and these must be synchronized to prevent overloading. This is a complex problem because the length of the purification stages differ depending on the quality of the ore.

The productivity of a copper plant is chiefly determined by the scheduling of the batches through the plant. ABB has developed an optimization solution to determine the optimum schedule for this process [1] 6. The task was to determine a production schedule that maximized the plant's throughput, by determining the optimal material quantity and detailed timing for each batch of copper production. The overall schedule was constrained by equipment availability for each stage of purification, as well as by processing and transportation times. The problem was formulated as an MILP and the solution used ILOG CPLEX to generate the schedule and the optimal recipe definition for each batch. The objective was to minimize the makespan[9] tm of all products p on all machines m:

$$\min\ tm \quad \text{subject to} \quad tm \geq tf_{pm}\ \forall p, m$$

Where tf is the finishing time of a product p on machine m. The optimization solution showed the plant's potential to increase throughput by up to 20,000 tons of copper concentrate per year.

Energy efficient hot rolling

In a hot rolling mill, steel slabs are heated to several hundred °C and rolled into thin sheets. An important decision variable is the speed at which each slab is rolled.

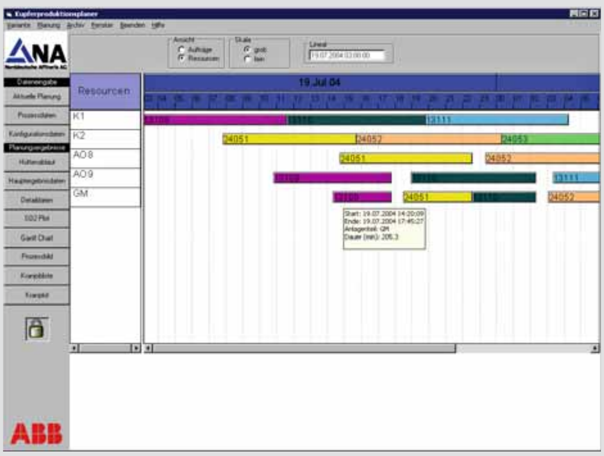
Minimizing energy consumption is one optimization objective the opera-

Footnotes

8) For further information visit NEOS website: http://www-neos.mcs.anl.gov/(December, 2008).

9) Makespan is the total production duration, ie, until the last product has finished on the last machine.

6 Copper production and Gantt chart of the optimal schedule



7 Hot rolling mill optimization solution faceplate [2]

Structure of a rolling optimization set-up

Objective
Minimization of total rolling POWER/ENERGY, or,
Maximization of PRODUCTION SPEED, or,
Minimization of deviation from target powers (LOAD SHARING), or,
Minimization of deviation from target widths (GROOVE UTILIZATION), or,
Minimization of deviation from target areas (GROOVE UTILIZATION)

Parameter Bounds
… < Roll gap < …,
… < Motor speed < …,
… < Interpass tension < …,
… < Width < …,
… < Area < …,
… < Production speed < …,
… < Billet temperature < …,

Variables
Roll gaps, motor speeds

tor may pursue, while at the same time meeting upper and lower speed limits for bar width, area, speed, interpass tension, roll gap and motor speed. In short, the question is: what is the best production speed for a hot rolling mill if the system is limited by available motor power and torque?

ADM™ (Adaptive Dimension Models) is an ABB software tool that formulates solutions to the optimization problem as a nonlinear program[10)] [2]. In addition to minimizing energy consumption, the user interface allows the operator to choose between alternative optimization objectives, such as maximizing throughput, minimizing deviations from target power, width or areas 7.

ABB's ADMTM software tool formulates solutions to the optimization problem as a nonlinear program.

Minimizing trim loss in paper cutting

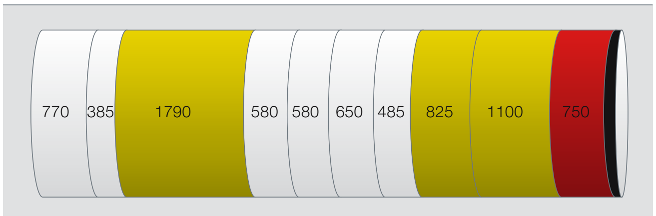
Paper mills produce so-called jumbo paper reels, 10 meters wide, which are cut down after production to meet customer specifications. Qtrim[11)], a re-trimming solution developed at ABB, takes an existing cutting plan for a jumbo reel and re-plans it according to the requirements [3]. The quality-based trim loss problem asks the following: What is the best way to cut rolls to customer-specified dimensions while also meeting the customer's quality requirements? The objective can be expressed in mathematical terms as follows:

$$\max \sum_{r,j} c_{rj} \cdot xd_{rj}$$

where index r indicates the rolls and index j indicates discrete slices, corresponding to a position on a jumbo reel. The cost coefficient c_{rj} is the value of a roll r at a given position j. The binary variable xd_{rj} indicates if roll r is allocated to slice j ($xd_{rj}=1$) or not ($xd_{rj}=0$).

The output of the optimization is a cutting plan that minimizes the quality losses. By implementing the best quality considerations in the cutting process, profit margins can be improved by up to 15 percent 8.

8 Optimized trim set of a jumbo reel
(Quality A = white, B = yellow, C = Red) [3]



Complexity and uncertainty

In the processing industries, there are already numerous optimization solutions to improve productivity. However, there still remain some unresolved issues that were discussed at the workshop. One is the ever-increasing complexity of problems 3n. The reasons for this are manifold, but many problems that were previously solved manually should now be optimized mathematically. Also, separate problems concerning the same production process can be combined. For example, a production process can be optimized for both throughput and energy consumption. More and more information can be measured, stored and used for optimization, which increases the number of decision variables and constraints. With an increase in complexity comes the problem of performance. Solutions to problems should be available in seconds or minutes.

A further open issue is the fact that optimization software solutions have to be integrated into the existing landscape of IT systems and cannot be used independently 3o. They require information from other systems, from the control, business-planning and logistic systems. There are a number of useful industrial standards for integration. For instance, the ISA-95 standard describes the necessary standards for interfacing between these systems.

Lastly, most optimization solutions assume that the input parameters are correct. The decisions must be made based on information that is available before the optimization algorithm is run. In the real production environment, the correct parameter values are often not known. A batch may take on average 10 minutes to produce but can in some instances be finished after eight minutes, in others after 12. Dealing with these uncertainties is a key challenge for real-world applications of these solutions 3p. Evolutionary algorithms, in combination with traditional solution algorithms, show potential to deal with these types of problems.

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Footnotes

10) http://www.abb.com/metals → Profile mills → Profile mill products → ADM

11) http://www.abb.com/cpm → CPM for the Pulp and Paper Industry → Quality Based Re-Trim Optimization

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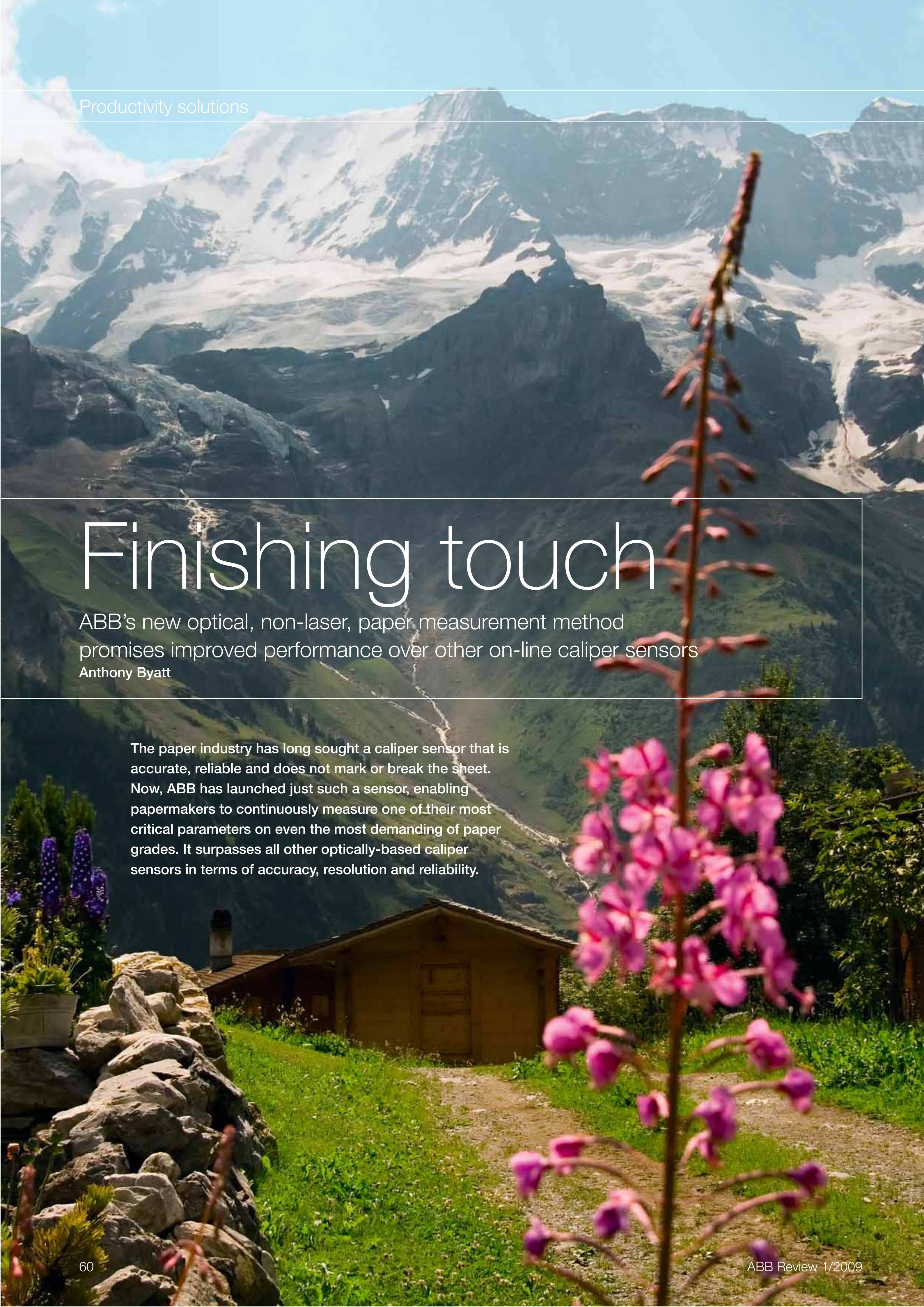
[3] **Harjunkoski, I., Säynevirta, S.** The cutting edge: cutting the inefficiency out of paper re-trimming. *ABB Review* 4/2006, 53–58.

Finishing touch

ABB's new optical, non-laser, paper measurement method promises improved performance over other on-line caliper sensors

Anthony Byatt

The paper industry has long sought a caliper sensor that is accurate, reliable and does not mark or break the sheet. Now, ABB has launched just such a sensor, enabling papermakers to continuously measure one of their most critical parameters on even the most demanding of paper grades. It surpasses all other optically-based caliper sensors in terms of accuracy, resolution and reliability.



Paper "thickness" can be a misleading term as some paper grades, on a microscopic level, resemble the Swiss Alps 1. In a lab measurement of paper thickness, a standard weight lightly compresses the peaks and the residual sheet thickness is, by definition, the "caliper." Caliper is a need-to-have measurement for almost every papermaker.

In most on-line caliper sensors, the paper is "pinched" between a pair of skis. A magnetic distance sensing device in one ski measures the distance between the skis and thus provides a measurement of sheet caliper.

Paper thickness can be a misleading term as some paper grades, on a microscopic level, resemble the Swiss Alps!

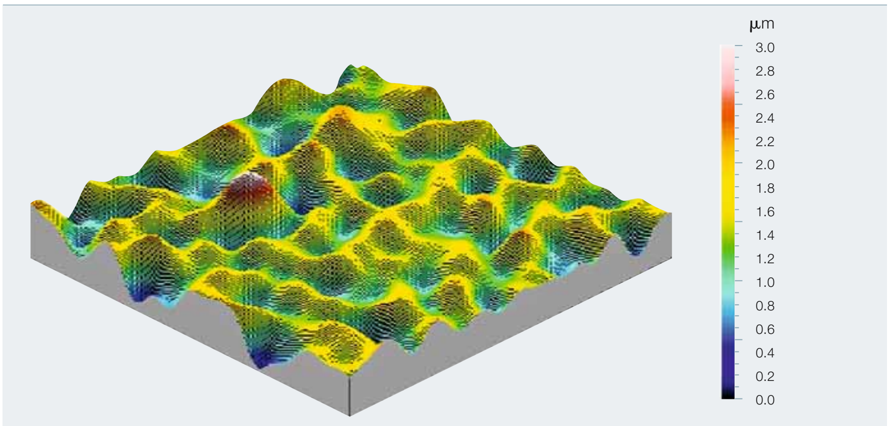
The current top-of-the-range ABB "GT" caliper sensor employs this simple principle, though years of engineering finesse have gone into refining the materials and lightening the ski's touch. In this way, a caliper accuracy of better than 1µm across a 10-meter wide sheet running at 120 km/h can be achieved! This dual sided contacting ABB sensor has become an industry standard, now utilized on more than 1,000 paper machines.

ABB's optical caliper sensor enables papermakers to continuously measure their most critical parameters on the most demanding of paper grades.

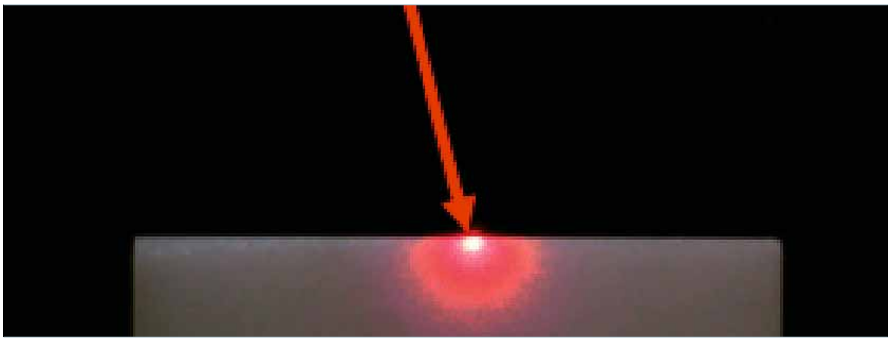
Uphill skiing

However, the touching skis can cause quality problems: coated paper can be scratched; dirt in recycled paper or non-cured coatings can build up and generate an uneven surface on the skis, thereby falsifying the reading; and lumps in the paper can come whizzing along and damage – or even

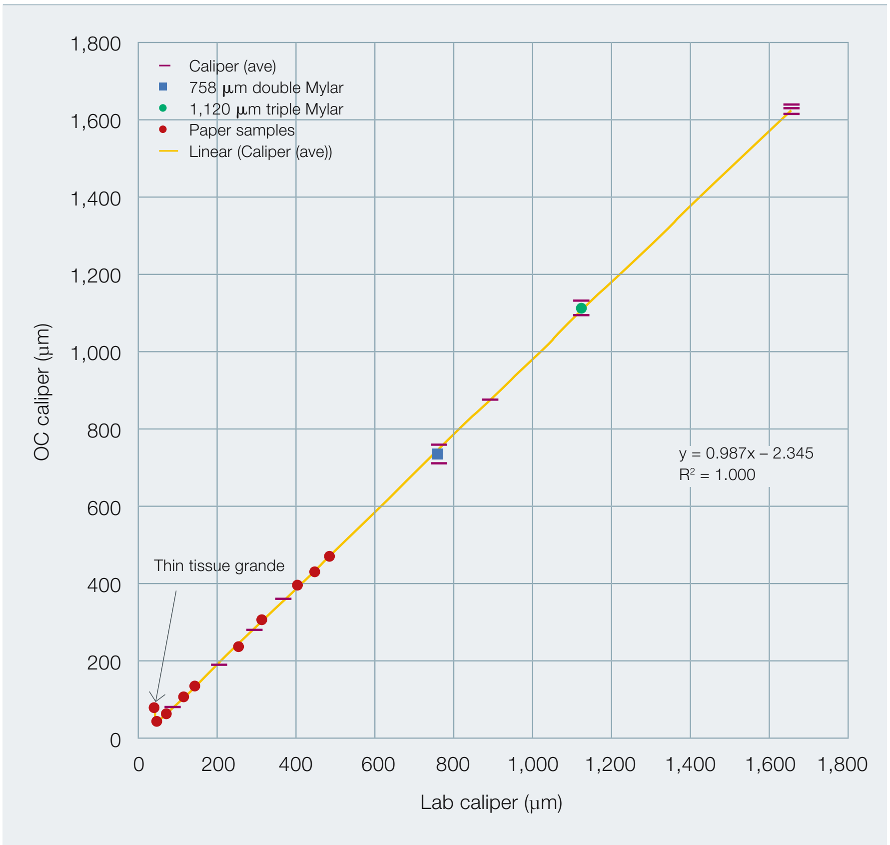
1 On a microscopic level paper resembles the Swiss Alps!



2 An illustration of the "glow-ball" effect of laser penetration into the paper surface



3 ABB's optical caliper (OC) performance versus a variety of paper grades



break – the ski or rip the paper. Of course, most paper grades do not have these problems and the sensor will function fine for years. But in those that do, the papermaker suffers a serious loss of insight into, and control of, his process.

The new ABB optical caliper (OC) sensor changes all this.

The footprint of ABB's optical caliper sensor is only 12 microns!

Look but don't pinch

The idea of measuring caliper without pinching the paper is not new. Indeed, ABB pioneered this – with air-bearing techniques – as far back as 1970. Laser triangulation methods also showed promise but are plagued by substantial errors caused by instability in a fast moving sheet, tilt effects from a non-flat sheet, sensor alignment, surface topography effects, and not least, laser light penetration into the semi-translucent paper body (ie, glow-ball effect) 2. These problems have hindered the market success of sensors based on laser triangulation. Therefore, ABB decided to assess the potential of technologies from other industries. One technique in particular caught its eye – a confocal optical inspection method.

