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AUTOMATED TIE-IN – NEW TIE-IN TECHNOLOGY FOR PIPELINE CONSTRUCTION

Main Author

Peter Schwengler, E.ON Ruhrgas AG, Pipelines Competence Centre
Germany

Co-Author

Graham Freeth, BP Exploration
Great Britain

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1. ABSTRACT

This paper describes the first step of a project to develop a “Automated Tie-In Machine” for Oil and Gas Pipeline Construction focusing on the automation of the Tie-in process, providing improved productivity and reduced costs. The “Automated Tie-In” project is jointly managed and funded by BP Exploration & E.ON Ruhrgas. The paper also briefly addresses the issues associated with the wider business context and historical innovation barriers in the onshore oil and gas pipeline industry which underpin the premise driving this project’s initiation.

Many existing pipeline networks are reaching the end of their design lives and have to be replaced or supplemented by new systems. Pipeline R&D strategies, therefore, are increasingly focused on reducing construction costs. Manual activities are key cost drivers of the construction or re-construction process and automation can deliver many benefits. The Tie-in process is a largely manual process which lends itself well to automation and therefore will provide significant value from the implementation of new technology.

The term ‘Tie-in’ is generally used to describe the connection of a pipeline to a facility, to other pipeline systems or the connecting together of different sections of a single pipeline. It also refers to additions or modifications to existing systems, for example to connect re-construction pipelines, insert Tees, spool pieces, valves etc. Existing “Tie-In” methods are based on traditional construction methods which were developed some 40 or more years ago, requiring significant manual intervention and operator skill. Tie-ins are normally performed with the pipeline already in the trench. As the joint has to be made between 2 ends of pre-completed pipeline sections there is no way for introducing any internal equipment into the pipe. All operations are therefore carried out externally and the accuracy of cutting, preparation and alignment of the pipe ends prior to welding becomes critical. External alignment clamps are used which limit the opportunity for using automated welding. It is recognised within the pipeline construction industry that the “Tie-In” process would benefit from the automation of a currently largely manual process.

2. Body of Paper

2.1 Introduction

Existing “Tie-In” methods are based on traditional construction methods which were developed some 40 years ago, requiring significant manual intervention and operator skill. Consequently, the “Tie-In” activity represents a significant productivity constraint which frequently impacts overall pipeline construction efficiency.

Automated “Tie-In” technology currently does not exist.

Current situation: Conventional construction methods require a “tie-in” to be made at regular intervals or more frequently when a crossing is reached. The “Tie-In” process requires a skilled work force and overall productivity, and therefore, costs can be severally impacted by “tie-in” efficiency. This issue is most notable in urban and semi-urban environments. However, even in rural areas where drainage channels, river deltas and other natural features exist there will be a significant detrimental impact on progress rate. Another consequence is also the lengthening of the overall open ditch with a consequential HSSE (Health Safety Security Environment) impact.

Possible Solution: The automation of the tie-in process will bring significant cost and HSSE benefits to the construction process, particularly in areas of a construction spread where more than one tie-in will be required per day. It is proposed that the development of a automatic “Tie-In” technology, maybe mobile, will be the appropriate way forward.

2.2 Tie-In Project Scope

The conventional Tie-In process comprises a sequence of predominantly manual operations. To get an idea how the tie-in process in details is, and what kind of development is suggestive, a feasibility study was drawn up as follows:

- Stage 1: The Conventional Tie-In Process: Clear definition of the key activities of the "Tie-In" process using conventional methods.
- Stage 2: Technology Matching: Research and identify potential ideas and lessons learned from other parallel industries
- Stage 3: Performance Specification: Develop a performance specification for potential automated "Tie-In" technology
- Stage 4: Identify Options: Identified conceptual options for automation
- Stage 5: Market Research: Define and understand the size and nature of market needs
- Stage 6: Option Selection: Analysis and selection of preferred option(s), including a clear definition of productivity improvement
- Stage 7: Develop Conceptual Design(s): Development of a conceptual design of the preferred option(s)
- Stage 8: Cost Estimates: Develop cost estimates for the product development and manufacturing unit rates. Also calculate the potential "Tie-in" cost using the new technology, including equipment and man-power costs.
- Stage 9: Risk Analysis: Undertake a Risk Analysis, including the risks associated with Marketing, Technical and Manufacturing

2.3 Conventional Tie-In Process

2.3.1 Definition of a Tie-In

The term 'Tie-in' is generally used to describe the connection of a pipeline to a facility, to other pipeline systems or the connecting together of different sections of a single pipeline. Furthermore it can be defined as a welded joint that cannot be carried out by the main front end welding/production during the main line laying.