Customer demands

An evaluation showed that this technique did indeed work. Even better, there were commercially-available optical devices which could form the core of the sensor. The optical non-laser, inspection method had been successfully proven in the lab 3, but the question remained as to how it would work on a paper mill – under harsh conditions – with high-frequency vibration signatures well outside the fine micron measurements to be measured?

The optical measurement provided better small-scale details of the machine variability 4. A contacting sensor ski has a footprint of some 1 to 2 cm, while that of the optical sensor is only 12 microns!

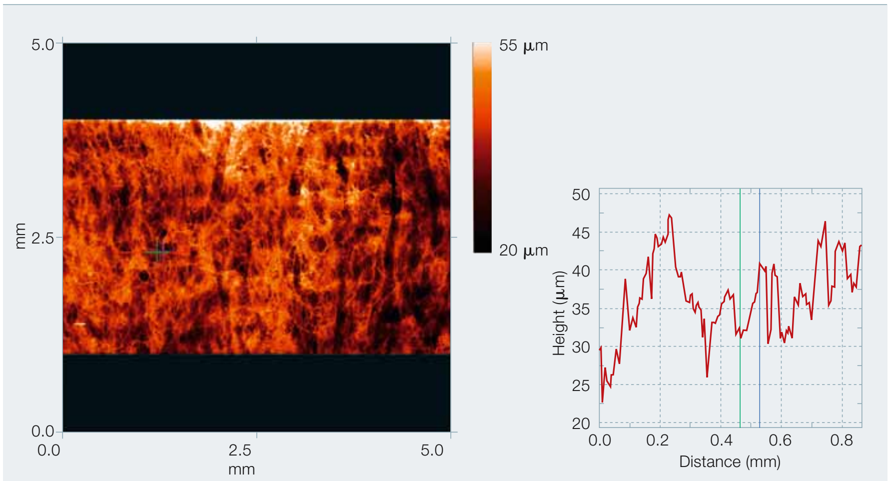
The optical caliper sensor surpasses all other optical-based caliper sensors in terms of accuracy, resolution and reliability.

From prototype to product

Much work was needed to productize and optimize the sensor. The old saying of "5 percent inspiration, 95 percent perspiration" came into its own with a vengeance! One major challenge was to preserve the micron accuracy on a large steel structure that heats up from room temperature to 80°C with all the attendant thermal expansions!

The product was launched in March at the ABB sponsored conference "Automation and Power World 2009" in Orlando, Florida. An article discussing the sensor in greater detail will appear in a future issue of *ABB Review*.

4 High-resolution surface profiles of 80 gsm copy paper viewed by optical caliper inspection technology



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Green robots

Robot-based automation is enabling energy efficiency in the plastics industry

Anna Liberg, Malin Rosqvist, Alexander Farnsworth

Green thinking is smart thinking. At least that's what governments, businesses and consumers all seem to agree on. Concern for the environment is no longer a fringe issue that interests only a small segment of the population, and industries – including plastics – have taken heed. Lessening the impact on the environment often results in cost savings, in particular when it comes to saving energy, a key element in the environmental improvement equation. The fact is, increasing energy efficiency is currently one of the biggest trends in the business. In the plastics industry, robots are helping increase energy efficiency by making processes more precise and efficient, and by becoming more precise and efficient themselves.

Energy efficiency is an important element in increasing overall factory efficiency. Effectively managing energy requires involvement and accountability of all people and departments. It also means that goals and targets must be set and that energy consumption must be measured for continuous improvements. To improve energy efficiency, factories must focus on life-cycle costs, rather than front-end costs.

Cantex Inc. increased production by 30 percent by retrofitting 75 kW, 90 kW and 110 kW ABB drives for the motors powering the mixing screws of three extrusions.

"Most plastics processing plants can reduce their energy costs by 10 to 30 percent through a combination of no-cost, low-cost and investment actions," said Santiago Archila, manager of the factory planning group at Husky Injection Molding Systems in Canada. The group specializes in factory efficiency, and is also looking into how machines can be used more efficiently, an area with great potential for savings. With smart planning, the number of machines can be reduced, and more energy can be saved.

Builders of injection molding machines are also looking at the whole molding process to improve energy efficiency. The choice of machine, mold and peripherals all work together, and the right choice and installation process will reduce energy consumption as well as material, eg, the number of rejected parts. By optimizing the processes and reducing downtime, as well as reducing setup, heating and start-up phases, unproductive high-energy phases will be shortened. Here, not only do mold and machine maintenance play an important role, but well-functioning automation solutions also have a striking impact.

Less energy per produced part

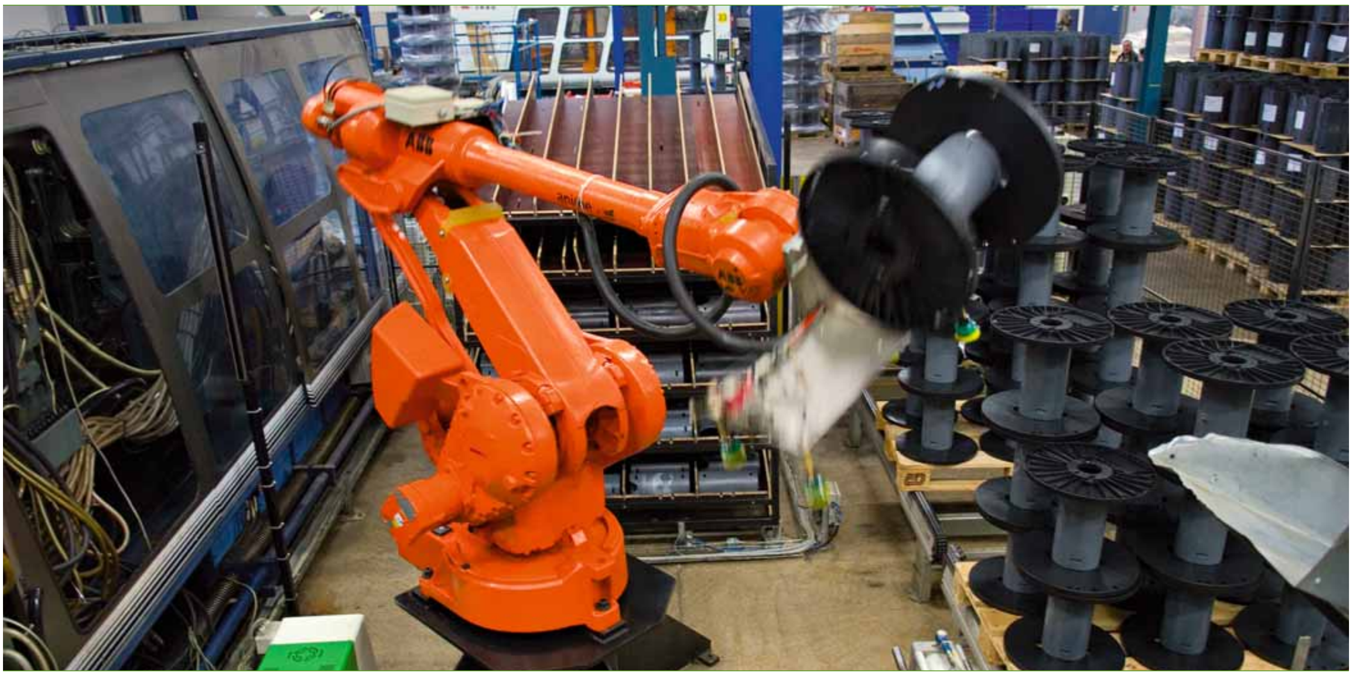
One important trend within the plastics industry is the progressive shift from hydraulic-powered injection molding machines to electric machines. A study performed by Materialdepån, a Swedish supplier of plastics material and equipment, compared 160 metric ton hydraulic- and electric-powered injection molding machines running at the same number of hours per year. Savings of about $7,000 in running costs were achieved with an electricity-powered machine. With the same total hours of operation, the hydraulic machine used 16 kWh of electricity compared with only 7 kWh for the electric machine.

Another big trend in production processes is reducing waste, which incidentally is also one of the main benefits of working with robot cells.

TOYO, a Japanese producer of injection molding machines, claims users can expect energy savings between 30 and 70 percent with electric machines. This can mean as much as $4,600 per year when comparing an 80 metric ton hydraulic injection molding machine with an electric-powered machine running at the same number of hours per year (cost for hydraulic oil and grease included). The hydraulic machine uses 5.65 kWh, while the electric machine uses only 1.85 kWh. Extrapolating these figures for several injection molding machines, the savings become quite significant.

Related to this finding is an increased awareness of the role electric motors

1 The IRB 4400 is extracting parts from the injection molding machine and assembling plastics reels at Axjo in Sweden. [Photo: Alexander Farnsworth]



play in industry. Cantex Inc., for example, is a leading producer of polyvinyl chloride (PVC) pipes in the United States. Cantex has upgraded three of its 18 extrusion lines at the plant with ABB industrial drives. The extrusion lines were formerly driven by non-ABB DC drives. The company increased production by 30 percent by retrofitting 75 kW, 90 kW and 110 kW ABB drives for the motors powering the mixing screws of three extrusions.

ABB's Machine Sync is an energy- and time-saving system that further increases the output of robot production by overlapping the workflow of the robot and machine.

Reducing waste

Another big trend in production processes is reducing waste, which incidentally is also one of the main benefits of working with robot cells. International Auto Components (IAC), a Tier-1 supplier[1)] to the automotive industry, is one company that successfully reduced waste through the use of robots. Before installing the latest automated cell in its factory in Skara, Sweden, it had a defective parts rate (of those shipped to customers) of 150 parts per million. Following the robot installation, this number fell to 50 parts per million, a distinct advantage in the highly competitive auto industry. An improvement in quality means less scrap – and less waste of material.

"To compete on the world market from a high-cost country like Sweden, we have to be as efficient as possible. And these robots give us efficiency, quality and confidence in our products. Robots are a must-have in our industry," said Steve Hammond, the IAC factory manager in Skara.

Another example of how robots improve productivity can be found at First Engineering in Singapore. The company produces ultra-precision molds and plastic parts for use in high-tech products like hard disk drives and PC peripherals. Since First Engineering introduced a 6-axis ABB robot in its production, output has increased by 75 percent from about 170,000 to some 300,000 parts per month. Part quality has improved, labor costs have been reduced and the company is using energy more efficiently.

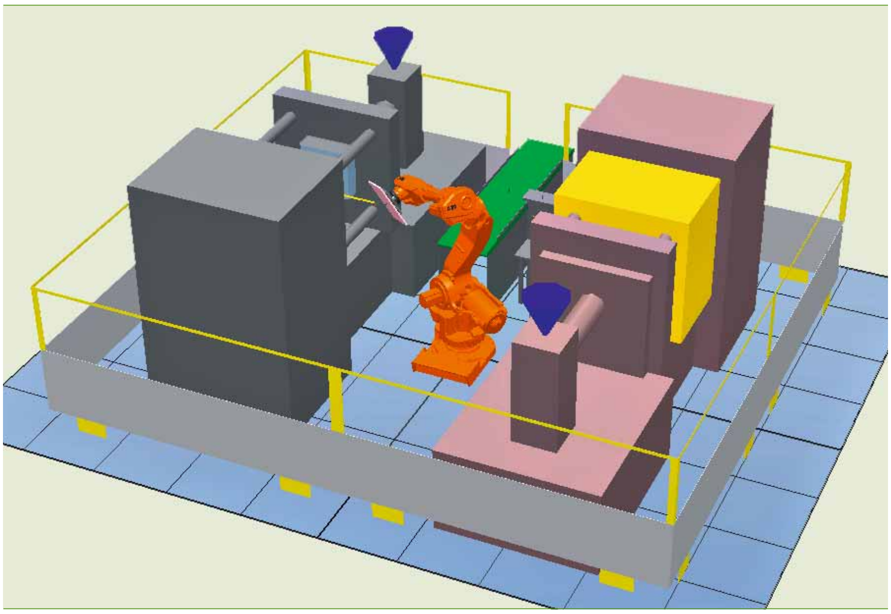
Using ABB's RobotStudio software tool to simulate the actions of a robot before it goes live is one example of lean manufacturing.

Optimized cycle time

There are other ways of conserving energy during the production process, of course. For example, ABB's Machine Sync is an energy- and time-saving system that further increases the output of robot production by overlapping the workflow of the robot and machine. This is done by coordinating the opening and closing of the machine to extract the plastic from the mold, thereby reducing cycle time and yielding more parts. This synchronization also reduces robot wear and helps avoid collisions. In a typical case involving an IRB 6650 shelf robot and a 3,000 metric ton injection molding machine molding a typical automotive part, the savings in extraction time using synchronized early-enter and early-closing is 10 percent. Ex-

2 At IAC in Tidaholm, Sweden, two IRB 2400 robots are used for waterjet cutting of interior auto parts. [Photo: Pontus Johansson]

3 ABB's RobotStudio software tool allows the application engineer to program the robot's motion first in a virtual 3-D world on a computer.



Footnote

[1)] Tier-1 suppliers are companies that sell products directly to original equipment manufacturers, who are in this case the car makers.

Productivity solutions

Factbox A life-cycle analysis approach

In the plastics industry, "energy efficiency" is a term used to describe a variety of issues including scrap reduction (less waste, therefore less energy used); material savings in paints, coatings and sealing components; and increasing productivity by minimizing cycle time. It involves a life-cycle-analysis approach, taking into account every step, from obtaining the raw material to the recycling of a plastic part.

Smart painting
In Australia, paint specialists D&M specialize in painting small auto parts. Three IRB 5400 robots working 12-hour shifts not only have boosted productivity by 80 percent, they've reduced paint consumption by some 35 percent using ABB's special Pattern Control Bell (Robobel 951), developed specifically to reduce waste.

Fiskars in Finland is another company that has seen great benefits with automated spraying. Fiskars manufactures, among other things, state-of-the-art axes. The blade has PTFE coating to make it lighter and easier to use. The IRB 540 robot used for spraying the blade is so accurate it uses 30 percent less PTFE than the previous solution. The process is thus not only safer for employees but also more environmentally friendly.

Efficient packaging solutions
ABB offers several robots specially designed for picking, packing, and palletizing – basic operations in the food and beverage industry. Of special interest is the FlexPicker robot. The FlexPicker can help food manufacturers dramatically reduce product waste – a major resource and energy eater – and increase productivity.

Pretzel manufacturer Roland Murten AG experienced a significant reduction in scrap, with breakage of its delicate product dropping from 15 percent to 2.3 percent, allowing the company to cut power consumption on its main production line by some 12 percent (a savings of $17,000 per year). Walter Fuchs, head of production at Roland Murten, said, "You have to take more than just procurement costs into account. The savings in operational costs also need to be factored in, and in our case we achieved significant reductions in costs for staff, energy and wastage."

Robots are a tool for improving total efficiency – the heart of the matter when it comes to eco-friendly production and sustainability. Ben Miyares, vice president of industry relations for the Packaging Machinery Manufacturers Institute (PMMI) and keynote speaker at the 2007 ABB Global Packaging Forum, said, "We need to stop thinking about pricing in terms of what a robot costs, and instead look at the total cost of operations."

Auto parts painted by ABB robots at D&M in Melbourne, Australia

trapolating this number for a machine running around the clock all year round, with an extract time of 10 seconds and a complete cycle time of 30 seconds, 35,000 more parts can be produced.

Lightening the load
Another major trend affecting the plastics industry is the automotive industry's push to produce lighter vehicles, which in turn consume less energy. This poses a great challenge for the automotive industry, as well as its sub-suppliers, to move from today's primarily steel- and aluminum-based materials to lighter magnesium and plastic composite materials.

New techniques are being explored that combine composite materials with glass fiber, fabrics and metals to achieve properties similar to metal with respect to stiffness, impact strength and aging. To produce such parts requires working with fiber, metal and textile inserts, and also demands a controlled means of moving plastic parts between several different processes that involve stamp presses, molding machines and secondary molding.

This can only be achieved with 6-axis robots, since the parts must be precisely positioned all through the process. Hence, 6-axis robots play a crucial role when it comes to developing smartly designed, environmentally friendly products.

New products and methodologies are helping customers surpass business goals while lowering environmental impact.

Lean manufacturing
Laser, water-jet or mechanical cutting is used for cleaning, deburring[2)] and drilling of molded, thermo-formed or foamed parts. These cutting techniques are often used for trimming automobile interiors and exterior parts like carpets and bumpers, and in the process of air-bag scoring, as well as white goods[3)] and large parts like chairs, bins, etc. Getting it right still requires much trial and error, wasted

energy and a lot of scrapped plastic parts, all of which could be avoided through simulation of the process.

Simulating the actions of a robot before it goes live is one example of lean manufacturing. ABB's RobotStudio software tool allows the application engineer to program the robot's motion first in a virtual 3-D world on a computer, tweak all the steps and then transfer the information directly to the robot. The benefit: no trial and error waste, which translates into materials savings and therefore energy savings.

Swedish company ABB Kabeldon installed an assembly line to manufacture different variants of fuse-switch disconnectors. The system integrator AVT-Specma used RobotStudio to simulate the complex process, which saved not only a considerable amount of energy and materials, but also a significant amount of time for both the integrator and the customer. All tests were conducted in a virtual environment before the program was loaded to the robot controllers.

Raw material savings

Plastics of all shapes and sizes are given their final finish in the paint shop, where there is certainly potential for energy savings and waste reduction. Paint application is a difficult industrial process but it is an area in which ABB has ample experience.