2.3.2 Principal Reasons for Tie-Ins

Tie-in welds are, for instance, required at any joint that has not been welded by the front end welding crew. As the construction programme and cost efficiency of the main pipeline production will rely on close to continuous advance and optimum utilisation of the front-line crew and equipment then any delays to this continuous process have to be minimised. Some joints will have been left because they could not be physically made at the time, others because making of particular 'non-standard' or awkward joints would cause a disproportionate delay to the main production. Tie-ins also refer to additions or modifications to existing systems.

2.3.3 Primary Differences between Tie-In and Main Line Joints

Figure 2-1: Main Line Joints

Main line joint welds are carried out by specialised crews generally using highly automated equipment in a series of efficiently sequenced operations moving along the spread.

The line-pipes are above ground, supported on skids, and handled by side booms. As the process involves the progressive welding of single, or sometimes double, pipe lengths to the end of the pipeline it means that there is always access to the open end of the pipe. This allows the use of automated equipment inside the pipe, such as an internal joint alignment clamps, root run internal welding machines and in some cases sources for weld inspection by radiography. The use of such internal equipment also facilitates the use of automatic welding equipment for the external fill and cap passes of the welded joint.

Conversely, it is generally accepted that a single tie-in crew can complete between1 and 2 tie-in welds per day. Tie-in welds are normally performed with the pipe already in the trench. As the joint has to be made between 2 ends of pre-completed pipeline sections there is no facility for introducing any internal equipment into the pipe. All operations are therefore carried out externally and the accuracy of cutting, preparation and alignment of the pipe ends prior to welding becomes critical.

Figure 2-2: Typical Tie-In Welding Arrangement for new construction

External alignment clamps are used which limit the opportunity for using automated welding processes and welding is normally carried out manually.

Compared to new construction there is another demand on the tie-in process at pipeline reconstruction tasks.

Additional to the methods above It is possible that pipes are jointed by welding with fitting piece, bushing and sleeve. This way has to be used for tie-ins during pipeline re-constructions.

Figure 2-3: Tie-In Welding Arrangement for Re-Construction

2.3.4 The Tie-In Process: Summary

The conventional Tie-In process comprises a sequence of predominantly manual operations. The relatively high level of manual intervention poses unnecessary exposure to HSE risk and contractors to high unit costs and the perennial difficulties of finding skilled operatives.

The equipment utilised has not developed greatly but has the advantage of being “industry standard”. Although recognised as labour intensive and costly, the methods have been proved over many years and the potential problems are known and understood and risk is considered to be minimal by most contractors. However, applying new technology to automate the Tie-In process offers significant opportunities for improvement. The tie-in process is summarised below.