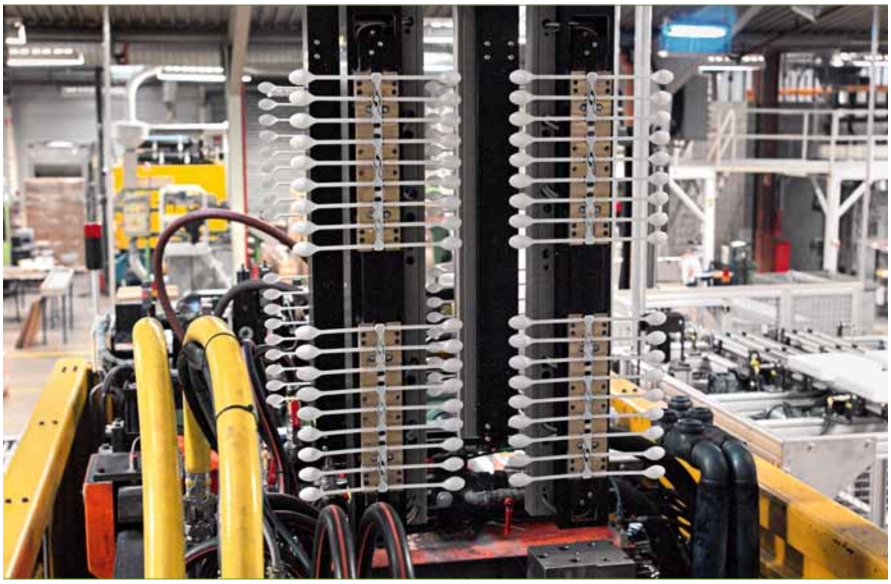
With a robot, it is possible to optimize the whole painting process and minimize the use of paint. ABB has developed an air recirculation system combined with a state-of-the-art energy-saving process in the paint booth, which is fully compliant with environmental regulations. This solution combines air recirculation, solvent disposal and energy savings. It reduces the amount of fresh air used, and thus the energy consumed, by a factor of 10. Automated systems can achieve as much as 30 percent paint savings compared with human operators [1].

The new non-electrostatic atomizer Robobel021-MINI reduces paint consumption by up to 30 percent. It is compact and lightweight, suitable for general industry where small painting robots paint small plastic parts. New painting methodologies double the flow rate per atomizer, making it possible to reduce the number of paint atomizers and painting robots by half. The paint booth can thus be downsized by 50 percent, and the time required for the painting process is cut in half, leading to savings in energy, paint consumption and CO_2 emissions. These new products and methodologies are helping customers surpass business goals while lowering environmental impact.

Every step of the process

From almost any aspect of the production process, whether it's injection molding, blow molding, extrusion or downstream applications such as cutting and painting, robot automation has a role to play in improving energy efficiency. Hence, energy can be saved in every step of producing a plastic product, and all savings are important, whether they are optimized cycle times, saved raw material, reduced scrap or enabling production of lightweight products – green thinking, indeed.

IRB 6650 taking spoons out of an injection molding machine at deSter in Belgium



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Footnotes

2) Deburring is the removal of burrs (ie, protruding edges) from a casted or machined part.

3) "White goods" is a general term for household appliances.

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The robotized field operator

Greater safety and productivity by design

Charlotte Skourup, John Pretlove

The aim, in almost all industries, is to have a high level of automation to increase productivity and efficiency. Industrial robots, which have been one important technology enabler in achieving this aim, are designed to perform repetitive, heavy, dirty and dangerous tasks. Within the oil and gas industry, robots have been used in very specific niche applications where the main driver has been safety, but this trend is now changing. Oil and gas companies have started to explore broader applications where robots may also have a positive impact on productivity and efficiency. One such application is the remote operation of oil and gas fields, particularly those in hazardous environments. ABB is a leading manufacturer of robots and is committed to developing "robotized field operators" for the oil and gas industry.

An orange robot moves around the process site and performs a combination of routine inspections and replaces a safety valve. This robot works along side two others. All three are supervised by a human operator located hundreds of miles away in the process control center. The human supervisor has defined and initiated the maintenance tasks in response to a condition-based monitoring (CBM) report generated by the automation system. With overall responsibility for safety, the operator instructs the automation system to reschedule the subtasks. Using the 3-D camera mounted on one of the robots, the operator inspects the machinery and identifies further components that require removal and replacement.

Frequently, robots are used to carry out repetitive routine tasks, which may be heavy, dirty, remote, dangerous or otherwise better suited to a robot than a human.

Although this scene is set sometime in the future, it is not far from reality. Some aspects of it are already happening in space and deep beneath the oceans, where tasks cannot easily be performed by humans. The scenario shows how robotics technology could be taken a step further and moved into oil and gas facilities to improve health, safety and the environment (HSE) and to increase productivity.

Trends in oil and gas

The oil and gas industries are facing a number of challenges that require novel technical solutions and business models. The world's energy consumption is growing and although alternative energy sources are currently expanding, there remains a high demand for oil and gas. However, recovering oil and gas from existing reservoirs and new fields has become more challenging with reduced profit margins. Many of the more accessible oil and gas fields have already been exploited, leaving the more remote and technically challenging reserves for future exploration. Furthermore, experienced crew are fast approaching retirement age, which means that fewer experienced workers will be available to extract these reserves. Based on the expectation of continuous market growth, the trend will be for stronger cuts in costs and increased energy efficiency. These trends suggest there will be increased investments in new solutions and business models to build on the existing infrastructure and also to develop new oil and gas fields. To successfully meet these goals, the oil and gas industry is prepared to change working practices and adapt their infrastructure.

Collaboration is recognized by the industry as an essential element to achieve the efficient and safe operation of their industrial processes. In many cases, the collaboration takes place over a distance, for example, between the control room and a remotely located expert or field operator 1. Integrated Operations[1] (IO) (also known as eField, iField, SmartField, etc) is a broad philosophy that aims to tackle the overriding challenges faced by the industry. The IO idea attempts to achieve goals through a combination of new methods focusing on the latest developments in technology and work processes.

Robotics business and markets

The use of robotics technology has made a large impact in many industries, particularly in the manufacturing area. Efficiency and productivity remain the main incentives for industries to use robots to automate their manufacturing processes. Most often, particularly in manufacturing plants, robots are used to carry out repetitive routine tasks, which may be heavy, dirty, remote, dangerous or otherwise better suited to a robot than a human. Also, these tasks typically require very high reliability and accuracy for which industrial robots are designed.

The automotive industry has had a major influence on the development of industrial robots. The principal goals of the car manufacturing industry are to increase productivity, flexibility, reliability and product quality at a lower cost. These business aims have pushed manpower away from

1 ABB-Shell collaboration room – an example of an integrated operations center

Footnote

[1] Integrated Operations (IO): StatoilHydro defines IO as "collaboration across disciplines, companies, organizational and geographical boundaries, made possible by real-time data and new work processes, in order to reach safer and better decisions – faster." To help identify the methods, technologies and work processes necessary to integrate its operations, StatoilHydro appointed an R&D consortium consisting of ABB, IBM, SKF and Aker Solutions. One of the seven sub-projects concentrates on robotics technology to supplement and extend human inspection and intervention capabilities at topside and onshore facilities. The objective is to develop solutions that combine tele-robotics and advanced visualization to enable remotely operated inspection and maintenance operations, as well as to identify and close technology gaps.

the production lines in favor of robots. Robotic production facilities are largely fully automated and run 24 hours a day seven days a week (24/7). Robots handle everything from sheet metal cutting, assembly and welding to painting, coating and general material handling 2. Robot manipulators are typically developed to handle one specific task and have even, in some cases, been developed particularly for a certain application such as to open and close car doors.

When automating a manufacturing plant with robotics technology, the greatest impact can be made when the entire process from start to finish is redesigned, rather than when only individual processes are automated.

A higher degree of automation naturally implies changes in technology, peoples' work patterns and organization. Although robotic systems can carry out repetitive, heavy and dirty jobs, they can rarely operate entirely without human intervention. Operators are required to monitor and control their operations and hence, they become an integrated part of the control loop and the receivers of the robot's output. Naturally an increased degree of automation results in job description changes so that personnel with different competences, such as planning, programming and maintenance, are required to maintain productivity. A critical component to successfully implement automated processes within a manufacturing plant is to be prepared and plan for such organizational changes by updating job descriptions, roles and responsibilities to suit the reorganization.

> A higher degree of automation requires changes in technology, peoples' work patterns and organization.

Robotics for oil and gas

The use of robots in the oil and gas industry has been limited. The industry has generally only automated processes that are either difficult or impossible for people to perform, or that would dramatically improve HSE issues. Examples of such applications are found in subsea facilities and pipeline inspections, in the automation of drilling operations, well tractors and in special inspection applications. Very often, the industry has experienced a negative impact on productivity with automation, running counter to the general goal of automation. This trend, however, is now changing. Today, the oil and gas business sees robotic technology as an enabler to increase efficiency, productivity and to improve HSE issues. The oil and gas extraction processes are generally dangerous and risky. Offshore facilities operate in rough seas and all kinds of weather conditions. In addition, hazardous environments are encountered, for example those with high concentrations of dangerous gases, such as hydrogen sulphide (H_2S). The use of robots in such environments has the potential to reduce human exposure to hazards. They are designed and manufactured to operate reliably 24/7 and can be designed to cope flexibly with a range of operations. With greater demands for energy and the increasing difficulty experienced by the industry to extract oil and gas economically, it is clear that the oil and gas industry will have to change its strategy and think afresh, especially if it is to successfully extract tail-end production from existing sites and exploit the smaller more marginal oil and gas fields of the future.

There are two broad areas in which robots can be used for oil and gas: those applications that demand completely new robot designs and those in which existing industrial robots can be applied. The further development of subsea oil and gas production relies heavily on remotely operated vehicles (ROVs). These are used for exploration, inspection and interaction with the process structures. Such applications are unique to the oil and

2 ABB robot spray painting in an automotive production facility

3 ABB robot at work performing routine inspection of process equipment

gas industry and require completely new robot designs.

Robots in the oil and gas industry would be expected to perform inspection and operational tasks to maintain the process infrastructure.

Other applications show clear similarities to manufacturing processes, where robots have already been deployed to carry out repetitive tasks and where this increased automation has already produced benefits. However, the characteristics of the tasks in the oil and gas industry differ from conventional manufacturing processes. Robots in the oil and gas industry would be expected to perform inspection and operational tasks to maintain the process infrastructure 3. This means that the robot would have more than one task and not all tasks could be predicted. Furthermore, offshore topside[2] facilities would have to be redesigned, since space is restricted, so that robots could move around and access the process equipment. The design of such automated topside facilities focuses on existing industrial robots, with minor modification, so that applications for the oil and gas industry can be performed successfully in harsh environments. This application is recognized as a "game changer" for the oil and gas segment.

Challenges for oil and gas robotics

Robotizing oil and gas facilities present many different challenges. These challenges are not only technical, but also have an impact on the whole organization, including the workforce. Although robotics technology has already been proven in other industries, it must be applied and adapted to the specific applications of the oil and gas industry. These applications are typically carried out in extreme environments and are often located far away requiring remote operation 4. There are also system integration issues with a prerequisite for full data access and availability.

The roles of the robot will, therefore, change from the more conventional single repetitive, yet continuous task, often encountered on a production line, to the execution of a number of different tasks, each requiring flawless performance on demand. The robot will have to operate at various levels of automation, from fully automatic, requiring no human intervention at one extreme, to completely manual operation at the other extreme. In between there will be various tasks with semi-automatic features, which will require varying degrees of human interaction. This represents a departure from the more traditional industrial robotics applications, in that human decision makers must be integrated within the control loop to collaborate with the robots and the control system. The successful automation of the oil and gas industry will, like all human-machine systems (HMS), rely on the seamless integration of man, technology and organization (MTO).

Oil and gas installations impose different demands on the design and requirements of the robot. The robot will have to be explosion-proof approved, in addition to being resistant to harsh weather conditions. Offshore robots will have to tolerate extreme temperatures, extreme winds, exposure to salt water and even exposure to snow and ice. Onshore robots will have to tolerate sand storms, direct sunlight, rain and humidity, extreme temperatures and exposure to different poisonous gases such as H_2S. Such specifications are not usually required for reliable robot operations in conventional manufacturing process plants.

To a large extent, the success of an automation project is influenced by the design of the facility in which the task is to be carried out. It is much more difficult to automate tasks in an existing facility than it is in new purpose-built facilities. The layout of existing facilities is not designed for standard industrial robots, particularly offshore topside installations, which

4 The offshore StatoilHydro Troll A gas platform located in the North Sea

Footnote

[2] Topside means offshore oil and gas installation (or the body of a boat or ship) above the water level.

are generally compact, presenting difficulties even to human workers when executing tasks. Modifying existing installations is rather limited and represents major costs. It is generally more effective to design new facilities, or to perform a major redesign of existing facilities, with the automated process in mind, so that many tasks can be carried out in a single facility and design features can be made to accommodate further additions should the process require scaling up. Such flexible facility design will allow greater process flexibility, increased productivity and reduced cost.

Telepresence keeps the human operators in the control loop, allowing them to use their high levels of skill to control the robot's operations.

While a robotized task, application or facility provides many safety and productivity advantages, it also presents additional challenges with regard to their maintenance and operation. Industrial robots are designed in general to replace human operators in the field; however, these robots are tools, which must be supervised and controlled. The robots themselves and how they perform a task should be of no concern to the human decision makers. The human supervisor's role is to control the robot's operations through the automation system based on the need to monitor, inspect and maintain the oil and gas process equipment. Data concerning the state of the process equipment must be collected either automatically or on demand. Such data cannot replicate the human senses and hence, cannot provide a similar representation of the process as it is carried out today. However, the robots can use other sensors that human operators are unable to use, such as x-ray and computer chromatography. This so-called telepresence provides an advanced representation of the current process infrastructure so that human operators are kept in the control loop, allowing them to use their high levels of skill to complement the power of remote manipulators. Robots as extended operator tools make up a natural part of the IO concept. The robots represent assets that are fully integrated in the automation system. The various IO teams will base their understanding of the process and decisions on such representations.

The automation system receives and processes data collected by the robot before the system stores them for later use in other applications, or presents them directly to the operator, eg, in the form of a report. The operational team use this information to make decisions. Team members can also actively search and ask for information. Their ultimate goal is to use all the information to monitor the current process and make decisions that will optimize the operation of the facility.

5 The ABB robot test laboratory in Oslo, Norway

A major challenge for tele-operation within the oil and gas industry is, in particular, the remote nature of offshore installations. These can be located hundreds of miles away from land, conducting complex and dynamic operations in harsh environments. Operation failures in such installations may result in major consequences for the environment and process equipment. Safe and efficient tele-operation is critical for such unmanned facilities, securing added value and optimal productivity at remote locations.

The ultimate goal of the operational team is to use all the information to monitor the current process and make decisions that will optimize the operation of the facility.

There is a clear incentive for oil and gas companies to automate their oil and gas facilities, starting with isolated operations, such as pipe handling and assembly for drilling and tasks related to pig operations[3)]. These examples represent high-risk operations for humans and therefore provide opportunities to improve HSE. A major step in the future will be to fully automate larger parts of the facility or even the entire facility. Such an approach has the potential to make a large impact on the flexibility and productivity of a facility.

ABB oil and gas robot test facilities

Currently, three ABB robots communicate daily to perform inspection tasks on a "working" process module in an ABB facility in Oslo 5. Either the control system or the operator initiates tasks for the robots. The (remotely-located) expert uses a 3-D process model to interface with the robots, defining and initiating tasks, and receiving feedback. The robots act as the operator's extended "eyes, ears and hands" in the process to maintain presence and awareness of the status of the process infrastructure. The focus has been to build and configure a highly advanced working facility for remote inspection. The robotics system is further configured to handle maintenance tasks, such as to open and close a valve, replace wireless sensors, or exchange components and handle material.

ABB, together with StatoilHydro, is addressing both the technical and personnel-related challenges in an ambitious cooperative research project to automate the oil and gas industry.

This lab provides a unique robot test facility to explore, demonstrate and test concepts for future robotized oil and gas applications. The lab is a part of a larger research project conducted in collaboration with StatoilHydro to integrate remote automated operations. The main lab comprises three robots and a "working" process module. Typically, one robot is used for inspection and the other two for co-operative maintenance. The inspection robot is mounted on a flexible gantry crane, while the two maintenance robots are mounted on rails 6. In addition, a waterproof ABB robot is located outdoors at the StatoilHydro site in Kårstø (on the West coast of Norway). For a six-month test period the robot will be analyzed in severe weather conditions as a first step toward the creation of a robot able to withstand extremely harsh environments.

6 An ABB robot equipped for visual inspection mounted on flexible gantry crane

These two ABB robotics test labs provide excellent facilities in which to demonstrate and pilot a variety of automated tasks for the oil and gas business.

Robotized operators for the future

Oil and gas facilities have huge potential to increase productivity, a significant part of which will result from the use of robotics-based automation. In addition to productivity and efficiency gains, robots used for high-risk tasks will also lead to improvements in HSE. Such tasks are not necessarily always predictable and represent unusual robot activities. The robot will therefore require features that extend the "eyes, ears and hands" of the human decision makers as they carry out inspections and maintenance operations on the process infrastructure. The new role of the oil and gas facility operator will be to supervise and instruct the robots and to make operational decisions. The robotized facilities will allow marginal, remotely located fields to be cost effective for oil and gas production.

The greatest gains will come when the robotics systems are fully integrated with the automation system, providing a tool for the human decision makers that is aligned with the IO concept. The goal of IO is to make real-time data available to the decision makers in (virtual) teams so that they can make better and faster decisions. The robotized field operator is one of many means by which data can be collected and tested to achieve a complete IO environment. A major advantage of robots is that such data collection tasks can be performed in environments impossible for human operators, such as those rich in H_2S, or can be collected using methods hazardous to human health, such as x-rays.

Two ABB robotics test labs provide excellent facilities in which to demonstrate and pilot a variety of automated tasks for the oil and gas business.

The degree to which the oil and gas industry benefits from robotics technology depends on how willing the industry is to change its organization and work processes in order to fully integrate the technology and overcome the technical challenges of IO.

ABB, together with StatoilHydro, is addressing both the technical and personnel-related challenges in an ambitious cooperative research project to automate the oil and gas industry. Access to operative sites, together with unique competence in robotics, oil and gas, and systems integration, means that ABB is well placed to develop integrated robots and automation systems specifically adapted for the harsh and demanding oil and gas industry applications.