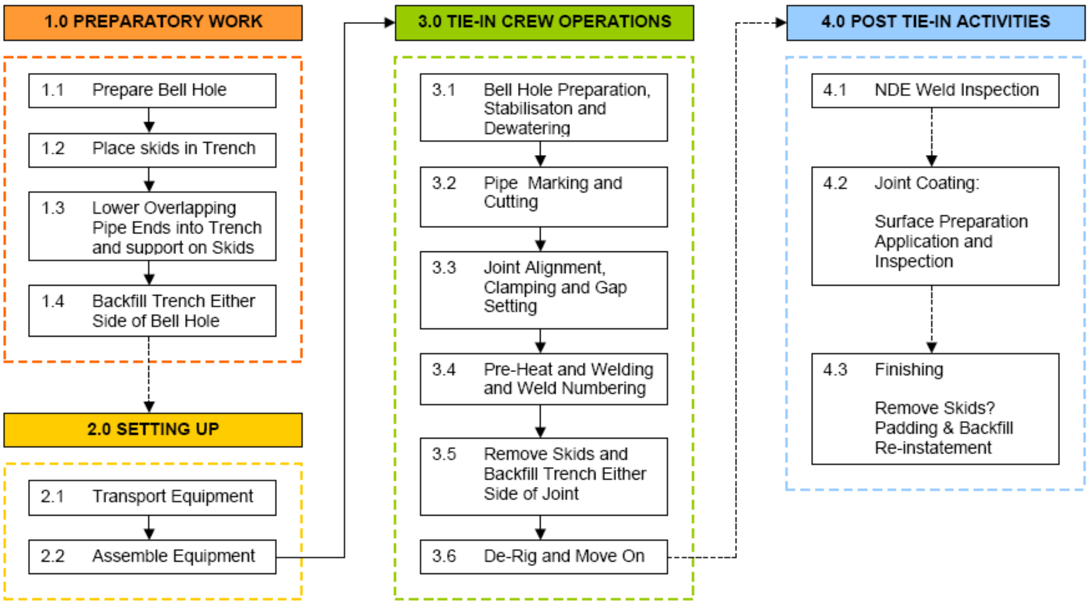

Figure 2-4: Summary Conventional Tie-In Process

2.3.5 The Tie-In Process: Setup and Front End Crews

Tie-in sites may be located a considerable distance behind the front end production crews and distances between tie-in sites will also vary. Depending upon location of a tie-in site transport of human resources, material and equipment will bring own specific logistical problems. For instance, if transported by low loader side booms will require rigging for operation, this involves assembly of the booms and counterweights to the base vehicles.

The two pipe section ends to be joined are usually located in the trench by the lowering in crew, overlapping horizontally and supported on timber packs or skids. The trench will have been previously widened over a distance of between 3 and 4 pipe lengths local to the joint position (often referred to as a 'bell hole') to allow space for the pipes to overlap and subsequent access around the pipe joints. The amount of bell hole preparation work carried out in advance of arrival of the tie-in crew and will also vary depending upon local ground conditions. In high water table areas it may be necessary to pump out the bell hole and make safe by either further excavation, battering back or installation of a trench box. Use of a trench box may also restrict some operations. The Health and Safety issues associated with working in trench excavations present significant challenges which justify the Automation of the Tie-In Process in its own right.

2.3.6 The Tie-In Process: Measurement and Cutting

If there are pipes with overlapping pipe ends, the first pipe is set as close to level as possible using a side boom and possibly with the assistance of airbags. The second overlapping pipe end is then lifted over the other using 2 side booms and marked for an approximate cut to remove the excess length. The pipe coating local to the cut position is removed and the excess pipe length is then cut off. The weld prep on the first pipe end is formed either by using a tracked burning bug and grinding, or a pipe facing machine. The second pipe is again lifted over the first and the accurate position of the final cut marked using chalk and line. The final cut is then made and the pipe end faced off as before. The initial marking and cutting operation will take in the order of 30 minutes with the subsequent cutting and bevelling operations taking up to several hours.