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Footnote

[3] These are operations that are performed within the pipeline, without stopping the flow, and include inspection and cleaning. Pigs get their name from the squealing sound they make while traveling through a pipeline.

Tanking along

Increasing fuel efficiency and cargo capacity of LNG carriers using electric propulsion

Jan Fredrik Hansen, Alf Kåre Ådnanes

As the world's demand for energy has increased, so too has the demand for large liquid natural gas (LNG) terminals and floating LNG production facilities. The transportation of LNG is, therefore, likely to increase rapidly in the coming years, requiring an increase in the number and size of LNG carriers.

Traditional LNG Carrier propulsion systems (steam turbines) deliver less than 30 percent fuel efficiency, however, today's electric propulsion systems can deliver more than 40 percent fuel efficiency. For LNG carriers, this translates to more than a 30 percent reduction in fuel consumption. In addition, because the electric propulsion system is more flexible, the cargo space can expand into the engine room, typically increasing capacity on a 145,000 m^3 vessel by a further 10,000 m^3.

ABB has been the world's leading supplier of electric propulsion systems to LNG carrier fleets since the first vessels were contracted in 2003.

The steady growth in world energy demand continues to drive the search for new energy sources. Natural gas has satisfied some of this demand for more than 30 years. Most of the world's gas is transported by pipelines from the producing fields to the consumer (over land and, for shorter distances, across the sea bed, from the North Sea to Europe, for example). From the late 1960s through the 1970s, the development of gas fields further offshore, in deeper water, and at more remote locations from consumers, has led to a growth in the production of liquefied natural gas (LNG) and its transportation by ship. The ships used were constructed with special insulated cargo tanks so that the LNG could be carried at a temperature of –162°C.

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With increasing energy demand in Asia, and particularly Japan, imports of LNG increased steadily, requiring more ships with greater capacities. In the 1970s and 1980s the ships were built mainly in Japan, but in the 1990s, South Korea emerged as a leading ship building nation and, by the end of the 1990s and early 2000s, the majority of LNG carriers were built in South Korea. The size of vessels had also increased to a standardized cargo capacity of 138,000 to 145,000 m^3 LNG. All of these LNG carriers were built for long-term lease, up to 30 years. They were chartered for LNG transport from gas fields to consumers, where pipeline use was not economically or technically feasible. The LNG producing and receiving terminals, including the surrounding infrastructure, were built for continuous gas supplies. This means that if one LNG carrier misses its loading slot at the terminal, a severe disruption in energy supply would result.

With this pressure to provide extremely reliable ships, with robust machinery and propulsion systems, less importance was placed on efficiency and fuel consumption. Steam-turbine propulsion systems were most commonly used because they offered excellent reliability and could use the gas onboard as a fuel. LNG is transported at –162°C, however, depending on the efficiency of the insulation and the roughness of the voyage, a small amount of gas is lost in transit. This "boil-off" gas, supplemented with heavy fuel oil, was used to heat the boilers, producing steam to drive the ship's turbine.

From steam turbines to gas electric

Although the steam turbine is highly reliable and requires almost no maintenance, the boilers upon which they rely, require regular maintenance. Twin boilers are generally installed to ensure reliability; however, the thermal efficiency of this type of system is lower than 30 percent. Alternatives, such as combustion engines are known to be 45 to 50 percent efficient; therefore, the potential for fuel saving by changing the propulsion system is huge. Despite this difference, the steam-turbine propulsion system, due to its reliability, remained the preferred solution, and LNG carriers are among the last major shipping types still using this form of propulsion.

As the vessels increased in size, so too did their need for installed electric power, the main purpose of which is to operate the larger cargo pumps. These are electric-driven pumps, submerged in the LNG tanks, and used to pump the gas out of the vessel at terminals. The installed electric power was increased to more than 10 MW for 140,000 m^3 capacity carriers, requiring high-voltage (HV) onboard power equipment. The first LNG carriers equipped with HV power plants of 3.3 kV and 6.6 kV were ordered in 2000. As a major supplier of electric power systems in the marine market, ABB took part in the design and supply of HV air-insulated switchgear for use in 40 LNG carriers between 2000 and 2006.

LNG carriers, however, were still built with steam-turbine propulsion, but there was growing interest in alternatives. In 2000, the engine maker Wartsila introduced dual-fuel combustion engines to the market, which could operate using either gas or diesel. These 4-stroke engines were basically designed to generate electric power, operating at constant speed, and requiring an electric distribution and propulsion system to drive the propeller. Even accounting for electrical transmission losses, the total propulsion efficiency for the dual-fuel system, known as DFEP (dual-fuel electric propulsion) was about 42 percent, much better than the 30 percent delivered by steam turbines 1. Today there are two suppliers of dual-fuel engines on the market, Wartsila and MAN.

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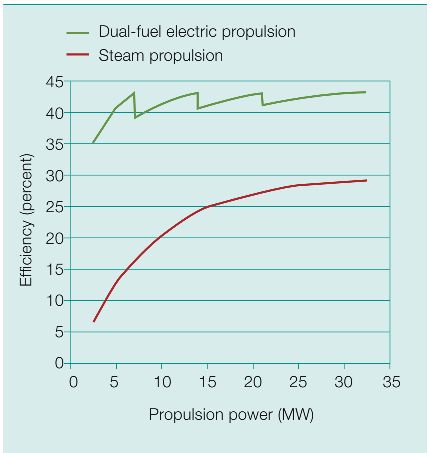
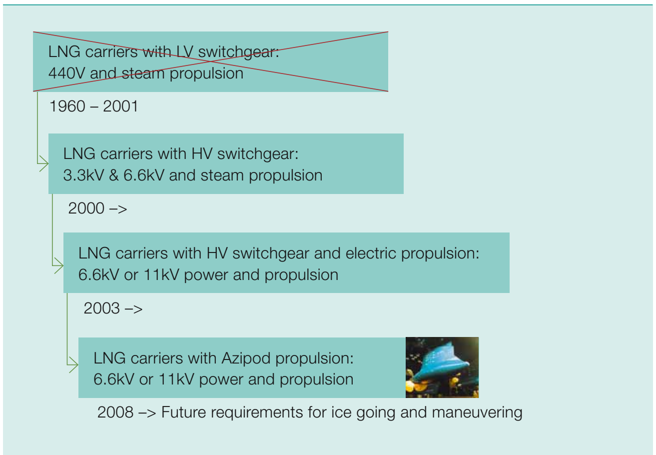
In 2003, Gaz de France (now GDF Suez) ordered the first three LNG carriers from Chantiers de l'Atlantique (now STX Europe) to be equipped with the new DFEP system. As soon as this first step was taken, other ship yards and owners followed, and by the end of 2005, almost all new orders for LNG carriers with capacities between 145,000 and 170,000 m^3, were

1 Fuel efficiency curves as a function of propeller loading of dual-fuel electric propulsion and steam turbine propulsion

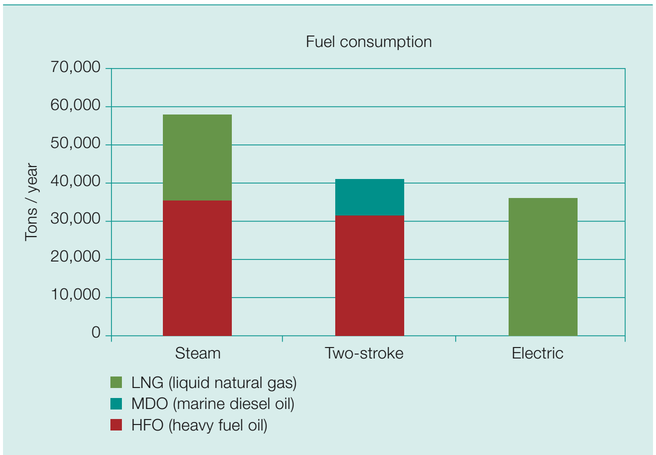


Productivity solutions

2 The basic steps in the development of new generation LNG carriers



3 The yearly calculated fuel consumption for the various alternatives based on efficiency considerations and an operation profile of 7,500 h per year



ordered with DFEP **2**. The main message from Gaz de France was that they could deliver more gas, more efficiently using clean gas as fuel.

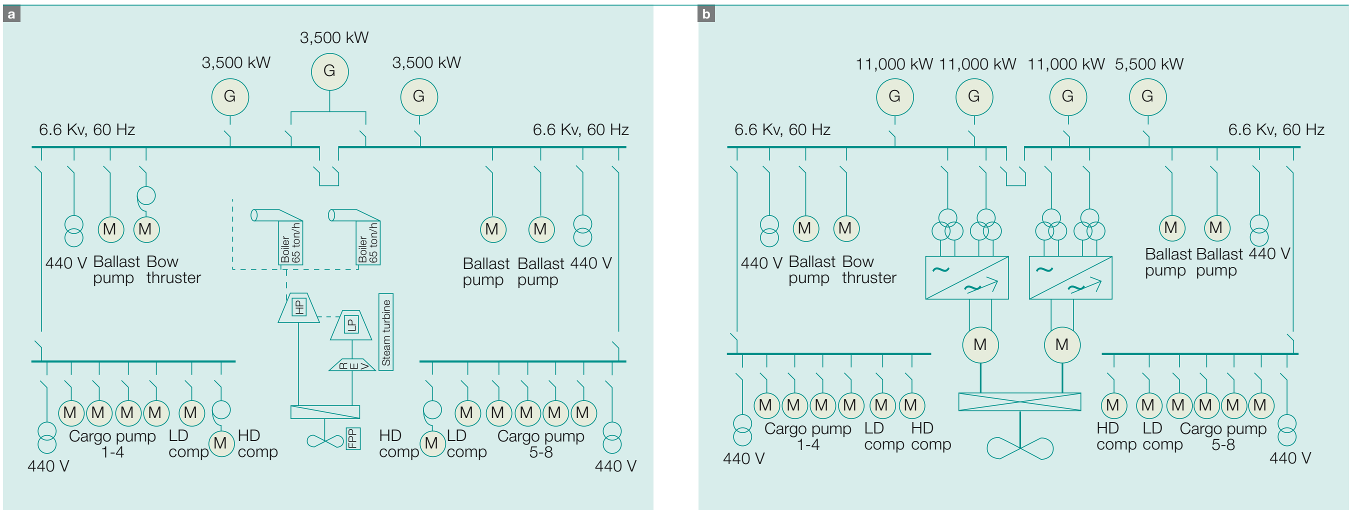
Not all LNG carriers have opted for the electric propulsion solution. The Qatar Gas Project has opted for LNG carriers with capacities up to 260,000 m³ and use a traditional two-stroke engine propulsion system alongside an onboard auxiliary plant to reliquefy the boil-off gas and return it to the tanks. This system, however, still requires quite a large HV electric power plant to feed the cargo pumps and the reliquefaction plant, which can consume up to 6 MW of electric power. This additional electric power consumption is much higher than the electrical losses experienced with an electric propulsion plant. With a propulsion power of 30 MW, for example, the electric propulsion plant's electrical losses would be at a maximum of 2.5 MW **3**.

The DFEP system not only provides energy efficiency, it also permits increased cargo capacity. The arrangement of the electric power and propulsion plant equipment is more flexible than that of mechanical propulsion systems. Even if additional electric components are installed, the flexibility of the DFEP system means it can still accommodate more cargo. The engines can be mounted on a higher deck level, reducing the volume of exhaust-gas piping that is usually required when engines are arranged on lower decks. There is no mechanical connection between equipment (ie, generators, converters, transformers and propulsion motors) only cabling, so the equipment can be arranged to optimize space savings. This has meant the capacity of standard LNG carriers of around 150,000 m³ capacity can be expanded by more than 6 percent, without altering the ships' external dimensions.

Configurations and ABB scope

DFEP has two main core technologies: dual-fuel, four-stroke engines, which are quite new to the general market especially to shipping, and electric propulsion, which is new to the LNG shipping market, but has been used,

4 The electrical power plant configuration for **a** an LNG carrier with conventional steam turbine propulsion, compared with **b** the configuration with electric propulsion.



especially in cruise ships, since the mid-1980s. However, the general shipping and LNG markets are quite conservative. Changing from a well-established and reliable propulsion system to a novel system has taken time. Before the first ship owners took the initiative, a period of product maturity and proven capability was required. Once the benefits of space and fuel savings were shown to be quite significant, other ship owners and yards could follow with more confidence. The potential operational cost savings were simply too large to ignore. However, such technology could be adopted only if its reliability was equal to that of conventional steam-turbine propulsion systems.

In the early stages of development, a great many different configurations were discussed, with respect to the number of engines, number of propellers, redundancy, etc. Of these alternative scenarios two or three alternatives were particularly favored, one configuration has become more popular and has been widely adopted 4.

In the most common arrangement, the power plant consists of four medium-speed, dual-fuel engines, each with a generator. The ratings of the generators vary slightly from project to project, but are usually optimized for the most commonly used operations, such as LNG loading and unloading, and transit sailing, each of which has a different power requirement. The HV power plant is split into four different sections, two main switchgears and two cargo switchgears. The reason for separating the two types of switchgear is purely to optimize the spatial arrangement of the installation. The propulsion system is also split into two separate drive systems, each with a corresponding drive transformer, frequency converter and propulsion motor. Finally, the two motors are mechanically connected via a common gearbox, with one shaft outlet to the propeller. This system combines simplicity with reliability. There is sufficient redundancy to keep the propeller operating even when maintenance or repair work force one of the engines or one of the electrical networks to be shut down. Mechanically, the propeller system is almost identical to that of the traditional steam-turbine system, with a gearbox and single shaft outlet to the propeller. Some schemes have twin propellers, which provide 50 percent redundancy all the way to the propeller shaft. Electrically, the twin system is identical to the single-propeller system, with the exception that the control system (located on the ship's bridge) allows the speed of each propeller to be controlled independently.

ABB has a long and proven track record in electric propulsion, especially in cruise vessels and has delivered or has on order, electric power and propulsion systems for 33 LNG carriers.

The propulsion power requirements for LNG carriers are in the range of 25 to 30 MW, which means each propulsion motor is usually rated somewhere between 12.5 and 15 MW. The power ratings vary depending on the ship's power to speed requirement and the design of the hull.

ABB typically supplies all HV electrical equipment for a ship, from the generators to the propulsion motors, and all the related propulsion control systems. ABB has a long and proven track record in electric propulsion, especially in cruise vessels with similar sized propulsion requirements and power plants to LNG carriers. In fact, as indicated in November 2008, ABB has delivered or has on order electric power and propulsion systems for 33 LNG carriers.

ABB's electrical propulsion products are manufactured in ABB factories dedicated to marine applications. To meet the high reliability demands of LNG carriers, ABB is able to draw on its long experience earned in the cruise-ship business and upon well-established ABB products. ABB's synchronous AMG generators and AMZ motors 5 have efficiency levels among the highest on the market. For some projects, these motors and generators have achieved efficiencies of 97.9 percent and 98.4 percent, respectively, in factory test facilities[1].

ABB's robust medium-voltage switchgear (UniGear) and air-insulated motor control switchgear (UniMotor), including the HD4 (SF_6-type) and VD4 (vacuum-type) circuit breakers, are used for HV distribution networks. The metal-clad, arc-proof switchgear housing provides high-level protection for personnel, even working in the same room. The cabinets also have a door interlocking system and compartment segregation to prevent access to live parts when the equipment is operational.

The propulsion system's drives use ABB's unique resin-encapsulated transformer, the RESIBLOC® 6, and the ACS6000 medium-voltage frequency converter. The RESIBLOC trans-

5 AMZ propulsion motor

6 ABB RESIBLOC Transformer

Footnotes

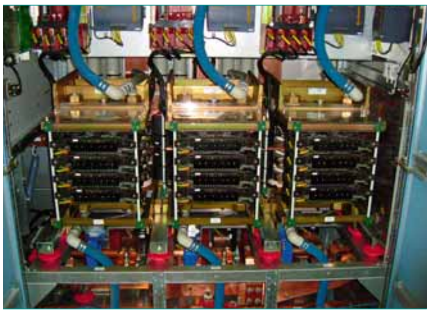
[1] Efficiency is measured at the Factory Acceptance Test [FAT] with sinusoidal supply, and with the addition of harmonic and auxiliary losses.

formers have a high mechanical strength, well suited to marine environments, where they experience strong vibrations and rough sea movements. Another feature of the RESIBLOC design is the linear impulse voltage distribution between the windings. This feature is especially important for marine applications where the switching voltage transients are much steeper than the normalized impulse voltage used standardly in transformer design.

ABB's RESIBLOC transformers have a high mechanical strength, well suited to marine environments, where they experience strong vibrations and rough sea movements.

The ACS6000 is a voltage source inverter (VSI)-type frequency converter, introduced to the market by ABB in 2000 7. It is controlled by an ABB-patented algorithm known as Direct Torque Control (DTC®) and can be combined with the well-established, synchronous AMZ motors, which suit the power requirements of LNG carriers.

7 Inverter unit of ACS6000 frequency converter



Experience from sea trials

Since 2003, when the first electrical propulsion LNG carriers were ordered, more than six carriers have been delivered with ABB propulsion systems. The performance of these carriers, all of which are still in operation, has met or exceeded design expectation in terms of control and energy efficiency. When selecting the DFEP system, one of the key concerns is that, when operating in gas-mode, the engines are more sensitive to load variations than when operating in standard diesel-mode. It is, therefore, essential that the propulsion drive system (the largest onboard consumer of electric power) keeps the load on the switchgear as constant as possible, even in rough seas. For this reason the control system is equipped to perform in two operation modes:

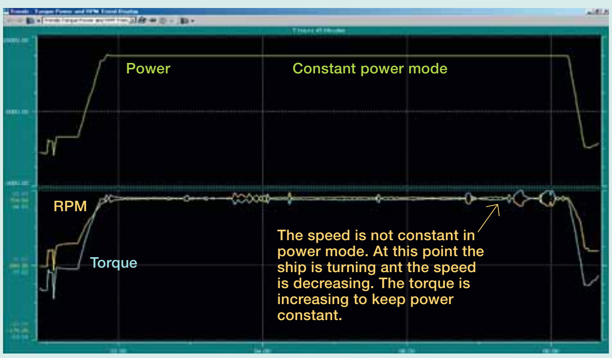
- RPM mode, in which the controller maintains a near-constant RPM.
- Power mode, in which the controller maintains a near -constant level of power.

When the ship is maneuvering, RPM mode is selected automatically in order to gain a rapid response to the captain's actions on the bridge. In open water, above a certain power level (>50 percent), power mode is selected, so that the RPM and torque on the propeller can fluctuate with sea conditions, while the electric power consumption remains near constant 8. During a six-hour endurance test, when the ship was sailing continuously at full propulsion power (ie, in power mode), data collected showed that the power consumed by the propulsion system indeed remained constant. One of the reasons for this unique performance profile was that the DTC algorithm, used in the ACS6000 frequency converter, was able to adjust the motor torque within milliseconds and compensate immediately for the varying wave-induced torque on the propeller.

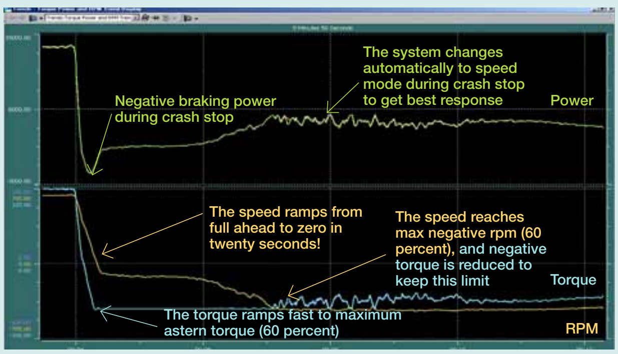
When a maximum (100 percent) load was applied to ABB's electric propulsion drives they showed a system efficiency of 94.3 percent, including the gearbox.

Crash-stop tests have also been performed and demonstrate that the machinery is capable of reversing the propeller thrust to rapidly bring the ship to a halt 9. In such situations the electric motor is superior to mechanical propulsion, since it can provide a stable reverse torque on the shaft whatever the RPM. Under such conditions, the motor actually operates as a generator, feeding energy from the propeller back to the drive system as the propeller speed is reduced to zero. This reverse energy is dissipated using separate brake resistors in order to avoid any reverse power disturbance

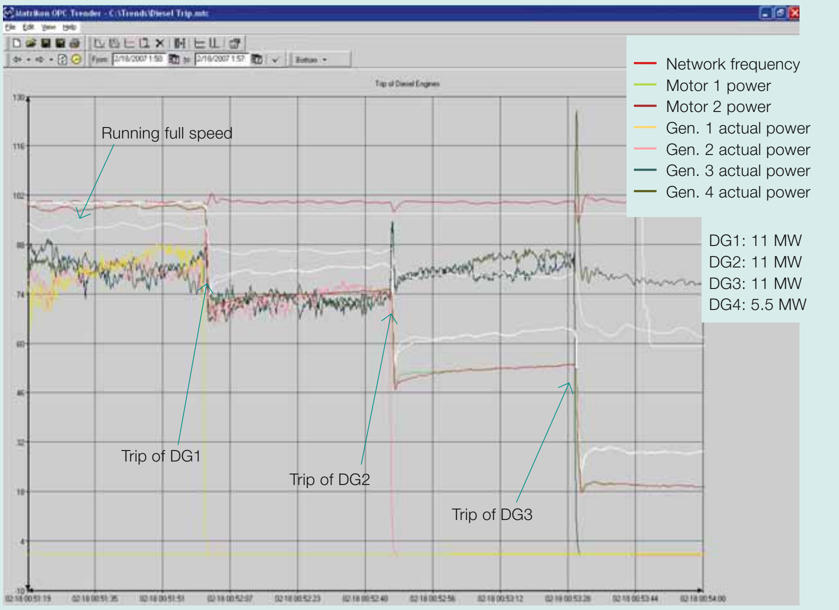
8 Power, torque and RPM recordings from sea trials; endurance test – constant power mode



9 Crash stop test recordings of propulsion motor power, torque and RPM



10 Blackout prevention test by intentionally tripping generators under conditions of 100 percent load



of the main engines. The test showed that the ship could be stopped within about 7 minutes, which is much faster than can be achieved using traditional steam-turbines. Here, reported stopping times are in the range of 20 to 30 minutes.

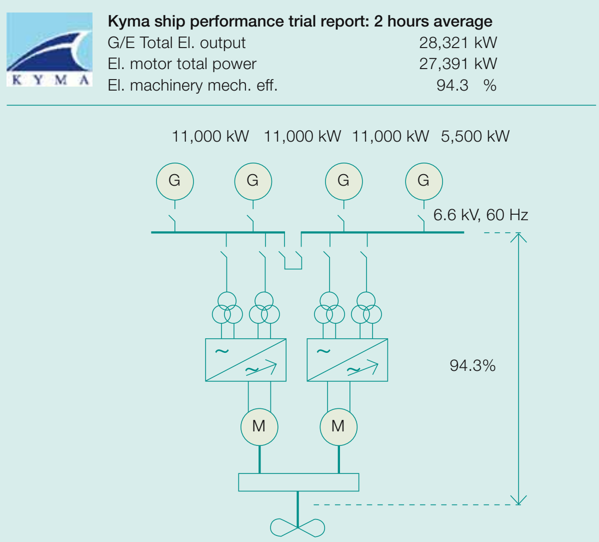
Another important feature of electric propulsion is the blackout prevention capability, which allows continued operation even during failure modes. The worst-case scenario is that one generator-engine trips and the disturbance from this leads to additional generator-engine trips, leading to a total blackout. The rapid load reduction in propulsion power protects the remaining generators. As soon as a generator trip is detected, the propulsion control system instantly reduces the propulsion power to avoid overloading the remaining generators. This feature was tested at sea with a generator configuration of 3 × 11 MW and 1 × 5.5 MW. During the test, the three 11-MW generators were intentionally tripped, one by one, until only the small, 5.5-MW generator remained. During this test, the generators were protected and the equipment passed the test without a blackout 10.

To measure efficiency, the ship's owner installed a system from KYMA[2] that was able to measure, using strain-gauges, the mechanical power driving the propeller shaft. By comparing the value obtained on the propeller shaft with the electrical load supplied to the propulsion drives from the switchgear, the efficiency of the propulsion drive system, including the gearbox, was obtained.

When a maximum (100 percent) load was applied to the propulsion drives, the reading showed an efficiency of 94.3 percent 11. The calculated expected efficiency of related equipment was approximately 93.6 percent (including 1.5 percent estimated losses in the gearbox). These measurements proved that the system efficiency was better than predicted by theoretical calculations.

The LNG market is still changing, and is expected to increase in volume more rapidly in the coming years than ever before. For LNG carriers, alternative propulsion methods are under consideration, such as steam-turbines with higher efficiencies, two-stroke motors with gas injection, etc. Today, with leasing contracts no longer tied to 30-year periods, LNG carriers must be more flexible. Carriers built for spot-markets need flexibility in operation speed, sailing distance, fuel type, etc. All these requirements make the electric propulsion system even more attractive. Future requirements for LNG carriers in the arctic will further strengthen demands for electric propulsion with ice breaker design, where ABB Azipod® propulsion has already proven its functionality and performance. The Azipod unit has previously been successful for ice-breakers and cruise ships, and also, more recently, for other vessels, such as oil tankers and container ships.

11 Efficiency measurement from propeller shaft to switchgear



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Footnote

[2] A company who supply various performance monitoring devices, in this case shaft power measurements. This was not ordered by ABB or the shipyard, but directly by the ship owner to verify the performance. See: http://www.kyma.no/

Keep on running

Field device diagnosis ensures reliable operation

Andrea Andenna, Daniel Schrag, Armin Gasch, Paul Szász

The technological advances of the last decade have brought with them increased expectations from industrial field device customers. Digital signal processing (DSP) and sophisticated communication technologies, for example, have enhanced the information exchange between field devices and the distributed control system (DCS), and devices are now expected to provide in-depth diagnostic information in addition to highly accurate measurement values.

In recent years, ABB Corporate Research has worked tirelessly to meet customer demands by creating multi-functional field instrumentation, and the results of its efforts are now reflected in a string of developments. For example, enhanced diagnostic information, such as automatic redundancy switching and sensor drift monitoring, are major market differentiators for the new head mounted temperature transmitter TTH300. Bubble and electrode coating detection, and conductivity measurement functions will be integrated in the next version of magnetic flowmeters, and future versions of vortex and swirl flowmeters will include an automatic vibration suppression algorithm.

The days when a measurement device was solely used just to measure have long since gone. Cost pressure and the need to improve efficiency by reducing downtime mean customers from the process industry now expect "intelligent" field devices. In fact, many customers want to replace common preventive maintenance by a more efficient and focused predictive maintenance and plant asset management strategy [1] Factbox.

ABB and its competitors are acutely aware of this trend and the keyword "diagnosis" is now more or less standard in market requirement specifications for new generations of instruments.

The trends concerning process sensors requirements were recently highlighted in an initiative of NAMUR and VDI/VDE in Germany titled "Technology Roadmap for Process Sensors" [2]. One trend seen from an end customer perspective is the measurement of parameters with even greater accuracy than is currently achieved. The requirements for process sensors extend from the measurement of purely process parameters towards intermediate and trend information about product properties for control purposes (eg, yield and yield trend, by-products, contamination-like content of solids in gases, quality).

With digital signal processing (DSP) and sophisticated communication technologies, measuring devices are now also expected to provide in-depth diagnostic information.

Signal processing in multifunctional field devices

In the past, the electric signal of a primary sensor was used as input to a readout device. However, the rapid development of digital electronics in recent years now allows meaningful and important information to be extracted directly from a sensor´s raw signal. The use of microprocessors and digital signal processing (DSP) give better sensor signal quality, reduced noise and higher measurement accuracy. In addition, diagnostic functions, such as device self-monitoring (eg, checking for electronic defects) and process data monitoring (eg, checking if the impulse lines of a pressure transmitter to the process are open), and advanced functionalities can be realized. Safety features can also be implemented at that level.

Factbox Industrial sensors in harsh environments

Industrial sensors, such as pressure and flow sensors are often exposed to extreme process and environmental conditions. Aggressive media cause corrosion and abrasion while other substances tend to form deposits picture. A device eventually gets to a point when it can no longer function properly and needs to be repaired.

Devices that recognize and report failures or degradation using so-called "self-diagnosis" are key elements of effective maintenance strategies. Very often new generation instruments not only discover internal faults, such as drift or ageing, but they can also recognize changing process conditions, like those from pulsating flow and bubbles in the flow, as well as the condition of other components connected to them. The detection, or even the compensation, of most of these effects is possible through appropriate signal processing algorithms.

Until recently, additional functionality was provided at the plant control-system level where much higher computation power is available. But improvements in electronics hardware and embedded software platforms now enable these functions to be integrated at the field device level. Anyway, some advanced functions can only be integrated in a field device because they require higher sampling rates than are possible with the usual fieldbus communication data rates.

ABB has worked tirelessly to create multifunctional field instrumentation that meet soaring customer demands.

There are two ways in which advanced functions can be realized in a device:

- *Employ a purely signal processing approach*. Sensors become essentially "soft" because the additional functions are implemented by applying mathematical routines and algorithms embedded in the processor of the transmitter. The sensing part or the mechanics of the sensor remain unchanged.
- *Integrate an additional (commercially available) sensor into the transducer*. For example, ABB's multivariable transmitter, 267/269 can measure differential and absolute pressure, and process temperature. These quantities are then used to calculate mass flow.

In general signal processing technology is used to extract relevant information from the raw signal. This can be accomplished either by straightforward mathematical data analysis or more complex physical modeling. If the former method is used, the time series of the raw signal can be analyzed by

1 Temperature sensors and a TTH300 transmitter

running a correlation, spectrum or noise analysis to find characteristic features and indications of dysfunctions. Another factor that broadens the spectrum of possible applications and functionalities is the emergence of novel and more efficient signal processing algorithms and techniques, such as statistical signal analysis, nonlinear data analysis, adaptive filters, neural networks and wavelets. In the latter method, a physical model of the sensor system is developed either by a set of equations describing the scientific principles underlying the respective sensor or by simulations. The decision regarding the suitability of advanced data analysis or the more elaborate physical modeling strongly depends on the application, the integrity of the measuring data and the available computational power [3].

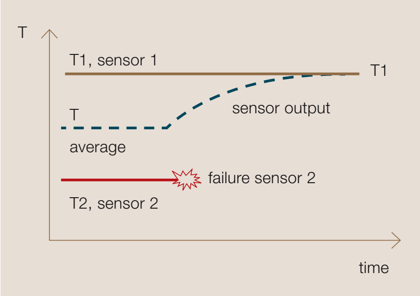
Devices that recognize and report failures or degradation using so-called “self-diagnosis” are key elements of effective maintenance strategies.

Constraints of more functionality

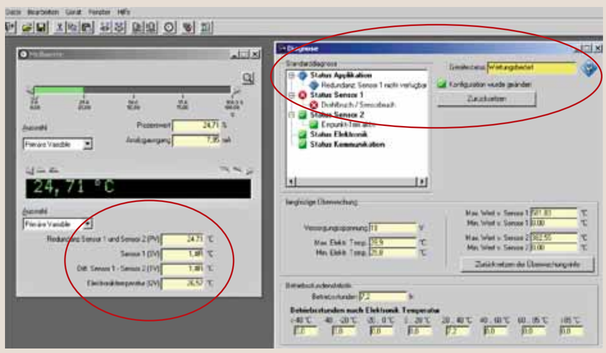
In the industrial instrumentation market, price plays a very important role in keeping or increasing market share. How big a role increased functionality plays depends on different points of view. Operators of big process plants with a multitude of expensive assets – like valves – are willing to pay more for advanced functionality. Device and process diagnostic functions in particular are highly appreciated because they promise to reduce maintenance costs and improve, in general, the reliability of the plant operation. Customers who primarily use the basic functionality only will not accept higher costs. Hence, during the functionality development phase, a trade-off needs to be found between cost and the feasible technical implementation.

ABB Corporate Research has invested consistently in the area of advanced diagnosis and signal processing, and some of the “fruits of this labor” are described in the following sections.

2 Sensor output with active sensor backup: A sensor failure results in a “soft” transition to the remaining sensor signal.



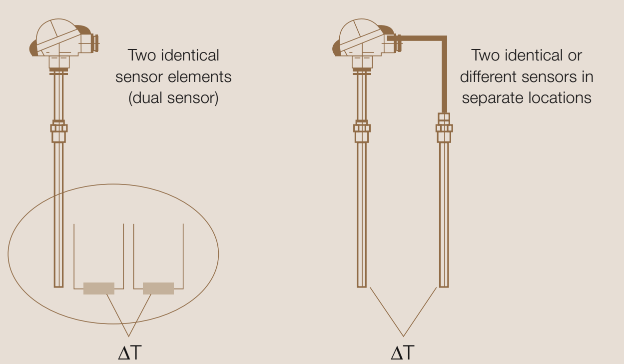
3 DTM (device type manager) output for active sensor backup function.



Continuously correct temperature measurements

Notification of status and service needed (redundancy active, sensor 1 not available due to wire break, replace failed sensor)

4 Sensor configurations suited to the use of the drift detection function



Drift detection based on difference between sensors

Reliable temperature measurement

Temperature sensors based on resistance temperature detectors (RTD) or thermocouples are highly accurate with straightforward measurement principles and simple technology. One would therefore assume that signal processing can do little to boost the performance of these temperature sensors. However, daily experience in process applications reveals how conventional plain temperature sensors can drift or even fail due to environmental ageing. While failure is easily detected, sensor drift can lead to wrong process conditions and unnoticed quality loss. Classical preventive maintenance consists of an annual costly re-calibration of temperature sensors in many process applications.

As the demand for predictive maintenance increases, customers are looking for new solutions. The productivity in processes where temperature control is critical increases significantly with reliable temperature measurements. This in turn drives the development of sophisticated diagnostic functions for temperature transmitters.

In ABB’s TTH300 HART temperature transmitter[1)], a large variety of self-diagnostic features have been implemented within a compact 44 mm diameter housing to enable high accuracy – up to 0.1°C is achievable – reliability and availability 1. To take full advantage of the high accuracy, the transmitter features two new diagnostic functions: sensor backup and drift detection. The increased computational capacity of the transmitter has enabled algorithms to be implemented at device level without increasing the data load in the communication system.

The TTH300 temperature transmitter can handle two RTDs or thermocouples, or a

Footnote

1) The TTH300 HART temperature transmitter was released in April 2006.

combination of both in parallel, and with the sensor backup function in place, the availability of the sensor is greatly increased. Previously, if a temperature sensor failed, a new sensor had to be connected manually to the transmitter, causing significant process downtime and cost. Now once a failure has been recognized by the built-in diagnostic functions, the transmitter automatically switches to the second sensor to ensure a continuous stream of correct temperature measurements 2. At the same time a message is generated for the device type manager (DTM) 3. Sensor replacement can be planned for the next routine service date without incurring extra downtime and at minimum cost.

ABB's reliable and accurate TTH300 HART temperature transmitter contains a large variety of self-diagnostic features in a compact 44 mm diameter housing.

Drift can occur in all sensors due to long-term mechanical or thermal effects, such as vibrations or overheating. Even though slow drift remains, for the most part, unnoticed in common processes, it can be fatal not only for the process but for the product quality as well. To date this problem has been addressed with regular but costly – in terms of downtime – sensor calibration. However, regular calibration can very often be unnecessary as the sensors remain stable if no severe environmental loads are acting.

Since the beginning of 2007 the new TTH300 offers a solution to this problem by performing predictive maintenance, ie, monitoring sensor drift, and calibrating only when necessary. In this solution, the TTH300 continuously monitors both sensors and compares their data. If the sensors operate within their defined tolerance (ie, without drift), the difference is very small. Drift in one of the sensors, however, causes the difference to exceed a definable threshold, triggering the transmitter to inform the operator that re-calibration or replacement should be planned for the next routine control. As actions are required only when drift occurs, the number and cost of sensor maintenance operations is significantly reduced.