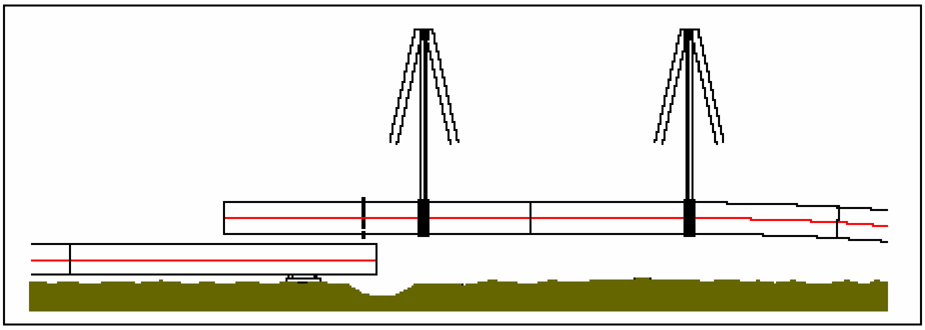

Figure 2-5: Measurement, Cutting 1 up to 5 and Bevelling

2.3.7 The Tie-In Process: Joint Alignment

The two pipe ends are brought into alignment using the side booms and if necessary further dressing of the pipe ends is carried out to achieve the required weld gap. An external centralising clamp is then fitted to align the two pipe ends. The clamp serves to align the pipes concentrically and to correct for any ovality between the two pipe ends. Out of round tolerances and acceptance criteria for pipes are normally only applied to pipe ends, tolerances along the length of the pipe are not subjected to the same acceptance criteria, so cutting pipe joints mid-length can result in unexpected ovality. The gap between the pipes is then adjusted using steel wedges to set the gap parallel around the full circumference of the weld. The use of these external clamps is seen as one of the obstacles to using automated welding equipment. The time to complete the above operations will be dependent upon the skill of the crew and alignment, and could take up to 2 hours to complete.

2.3.8 The Tie-In Process: Pre-Heat and Welding

Pre-heating and welding is started as soon as possible after clamping and alignment is completed in areas where temperatures can change quickly leading to pipe expansion or contraction, which in turn can alter the gap. This is another reason given as to why manual welding is preferred over automatic equipment in that a man can react to, and compensate for changing conditions. Pre-heating of the joint is usually carried out using a ring of heating torches and usually takes of the order of 20 minutes to sufficiently heat the weld area. Manual welding is employed for tie-in welds and generally as many welders as it is safe to employ will carry out the root, fill and cap passes, grinding back in between passes being carried out by a helper. Typically 2 – 4 welders may be employed on a pipe weld. The weld process lasts from 2½ hours to 4 hours depending on the pipe size, wall thickness and material. As the centralising clamp is an physical obstacle, it is removed as soon as it is considered safe to do so. This typically occurs after the root pass and 1 or 2 fill passes have been completed. The welding operation is considered to be the most predictable of the tie-in operations as everything has to be set up correctly to the satisfaction of the welders, engineer and inspector prior to commencement of welding.

2.3.9 The Tie-In Process: Post Welding

Side booms generally stay on station supporting the pipe throughout the welding operations. Once the welding is completed, the trench either side of the tie-in weld will be backfilled to support the pipe, leaving 2 – 3 pipe lengths exposed for later weld inspection and joint coating.

2.3.10 The Tie-In Process: Weld Inspection

The weld is inspected as soon as possible after the welding process is completed. Ultrasonic inspection of the welds is often employed as it gives immediate feedback. Radiographic inspection is also used but usually takes 24 hours to produce results due to developing times. Different contractors have their own preferences for which method to employ for weld inspections. Ultrasonic inspection can give a result within 10 minutes.

2.3.11 The Tie-In Process: Joint Coating

Final coating of the joint takes place after satisfactory completion of the weld inspection. Various types of coating are used: spray applied polymers, tar/urethane, heat shrink sleeves and cold applied fusion bonded epoxy of which there are many different types. As an example for two pack epoxy coatings it may take between 20 minutes to 1 hours to sand blast the joint area, 20 minutes to apply the first coat but then a curing time of 4 hours may be required prior to applying the second coat. Final inspection of the applied coating is also required.

2.4 System Requirements for Automated Tie-In Technology

The primary requirement of an automated tie-in machine is to increase productivity from 1 to 2 tie-ins per day to 4 to 5 tie-ins per day, with a reduced man power utilisation and a similar reduction in the capital value of employed equipment. The table below describes the requirements of a "Tie-In Machine"