The standard use-case is drift detection on a dual sensor 4. Even though drift is a non-predictable stochastic phenomenon, experimental investigations have confirmed that two sensors will not drift identically even if exposed to the same environmental ageing conditions. Alternatively, the drift detection feature can also be applied to sensors in different locations in a process, for example, to detect changes in the total process flow. This in turn allows local problems, such as poor heat transfer due to depositions, to be recognized.

The user can define the threshold level according to the sensitivity of the process to drift. The accuracy of the fit between the two sensors in question determines the minimum applicable alarm threshold. With a one- or two-point fit the detection threshold is about 0.5 – 1 °C because the characteristics of any two sensors will always differ by this amount. The detection threshold can be further reduced with more accurate sensor characteristic information. However, the 0.5 – 1 °C drift alarm threshold fulfils the needs of more than 90 percent of all applications.

A magnetic flow meter is a reliable and popular device that is applied in the water and waste, food and beverage, pulp and paper, and chemical industries.

Pure MAGIC

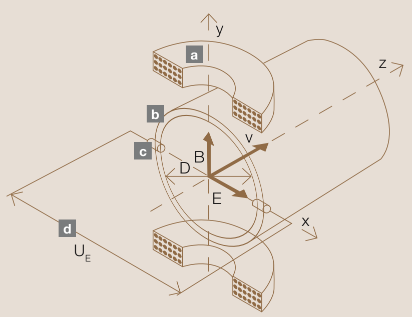
The global magnetic flow-meter market is valued at approximately $700 million. Invented in 1941 by Bonaventura Thürlemann, this reliable and popular device is applied in the water and waste, food and beverage, pulp and paper, and chemical industries.

The operation of magnetic flow meters is based on the principle of Faraday's Law of Electromagnetic Induction 5. When a conductor passes through a magnetic field, a voltage, U_E, is induced between the two electrodes, which is directly proportional to the volume flow rate q_v. Viscosity, density, temperature and pressure do not influence the flow velocity reading of a magnetic flowmeter.

The development of coating diagnostics for a magnetic flow meter is an interdisciplinary problem that relies on a thorough understanding of the process.

Project MAGIC focused on realizing a magnetic flowmeter with multivariable

5 Magnetic flow-meter principle



U_E = Signal voltage
B = Magnetic induction
D = Electrode spacing
v = Average flow velocity
q_v = Volume flow rate

$U_E \sim B \cdot D \cdot v$

$q_v = \frac{D^2 \pi}{4} \cdot v$

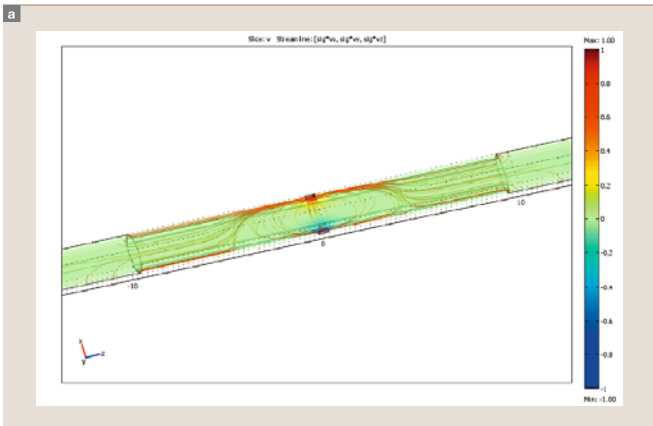
$U_E \sim q_v$

a Magnet coil
b Meter tube in electrode plane
c Signal electrode
d Signal voltage

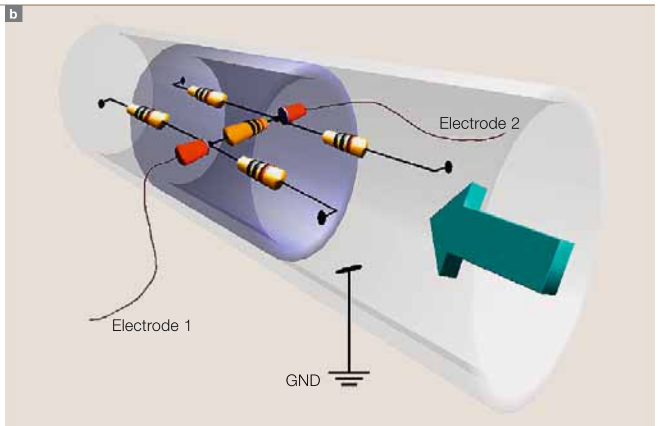
6 Coated magnetic flow meter in a pulp and paper application

7 Field simulation and flow-meter model with electric impedances

a



b



measurement, device and process diagnostics to detect gas bubbles in the medium and coating of a fabrication system, and to check the conductivity of the liquid.

If coating builds up in the fabrication system, it not only affects the pumps and pipes but also the magnetic flow meter 6. There are two types of coating, isolating and conductive, both of which affect the flow meter electrodes. Isolating coating continuously reduces the electrode area, eventually causing total flow meter failure, while conductive coating gradually increases the electrode area until a short circuit occurs. Therefore it is vital to monitor the system coating so that failure-prevention measures can be taken.

Algorithm design

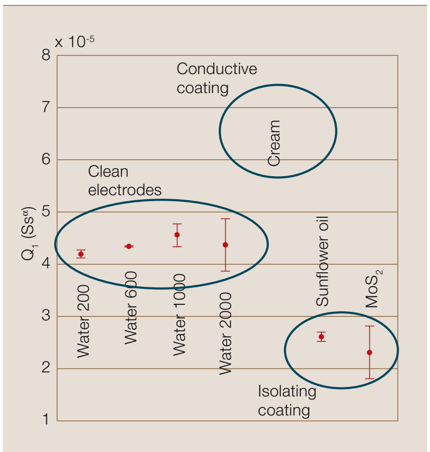
The development of coating diagnostics for the magnetic flow meter is an interdisciplinary problem that relies on a thorough understanding of the process. Therefore, the first port-of-call was the theoretical aspects of electrode-electrolytes interfaces. Device measurements in the flow lab under different conditions, followed by field measurements with ABB customers in different processes allowed an analysis of specific process coatings.

The effects of different liquid properties and coating materials were analyzed using measurements and simulations. The measurements and simulations were then used to develop physical device models that were extrapolated to aid the design of bigger flow-meter diameters.

Vortex flow meters have been successfully used as industrial flow-rate sensors for about thirty years and still they represent a growing business.

The effect coating has on a magnetic flow meter is modelled with frequency dependent impedances positioned between the electrodes and the flow meter ground 7. Constant-phase-elements accurately approximate the electrode-electrolyte interface characteristics, which in turn provide important information about the actual coating condition of the magnetic flow meter, (ie, clean, conductive or isolating) and therefore about the process system. The reciprocal value of the resistance between the electrodes at higher frequencies is strongly proportional to the liquid conductivity in the flow meter.

8 Coating detection based on physical device modelling



Laboratory measurements were carried out using different coating liquids. The conductivity of the medium (water) between 200 and 2,000 µS/cm hardly influences the electrode-electrolyte interface 8. A conductive coating with cream or an isolating coating with oil or MoS_2 changes the constant phase element. This effect allows coating to be measured independently of the conductivity of the medium.

In addition to coating detection, ABB's flow-meter platform was successfully enhanced – in collaboration with customers in Germany and Sweden – to measure conductivity and detect gas bubbles.

Vibrations-immune vortex flow meters

Vortex flow meters have been successfully used as industrial flow-rate sensors for about thirty years, and after all this time they still represent a growing business.

ABB's flow-meter platform was successfully enhaced to measure conductivity and detect gas bubbles.

The working principle of this type of flow meter is shown in 9. When the fluid flows through the pipe and passes the bluff body, vortices are generated which then hit a paddle mounted directly after the bluff body. Within the paddle a piezoelectric sensor detects the movements caused by the vortices passing by. The frequency of the paddle oscillations is proportional to the flow rate.

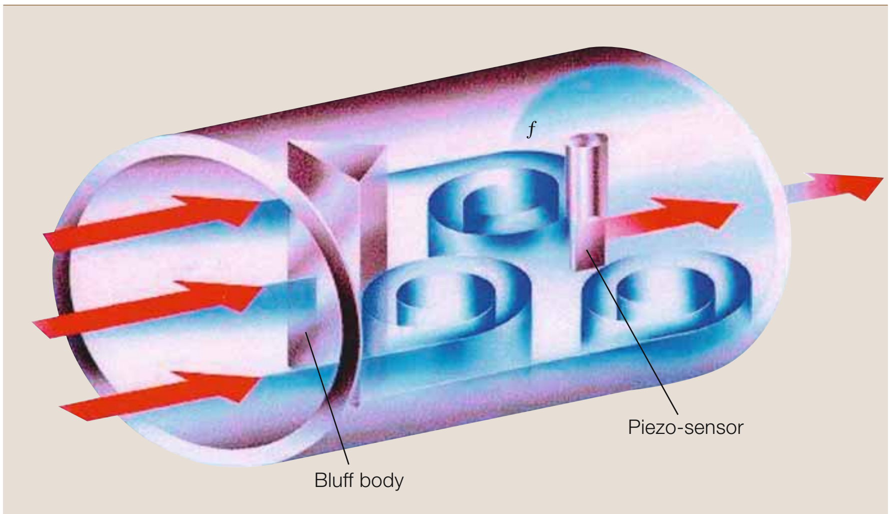
To ensure stronger noise immunity, ABB's vortex flow meters are equipped with a second piezoelectric sensor.

Because the sensor is based on a frequency measurement, disturbances, such as pulsating flow and vibrations (from rotating machines working near the vortex meter), may have a significant impact on the performance of the instrument. To solve this problem, ABB reviewed the computation algorithms and signal-processing concepts of Vortex and Swirl flow meters.

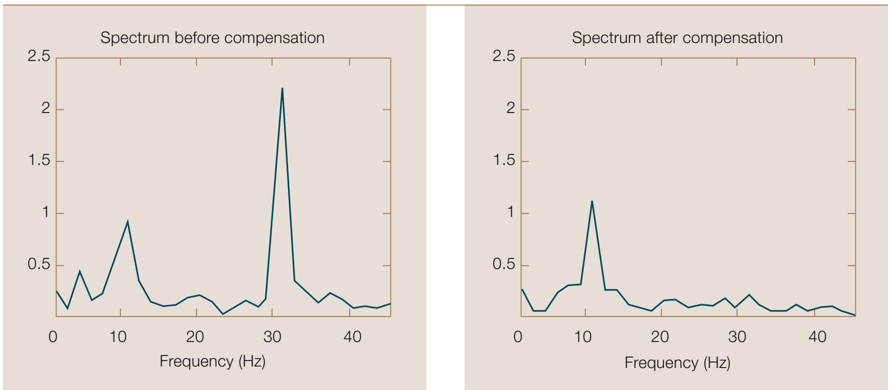
Under normal conditions and without significant noise, the frequency spectrum of the piezoelectric sensor output contains one main peak corresponding to the frequency of the vortices. Under vibrating conditions, the frequency spectrum may show additional peaks with high amplitudes 10. In the graph on the left, the spectrum of the piezoelectric signal shows a peak at 11 Hz caused by the flow. A disturbance peak at 30 Hz, almost three times the flow peak, is caused by vibrations. These types of effects are especially significant at low flow rates where the amplitude of the paddle oscillations caused by the vortices is small. This problem cannot be solved with "blind" noise filtering only.

To ensure stronger noise immunity, ABB's vortex flow meters are equipped with a second piezoelectric sensor mounted outside the flow tube and which is sensitive to disturbances only. The vibration compensation algorithm implemented is capable of removing vibration peaks without suppressing the flow peak when vibrations are at the same frequency. Referring to 10, without a vibration compensation strategy, the algorithm would give the wrong output of 30 Hz. The graph on the right shows the signal after vibration compensation – the vibration peak has been completely removed and the main peak remains intact.

9 Vortex measurement principle



10 Effects of the vibration compensation algorithm



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Pure improvement

Reducing waste by treating and recycling sub-products and effluents

Jean-Marie Hermant

Plant owners are always looking for ways to optimize production, ensure a reliable process performance and of course reduce costs. From the supplier's side, good engineering means anticipating a client's future needs for his plant and offering solutions that can cope with the evolution of economic and legal requirements.

Cellier Activity supplies complete automated installations for the paper, lubricants, paint and specialty chemicals industries. However, pollution from these industries has been of major concern for many years. Environmental issues now mean new technologies must be implemented that significantly lower the concentration of toxic substances in effluents. Many of the process solutions offered by Cellier do just this.

Cellier Activity, part of ABB France since 2000, is idyllically located in Aix-Les-Bains, in the French Alps and has over 50 years experience in coating preparation for the papermaking industry worldwide Factbox 1. As well as providing turnkey production units, Cellier also supplies innovative solutions for the management of chemicals, raw materials storage, powder transfer, dispersion, cooking, mixing, filtration, pipe cleaning systems and complete plant process control supervisory systems, as stand-alone equipment or as integrated process units. In addition, the company designs, engineers, procures and commissions services for the paper, board and tissue manufacturing and de-inking lines, lube oil blending plants, grease manufacturing units, production units for decorative and industrial paints and miscellaneous specialty chemicals like resins, adhesives, etc.

Because water scarcity affects an estimated four out of 10 people, it is important to conserve, recycle and protect water more efficiently.

Cellier also offers innovative solutions, such as clean-in-place (CIP) technology, filtration and piggable systems, to help its customers reduce waste generation by minimizing and recycling sub-products and effluents.

Working towards a cleaner environment

There are many reasons why companies must reduce the effluents produced as a result of their processes, but most probably the two most important ones are the scarcity of a valuable resource and compulsory regulations.

It is estimated that water scarcity already affects four out of every 10 people around the world[1], and the situation is getting worse due to population growth, urbanization and increased domestic and industrial water use. Because of this, everyone, and in particular companies, need to take responsibility by conserving, recycling and protecting water more efficiently.

For a start, companies can begin by reducing their "water footprint" (ie, reducing the consumption of fresh water) if they re-utilize filtered water in applications – such as rinsing – which normally use fresh water. In addition, they can recycle effluents by recovering concentrated raw materials or sub-products.

Growing environmental challenges and future legal requirements are creating more eco-conscious customers.

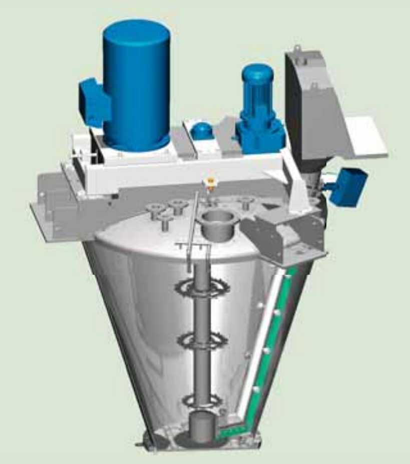
Legal requirements, such as the European guidelines known as REACH (Registration, Evaluation and Authorisation of Chemicals) and IPPC (Integrated Pollution Prevention and Control) contain measures to protect both the environment and human health. Economical factors are also important so that the plant depends less on water and chemicals supply, and more on treatment units.

Growing environmental challenges and future legal requirements[2] are creating more and more eco-conscious customers. Companies that anticipate the changes to come will, in the long run, save time and money and increase their overall profitability. Improved operation performance practically goes hand-in-hand with improved environmental performance, and this in turn leads to an improved image, a greater competitive edge and better risk management.

To help companies achieve operational- and environmental-performance improvements, Cellier provides innovative and value-adding process solutions designed to:

- Optimize consumption and resources
- Optimize process and production capacity by: operating in a closed circuit; increasing availability; reducing maintenance – by minimizing operator intervention; and reducing cycle times[3]
- Improve plant cleanliness by optimizing the cleaning phases (by scheduling a series of compatible

1 Clean-in-place (CIP) Delicel



Factbox 1 Cellier Activity

Founded in 1950 the Cellier company was initially concerned with the construction of stainless steel vessels. It progressively applied its know-how to the paper industry by supplying mixers, tanks and piping to the local paper mills in the Grenoble area. In the 1970s, the company opened subsidiaries in Great Britain, Germany, the US and Brazil, and by the end of the 1980s, Cellier was considered the world leader in the paper industry, supplying chemical preparation units and so called "coating color kitchens", with a market share of 65 percent. Its know-how now extends to other industries, such as the blending of lubricants and additives, the manufacturing of paints, varnishes, resins and other specialty chemicals.

Cellier proposes optimum solutions if a company needs to increase production capacity, change a production process, improve product quality or decrease product losses and effluents. Not only that but companies that seek to revamp their plants are supplied with an installation adapted to their needs and which integrates the latest technological developments.

Footnotes

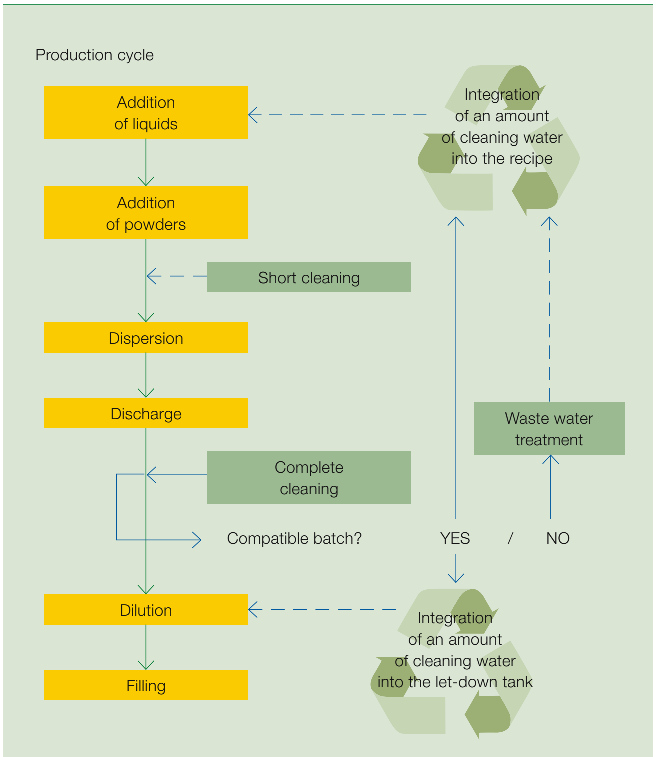
1) www.who.int (Retrived December 2008.)

2) Improved safety and working conditions as well as a duty to protect the environment.

3) Reducing cycle times can be achieved by using high-yield reactors to reduce batch time, or pigged lines to transfer products in hidden time.

batches, high-pressure cleaning operations, re-circulating waste water) and performing them automatically using CIP technology
- Easily control the manufacturing process by recording, measuring and managing components, needs and the quantities used and produced. In addition Cellier solutions ensure dosing accuracy and process repeatability by guaranteeing safe (ie, less manual) operation and system connectivity (ie, traceability).
- Reduce and recover effluents by concentrating or separating solids so that clear effluents can be reused as process and rinsing media, or as utility or "recipe" components.

2 CIP Delicel production cycle



CIP technologies

Some of the best available techniques employed to reduce effluents and control their generation utilize CIP technologies.

CIP technologies clean the internal surfaces of process tanks, pipes and associated equipment without having to dismantle them.

CIP technologies are used to clean the internal surfaces of process tanks, pipes and associated equipment without having to dismantle them. The cleaning operation is performed quickly, is repeatable and requires fewer personnel. These technologies can be applied to production units with a large product slate – including variable batch sizes – that require frequent cleaning or to production cycles of incompatible products. Because it is an automated operation, CIP can optimize the amount of cleaning product used. And most importantly, the equipment is much cleaner. Among the various CIP solutions available, Cellier proposes its innovative mixing and transfer systems.

Mixing solutions: the CIP Delicel

The CIP Delicel **1** combines high dispersion yields with an integrated automatic cleaning system. It allows dispersion and rapid circulation on the entire height of the tank and is suitable for varying batch sizes. The cleaning quality is ensured by high-pressure nozzles situated on the peripheral mixing arm. Automatic cleaning sequences, which use controlled cleaning water volumes, are adapted to the process.

A typical cleaning process in paint manufacturing involves:
- Dispersing the powders in liquids in the CIP Delicel before transferring it to a let-down tank. During this step, water is supplied through the cleaning nozzles to remove any powder remaining on the tank wall.
- The CIP Delicel is cleaned (through a self-cleaning process) and the water is then transferred to the let-down tank.
- Dilution (or finishing[4]) of the water takes place before storing in a let-down tank

The benefits of using CIP Delicel are many. For a start, the amount of effluents generated is reduced by up to 90 percent and part or all of the cleaning water can be reused. Cleaning is an automatic and immediate operation using controlled cleaning-liquid quantities and without the intervention of the operator. In addition, cleaning time has been reduced by up to 50 percent. The CIP Delicel is rapidly emptied and cleaned for another dispersing operation. Dilution takes place in hidden time, ie, in parallel to some other event, in a let-down tank.

Production is also organized according to batch compatibility to optimize the cleaning efficiency in terms of cleaning media consumptions, cycle time and cleaning quality **2**.

Pipe pigging solutions

Transfer operations are an effluent source. Because of this and for a line is to be completely emptied or cleaned, the pigging technology is im-

3 A piggable H-valve

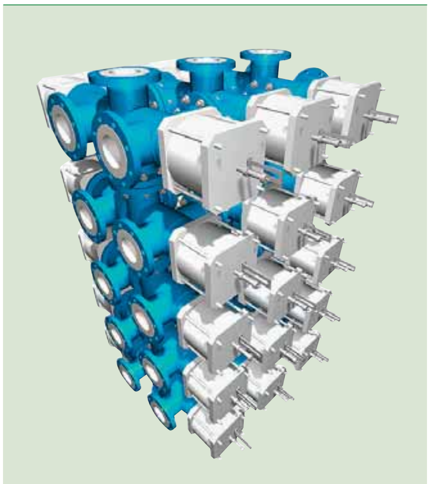
Footnotes

[4] A finishing phase is needed to obtain a product with a final concentration level that is lower than the initial one.

plemented in all industries where a large variety of products, whether they are compatible or not, must be transferred. This technology consists of moving a plug called a "pig" inside a pipe. The mechanical effect of the pig cleans and empties the pipe. A material recovery rate of 100 percent of the transferred product is the norm rather than the exception. Furthermore, the quantity of cleaning liquid is minimized by displacing a small buffer volume between two pigs in the pipe.

Pigging technology meets the requirements of safety and environmental protection. For example, the transfer circuits used in the reduction and recovery of effluents are closed. Another advantage of this technology is that it is capable of sequentially transferring different products in the same line. Pigged lines have become, in effect, a real process tool with the possibility to change and meter products without cross-contamination and to carry out hidden-time dosing or transfer operations. This in turn leads to more flexible workshops with greater modularity because the piping network is either simplified or it can be easily extended, and the allocation of equipment such as tanks, filling machines, etc, is optimized.

4 A module consisting of 15 H-valves



Cellier has developed a range of pigging components, including pig launching and receiving stations, distribution valves, cross-valves and so-called H-valves 3. These components are typically installed at the point where three lines – which may be of varying diameters – intersect thereby forming an interconnection 4. Assembled on a matrix principle, they enable several inlet and outlet points to be interconnected. Because they are automated, pigging systems are safer and their performance in terms of reactivity and reliability is greatly enhanced 5 6.

Drum decanting units (DDU)

Manual drum decanting operations increase the risk of spillage and/or accidents. In addition, the lack of accuracy and traceability in the product dosing is also a major drawback.

Cellier's drum decanting unit (DDU) is primarily used to transfer the liquid additives – without causing any spillage – stored in drums or containers 7. It also meters the product decanted from the drum, rinses both the drum and the transfer pipes after they have been emptied, and it either recovers the rinsing product or integrates it into the recipe as a component. In addition to these functions, the DDU is interfaced with the plant control system and contributes to the management of recipes and the planning of production operations.

CIP Delicel reduces the amount of effluents generated by up to 90 percent and part or all of the cleaning water can be reused.

The DDU enables:

- High dosing accuracy and reliability as control comes from the recipe manager
- Operation traceability. To assist him with the registration of the product to be decanted, the operator receives specific instructions on a local terminal interfaced with the plant control system. The management of any remaining volumes and inventory control are therefore made easier

5 A piggable manifold installed in the Sinopec plant (China)

6 Piggable lines installed in the Pintuco paint manufacturing plant in Colombia

Productivity solutions

7 A drum decanting unit (DDU)

A Dyrup production unit in Albi (France) manufactures wood treatment products and has reduced solvent consumption by 60 percent since 1990

- Safety, cleanliness and comfortable operation
- The recovery of high-value products and the recycling of cleaned drums
- The re-introduction of cleaning products in the recipe
- Easy maintenance.

Filtercel – the filtering solution

Filtercel is an in-line pressure filter with a filtering mesh size ranging from 50 to 500 µm 8. It automatically separates, concentrates and removes contaminants, thereby ensuring a high quality end product. As a CIP solution, Filtercel is a self-cleaning apparatus combining continuous declogging (using scrapers) and high-pressure cleaning through a rotary ramp used on the filtering basket. It is either installed as a single filtering point or on a re-circulating circuit. Filtercel is applied to products with high viscosity or solid contents. It is also used to filter pigment slurries for the paper industry and in the manufacturing of paint, resins and glues 9.

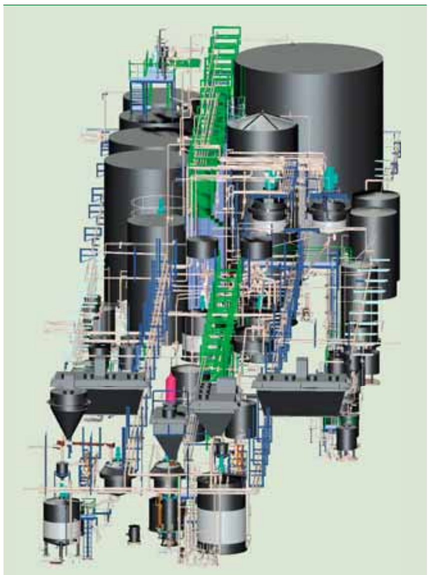
8 Filtercel

A drum decanting unit (DDU) transfers, without spilling, the liquid additives stored in drums or containers.

The advantages of Filtercel are:

- The consumption of cleaning liquid is reduced to 50 percent thanks mainly to two factors: cleaning efficiency is enhanced by the continuous action of scraper and high-pressure cleaning of the basket
- Effluent volumes and product losses are minimized because contaminants are concentrated and automatically discharged during a short draining sequence
- All functions, such as cleaning and draining according to the process

A 3-D view of a typical chemical formulation unit supplied by Cellier for the paper industry



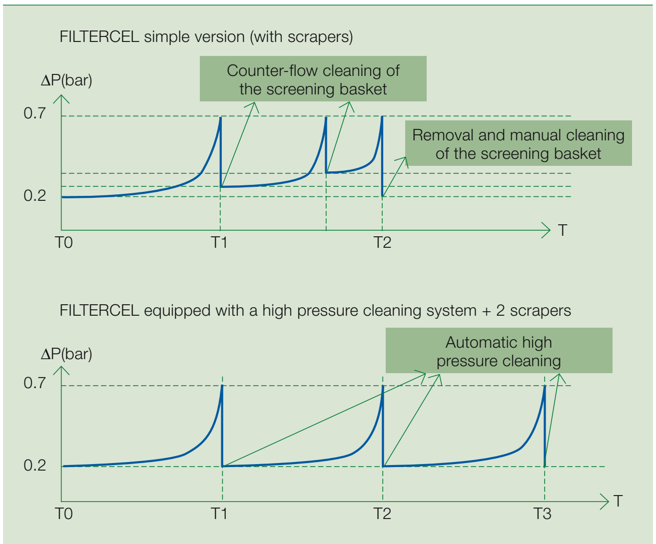
Dispersing units at the Blanchon Syntilor plant (France)

needs, are automatic with non-stop operation
- Reduced maintenance. Because cleaning is automatic, the metallic basket does not have to be dismantled.

Filtercel reduces both the frequency at which downstream filters clog up and the damage caused by the contaminants to other downstream equipment.

Filtercel is an in-line pressure filter that automatically separates, concentrates and removes contaminants.

9 Filtercel performance curves: batch after batch, the filtration efficiency remains unchanged



Complete automated installations

Within the context of effluent reduction, it is necessary to take into account defects that may occur in an automated installation which can lead to an environmental incident, such as tank overflow, the false connection of a flexible pipe, pump leakage, etc. Automation is considered the most efficient way of reducing or even eliminating the risk of human or process errors. It provides constant process management and supervision, emergency modes, organisational measures and operator acknowledgments, safety devices and interlocks.

Successfully reducing effluents depends mainly on simple and repeatable processes and measures where rigour is required. The benefits of an automated system implementing these with defined environmental key performance indicators (KPI) are given in Factbox 2.

Cellier Activity offers innovative process solutions based on continuing development. Eleven CIP Delicels have recently been installed in Thailand in a paint manufacturing plant after its owner decided to improve both operational and environmental performances. Another paint manufacturer in France included the CIP Delicel cleaning process in its quality standards. These successes show the growing interest of plant owners in exploring more environmentally friendly techniques and implementing a real water-management program to reduce water and solvent consumption as well as waste, while improving their economic efficiency by lowering production costs.

Factbox 2 The benefits of implementing simple and repeatable processes and measures with defined environmental key performance indicators (KPI) to reduce effluents

- The control of material flows because products and their containers are identified, registered and localized.
- The control of batches, quantities and status (ie, which component is in which batch, batch approval status).
- The integration of cleaning as production steps.
- The suppression or limiting of cleaning operations (line pigging).
- The concentration of effluents (pre-rinsing, high-pressure cleaning, filtering)
- Correct production scheduling to reduce the number of cleaning operations.
- The sorting of products in families according to their compatibility.
- The follow-up of equipment status (in terms of cleanliness and the name of the last product manufactured).
- The standardization of proven and repeatable procedures to minimize the risk of accidents and operator mistakes.
- The registration of manual or semi-manual transactions.
- The measurement and management of effluents. The system evaluates any performance improvement possibilities, minimizes effluent volumes and enables their re-use.
- The analysis of effluents using ABB analyzing solutions.
- High traceability including all relevant information, the measurement of volumes, and contents and histories.

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Compact and reliable

Decades of benefits: Gas-insulated switchgear from 52 to 1,100 kV

Lothar Heinemann, Franz Besold

It takes decades of experience to develop sophisticated technology. Over many years, ABB has developed a portfolio of gas-insulated switchgear in the 52 to 1,100 kV range. Continuous market-oriented development, creativity and competence has established ABB as a world leader in this type of technology. By constantly introducing innovative technological advancements, ABB has been able to provide a range of compact, versatile and reliable high-performance gas-insulated switchgear that continues to meet market needs and satisfy customers.

PERPETUAL PIONEERING

A safe, reliable supply of electricity depends on the circuit breakers that protect our electricity grids in the event of short circuits. Traditionally, these circuit breakers, installed in power plants and substations, were air-insulated. Air-insulated switchgear (AIS), depending on the rating, requires a minimum clearance between various active parts and earth in the order of tens of meters, which means a large area is needed to accommodate the installation. As an alternative, gas-insulated switchgear (GIS) are available, allowing the circuit breakers to operate safely within a confined space. A substation using GIS can be one-tenth the size of a conventional AIS substation [1].

Market-oriented product development, together with competence and creativity, has earned ABB worldwide recognition for its comprehensive portfolio of GIS products and services.

Such GIS is produced by numerous well-known manufacturers around the globe. Many of these companies have decades of experience in the production of switchgear technology. These manufacturers have now been joined by a number of other manufacturers who have only recently added GIS to their portfolio of products. These newcomers are now competing in the switchgear market, particularly at the lower voltage levels.

At first sight, the external appearance of competing GIS products suggests only marginal differences in their layout. However, upon closer examination, it becomes clear that the products offered by the traditional manufacturers of GIS have benefited from many years of innovation, modification and product development Factbox.

Establishing and maintaining a high level of competence in switchgear requires highly motivated staff, capable of continuous development in the face of technological- and process-engineering challenges. Market-oriented product development, together with competence and creativity, has earned ABB worldwide recognition for its comprehensive portfolio of GIS products and services.

Gas-insulated switchgear offered by ABB have benefited from many years of innovation, modification and product development.

To enable a company to cope with the technological challenges involved in the development of GIS, substantial investment must be made in research and development. This ensures that novel materials and system-related engineering technologies are incorporated in new products. Such innovation results in the development of reliable technology and ensures that technologically challenging milestones can be reached [4,5,6].

GIS technology originated in 1936, when a Freon-GIS assembly, rated at 33 kV, was demonstrated in the United States. Later, in the mid-1950s, sulfur hexafluoride gas (SF_6) was discovered, a gas that has excellent insulating and arc-extinguishing properties. By the mid-1960s GIS was sufficiently well developed to be commercially viable and appealing to a broader market.

Over time, progressive innovative steps have allowed ABB to develop a range of GIS rated from 52 to 1,100 kV. During this development period, many technological milestones have been achieved and protected by patents to safeguard ABB's intellectual property [7,8,9].

ABB provides a range of compact, versatile and reliable, high-performance GIS that meets market needs and satisfies customer requirements.

GIS products currently available from ABB fall into two main categories: those rated up to 170 kV 1, which are almost exclusively of three-phase design, and those above 170 kV 2, which are mostly of single-phase design.

Factbox Items of primary importance to GIS

- The availability of modular component design, which can be assembled in a variety of different ways to comply fully with the customer's requirements in terms of space restrictions and costs
- The provision of a safe and flexible system; the active parts of the equipment, at high-voltage potential, must interact effectively with the operating mechanism (ie, the interrupter, disconnector, earthing switches and the fast-acting earthing switches)
- The components should be traceable, consistent and have complete type-test certification, preferably provided by independent power laboratories, in accordance with international standards [2,3]
- The equipment should meet substation automation requirements such as customer-specific cabling and digital control technology; for the latter, each GIS bay should be able to link remotely to a customer's substation and control center
- The manufacturer should demonstrate competence in the handling of customer orders, managing projects, engineering, quality control, material procurement, production, assembly in the factory and on-site, including the supply of complete and comprehensive documentation
- The manufacturer should provide worldwide service coverage with quick-acting and well-trained professional teams; such teams should be able to service equipment, replace single components or modules in individual substations, and be able to replace old substation technology with new technology
- The manufacturer should maintain a highly skilled development team made up of a reliable mix of young, innovative and skilled engineers with many years of experience

PERPETUAL PIONEERING

Sub-transmission GIS (< 170 kV)
In the late 1960s, encapsulated switchgear assemblies, initially equipped with low-oil circuit breakers, were replaced by switchgear using SF_6 gas. The first GIS of this kind was the EBK-01-type with a rated voltage of 123 kV, a short-circuit current rating of 31.5 kA and an operating current rating of 2,000 A. This type of switchgear was equipped with an easy-to-operate, horizontally installed, double-pressure circuit breaker. When it was introduced to the market in 1969, this switchgear was already equipped with three-phase bus-bar modules. Almost all the original first series units (bays) delivered by ABB are still in operation. In 1973, the EBK-01-type circuit breaker was replaced by the EBK-02-type, capable of operating at increased rating values of 145 kV, 31.5 kA, 2,500 A.

The next major milestone was reached with the introduction of the ELK-01-type switchgear in 1978. This switchgear (145 kV, 31.5 kA, 2,500 A) was the first fully three-phase design in the world. It was equipped with a vertical, maintenance-friendly, single-pressure, circuit breaker with puffer circuit breaker technology. Its successor, the ELK-02, was launched in 1980. This model featured an improved modular design that clearly distinguished it from its predecessors.

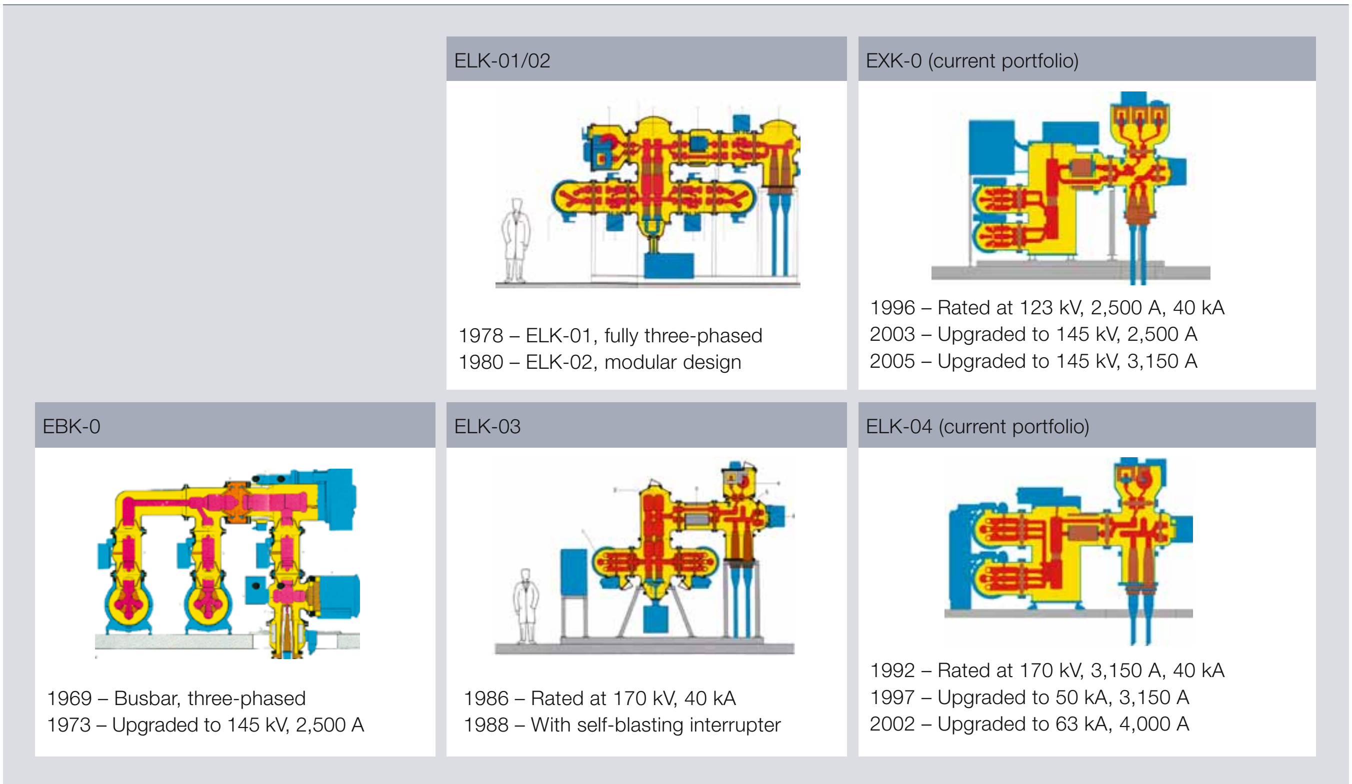
ABB's ELK-03-type GIS provided increased ratings, a single housing for the disconnecting and earthing switches, and a hydro-mechanical spring mechanism to operate the circuit breaker.

Until this time, the disconnecting and earthing switches of all switchgear models were housed separately and the circuit breakers were equipped with hydraulic operating mechanisms. The ELK-03-type switchgear (170 kV, 40 kA, 3,150 A), was launched in 1986, and provided not only increased ratings, but also a single housing for the disconnecting and earthing switches, along with a hydro-mechanical spring mechanism to operate the circuit breaker. Two years later, this ELK-03-type switchgear was modified to feature self-blasting circuit breaker technology, thus reducing the energy required for switching. Since this pioneering development, GIS rated up to 170 kV have been equipped with self-blasting circuit breakers.

In 1992 the ELK-04-type switchgear was launched (rated at 170 kV, 40 kA, 3,150 A). This new product was characterized by a further reduction in volume and a totally new design of connection between the busbar and the feeder modules. This new connection allowed unprecedented reductions in product size, enabling an entire switchgear unit to be accommodated within a single standard industrial container. Even today, years after its market launch, the ELK-04-type switchgear remains one of the most compact switchgear-types available in the 170 kV category.

Further advances in power ratings have been made with this type of switchgear, while retaining its compact design. The first of these improvements was to increase the ratings to 170 kV, 50 kA, 3,150 A in 1997, and then to 145 kV, 63 kA, 4,000 A in 2002. These versions were also

1 Historical development (overview) of sub-transmission GIS in the voltage range below 170 kV



equipped with switching units with self-blasting technology and hydro-mechanical spring-operated mechanisms 3.

In 1996, another model, the EXK-0 had been developed to comply with reduced rating requirements of 123 kV, 40 kA, 2,500 A. In 2003, however, the rated voltage was increased to 145 kV, 40 kA, 2,500 A and was increased again in 2005 to 145 kV, 40 kA, 3,150 A.

Over 15 years after its market launch, the ELK-04-type switchgear remains one of the most compact switchgear-types available in the 170 kV category.

As a result of further continuous developments in both switchgear types, the products, which had been initiated independently to satisfy different demands, have now evolved and converged to produce a highly standardized modular system. This not only includes the primary components, such as the circuit breakers, disconnector and earthing switches, but also their operating mechanisms. The convergent evolution of these two near-identical products prompted the launch of a single product under the now familiar brand name, ELK-04.

Transmission GIS (> 170 kV)

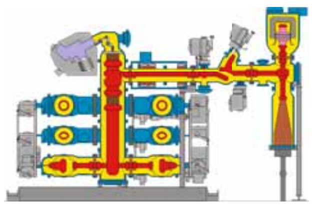
In 1967, the ELK-1-type GIS was designed for single-phase and single bus-bar applications for a rated voltage of 245 kV, 40 kA, 1,600 A 2a. This type of switchgear was developed in parallel with the EBK-type switchgear to cope with higher voltage levels. The individual circuit breakers were equipped with puffer-type interrupters and were operated by separate hydraulic mechanisms.

In 1976 the first 550 kV GIS, ELK-3, was launched onto the market. The individual circuit breakers, each with three interrupting units, were the first to be rated for short-circuit currents of 80 kA and an operating current of 6,300 A 2c. These breakers were installed vertically, and were equipped with a hydraulic operating mechanism and closing resistors.

The ELK-3-type GIS was used in a substation for the first time in Canada in 1979. It was the first GIS to be exposed to severe climatic conditions. Since it was developed to meet specific customer requirements, special attention was given during the develop-

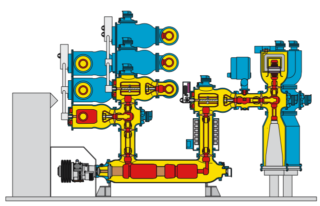
2 Historical development (overview) of transmission GIS in the voltage range from above 170 kV

a



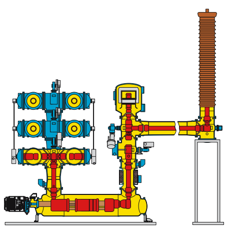
1967 – ELK-1: 245 kV, 40 kA, 1,600 A
1996 – ELK-14: 245 kV, 50 kA, 4,000 A

b



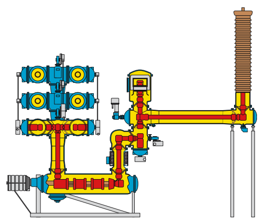
2003 – ELK-14: 300 kV, 50 kA, 4,000 A

c



1976 – ELK-3: 550 kV, 63 kA, 6,300 A
1979 – ELK-3: 550 kV, 80 kA, 6,300 A

d



1986 – ELK-4: 800 kV, 50 kA, 5,000 A

3 Typical substation with GIS of ELK-04-type in Spain (Mallorca) a and replacement of AIS by GIS of ELK-04-type in the United States (California) b

a

b

ment phase, not only to ensure that it would operate at higher ratings, but also that it would meet these operation requirements at sub-zero temperatures.

ABB's ELK-3-type GIS installed at the hydroelectric power plant in Itaipu, Brazil continues to protect the flow of electricity after more than 20 years of service.

In 1981, 51 bays of the ELK-3–type GIS, with ratings of 550 kV, 63 kA, 4,000 A, were installed by ABB at one of the largest transmission GIS substations in the world, at the hydroelectric power plant in Itaipu, Brazil. Each circuit breaker was positioned vertically and equipped with two interrupting units, each with an individual hydraulic operating mechanism. After more than 20 years of operation, this GIS continues to protect the flow of electrical energy to the grids of Brazil and Paraguay. Here, the challenge was to design and install a highly reliable, complex substation compatible with frequencies of 50 and 60 Hz. Individual components had to be designed in a way that would allow them to be exchanged easily if necessary.

Demand for even higher voltage transmission led to further innovations and the development of the ELK-4-type GIS, with ratings of 800 kV, 50 kA, 5,000 A 2d. This model maintained its compact design, allowing a substation capable of operating at very high voltages to be installed within a limited space. Each circuit breaker was installed in the vertical position, with four interrupting units and associated closing resistors. The new product was introduced onto the market in 1986 and was first installed in South Africa at an altitude of more than 1,000 m.

In 1996, the ELK-14-type GIS was developed, using the ELK-1-type GIS as a blueprint 2a. Here the ratings were 245 kV, 50 kA, 4,000 A. The interrupter was of the self-blasting type and operated by a hydro-mechanical mechanism. This was a significant milestone, since this was the first time the self-blasting principle had been used at voltages above 170 kV. Some years later, the success of the ELK-14-type GIS prompted further improvements to upgrade its ratings to 300 kV, 50 kA, 4,000 A 2b. Special attention was paid to ensure that a single enclosure housed both the disconnecting and earthing switch modules.

Early in 2003, a 550 kV substation (rated at 550 kV, 63 kA, 4,000 A) was installed by ABB at the Three Gorges hydroelectric power plant in China 4. This is currently the largest GIS transmission substation in the world. Many technical and logistical challenges had to be solved before the last of the 73 bays could be put into operation in the autumn of 2008 5. In this installation, the circuit breakers are positioned horizontally and equipped with the HMB-type hydro-mechanical operating mechanism 6. The layout is compact, making it possible to place the whole substation on top of the concrete dam.

ABB's ELK-5-type GIS for an ultra-high-voltage rating of 1,100 kV, 63 kA, 6,000 A is the most compact GIS ever produced for such extremely high voltages.

The most recent challenge for ABB was the development of the ELK-5-type GIS for an ultra-high-voltage rating of 1,100 kV, 63 kA, 6,000 A. This is the most compact GIS ever produced for such extremely high voltages [8]. The design is characterized by four interrupting units, connected in series and positioned in a horizontal arrangement, and is equipped with parallel closing resistors 7.

Modularity and scope of supply

Today, all types of switchgear have a highly standardized modular building-block design, irrespective of the voltage levels. They can accommodate a large variety of technical requirements within a small number of modules. This not only applies to the primary components, such as the circuit breaker, disconnector and earthing switch, but also to their operating mechanisms.

4 The Three Gorges hydroelectric power plant in China

5 A 550 kV substation with GIS (rated at 550 kV, 63 kA, 4,000 A) installed within the dam at Three Gorges hydroelectric power plant in China

All GIS-types currently available are equipped with a hydro-mechanical circuit-breaker operating mechanism, which also has a modular design. This allows the speed profile of the different interrupters to be adapted very easily, reducing switching speed, especially at the end of the motion. Therefore, the mechanical impact of the switching operation on the interrupter is very small. The energy storage in the disc springs is not restricted to the switching sequence O-0.3s-CO (open – 0.3 seconds – close-off operations) that is required to meet the relevant standards, but can provide the energy for even more complex switching sequences, eg, O-0.3s-CO-0.3s-CO, without recharging. This feature is frequently required by the Arabian and American markets. Moreover, using the various types of operating mechanisms, it is possible to achieve a timely and accurately adjustable, mechanically independent, single-pole operation with the additional benefit of a controlled switching operation.

In addition to the primary technology, with its modular design and the harmonized portfolio of operating mechanisms, the newest generation of digital control devices with the IEC-61850 communication protocol, is available [10]. The customer is offered a comprehensive diagnosis and monitoring system for the whole switchgear assembly. The system can be applied to several switchgear types and is designed as an add-on feature for conventional switchgear. It is characterized by open architecture and is also suitable for retrofits.

Over the years ABB has substantially reduced the amount of SF_6 gas used in its GIS despite the higher voltage ratings of newer models.

Environmental matters

Design changes and innovations in GIS technology are made to comply with market requirements and their ever-changing standards, and to reduce the environmental impact of the technology. This involves minimizing the use of potentially hazardous components during production and reducing the use of components that have complex disposal procedures at the end of their life cycles. It also involves designing products that require fewer raw materials and use fewer primary energy sources in their manufacture. In line with the aims of the Kyoto protocol (1997) to reduce greenhouse gas emissions, efforts have been focused on reducing the volume of SF_6 gas per GIS module and thus of switchgear as a whole.

Since the beginning of GIS development, reducing the use of SF_6 has been a priority with each new type of switchgear 8. A 40-percent reduction in the SF_6 content has now been achieved for the latest models of GIS, compared with their predecessor. It should be noted that this significant reduction has been achieved despite the higher voltage ratings of the newer types. If voltage ratings had remained unchanged, the SF_6 reduction would have been even greater.

Current market trends

With regard to both the primary and the secondary technology, all GIS types are characterized by a high degree of standardization and integration of functions. A module-oriented portfolio with a market-focused range of rating values ensures an adequate variety of products to meet customers' requirements.

On the global market, three main ranges of application and customer preferences are currently evident for GIS.

6 HMB-type hydro-mechanical operating mechanism

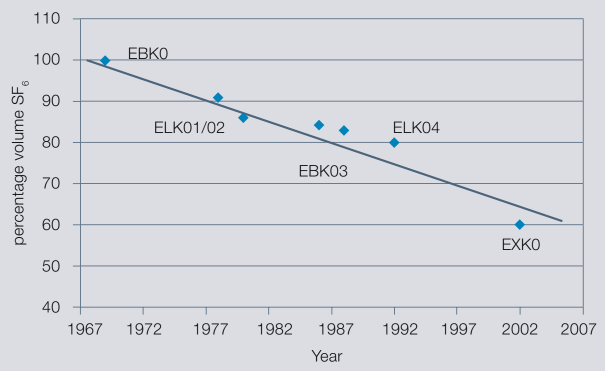
7 The 1,100 kV GIS substation Jingmen, China

PERPETUAL PIONEERING

Extension or replacement of switchgear at substations

Often in densely populated centers of traditional industrial regions, as well as in the megacities around the world, local substations are required to meet high-energy demands. In such areas real-estate prices are high, which makes the compact design of GIS an attractive feature when compared with AIS alternatives that require considerably more (costly) land for safe operation.

8 Continuous reduction of the SF_6 gas shown for the circuit breakers of the switchgear in 1 having the rating parameters 145 kV, 2,500 A (figures are normalized to 100 kPa and a temperature of 20°C)



It should not be forgotten that decades of experience at each product development step have enhanced the reliability and therefore the availability of switchgear installations, regardless of location or method of operation. For the customer, ABB's experience is reflected in lower operation costs and higher reliability over the lifetime of its products.

Rising energy demand in the densely populated centers

Densely populated centers of the world require higher-rated voltages, higher short-circuit currents and higher operating currents [11,12]. Greater numbers of people are living in urban centers, consuming ever-greater amounts of electricity. This demand requires efficient methods by which to transport electrical energy with low losses, reduced visibility and high degrees of safety. Efficient energy transfer can be achieved at high-voltage levels through cables. But this high voltage (HV) electricity must be reduced to lower-voltage levels using transformers in the vicinity of the end users. In densely populated centers, this leads to a persistent increase in the transfer capabilities of the networks, requiring higher nominal currents and higher short-circuit capacities within the networks.

Improved energy-technology infrastructure

New substations are required to create a new or improved energy-technology infrastructure in emerging industrial countries as well as in the countries with large primary energy resources, such as the Middle East and Russia.

The focus of new developments is to further reduce the use of SF_6 gas and to improve the energy efficiency of the entire manufacturing process. The complete GIS portfolio is set up so that state-of-the-art manufacturing technologies (machine processing of individual components), simplified assembly processes (both in the factory and in the field), together with shipment in standardized containers, can all be exploited.

To meet the changing and challenging market requirements of the future the following topics are of importance:

- Standardized modular component system that allows convenient and cost-effective extension of existing GIS installations and the simplified replacement of conventional air-insulated installations by GIS modules.
- Continued development in the range of switching technology, such as high-voltage switching interrupters with even lower energy demands
- Further combination of various primary functions into one module to reduce the number of flange connections

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ABB and sustainability

Sustainability is a topic that is very much on people's minds today. A growing world population with rising demands on their standards of living is increasingly coming into conflict with the Earth's limited resources. Just as technologies and processes have over the years been optimized for greater productivity, present day optimization processes are increasingly taking environmental impact and limited resources into account. Sustainability can be achieved through a shift to regenerating resources, and ABB is supporting that trend through many of its technologies, for example in the domains of solar or wind energy. Dependence on traditional energy sources can however also be reduced by making more efficient use of the energy that has already been harnessed. This can take the form of more intelligent deployment of energy through better control strategies. An example would be the optimization of power transmission and adaptation of the grid to better cope with the changing generation and consumption patterns that the shift to greener energies is causing. It can also be achieved locally through better use of technology, such as drives or turbochargers, or measures to reduce waste in manufacturing.

Besides the strictly environmental aspects, the theme of sustainability also encompasses such topics as human safety and working practices. These can range from avoiding hazardous working situations to ergonomics in the workplace.

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