	Activity/Equipment	**System Requirement**
1	Overall	Must be a self contained single vehicle
2	Ancillary/support equipment (if required)	e.g. Crane/backhoe etc. must be mobile or at least require no de-rigging for transport
3	Pipe manoeuvring	Remove the need for side booms during tie-in crew operations. Possibilities: Separate major pipe manoeuvring from accuracy of cutting and alignment Changes to upstream operating
4	Pipe measurement	Accurate method for setting cut positions to remove the necessity for repeated dressing and re-dressing of the pipe ends.
5	Pipe cutting	Method for facing off and forming weld preparation as a single operation to the accuracy required by the welding method! Pipe ovality must be adjusted.
6	Alignment and Clamping	External clamping arrangement for accurate alignment and ovality correction. Possibly also providing a facility for gap adjustment.
7	Weld pre-heat	Induction heating system
8	Welding	Automated welding system has yet to be fully developed for reliable automated welding of an externally applied root pass
9	Weld inspection	Phased array AUT
10	Joint coating	Utilise existing equipment after removal of the tie-in machine.

Table 2-1: System Requirements

2.5 An Outline Concept for New Tie-In Technology

Line-pipe is traditionally supported and manoeuvred using 2 or 3 side booms throughout the tie-in operation, or at least until sufficient weld material has been deposited. The elimination of side booms from the Tie-In process would provide economic benefits. An automated tie-in machine must have the capability to effect small pipe positional adjustments for alignment and weld gap adjustment. It is likely that attempting to incorporate this capability for carrying out major pipe manoeuvring within the tie-in 'machine' ,such as that required, would lead to the 'machine' becoming too large and unmanageable. The principal pipe alignment operation will need to be separated from the marking and cutting process.

The most appropriate method of achieving this is to allow a gap between the pipe ends so that the pipe ends can be roughly aligned in advance to within tolerances the tie-in 'machine' could easily handle. This will result in the insertion of a spool piece with two welds, instead of the traditional single weld.

If one pipe end needs cutting back to prevent it overlapping the other this would only need to be done with a rough flame, requiring little precision. The tolerance for the target gap will be between 0.5 D and1.5 D. The adopting of this standardised design/concept for the tie-in 'machine' will also allow the installation of Tee pieces (for new connections) and valves into existing lines. Pipe ends will need to be roughly aligned in advance of the main tie-in operations. It is likely that the preliminary alignment could be carried out by the lowering-in crew given appropriate positioning templates/guides/framework. It is assumed that the requirement for hydrotesting will remain and unless an in-line design of hydrotest head can be developed then there will still be situations where the line-pipes will be left overlapping by the lowering-in crew. For this situation it is feasible for a separate cutting and aligning crew to be utilised to remove the test heads and align the pipe ends, again with the aid of an appropriate positioning template/guide.

2.5.1 The Development of Concepts for Tie-In Technology

An outline concept for the system has therefore been generated on the assumption that construction contractors will require a self contained vehicle that deploys a 'machine' onto the roughly pre-aligned pipe ends, or continuous pipe in some cases, that once in position effects final accurate alignment and then becomes the framework for carrying out all necessary operations to complete the welds and final weld inspection. The productivity improvements should be self evident providing consequential cost reductions in manpower and equipment costs.

The following series of sketches demonstrate this outline concept, shown on a continuous pipe but equally applicable for installation on 2 roughly aligned pipe ends. The tie-in process will not allow the use of internal clamping arrangements so the concept is based on external clamping arrangements. The external clamp ('clam shell' or split frame type) will serve to align and squeeze the pipe ends using hydraulic rams to compensate for any relative 'out-of-round' or ovality between the pipe ends, thus allowing for the possibility of automatic welding. At the same time the clamps will grip the pipe to provide longitudinal pipe movement forcing them together, or apart, to the desired tolerance. This might be achieved by the use of tapered gripper segments located between a pair of tapered rings that when forced together (hydraulically) apply the necessary gripping and centralising force. The forces required for these clamping and alignment processes are feasible within the dimensions and scale of the equipment under consideration. The gripping force can be applied to the pipe ends to force apart, if necessary, to aid the insertion of a spool piece, without over stressing the pipe. By incorporating tie bars between two such clamps with secondary sliding clamps/tool carriers mounted inboard off the tie bars then a possible concept for a tie-in machine begins to develop.

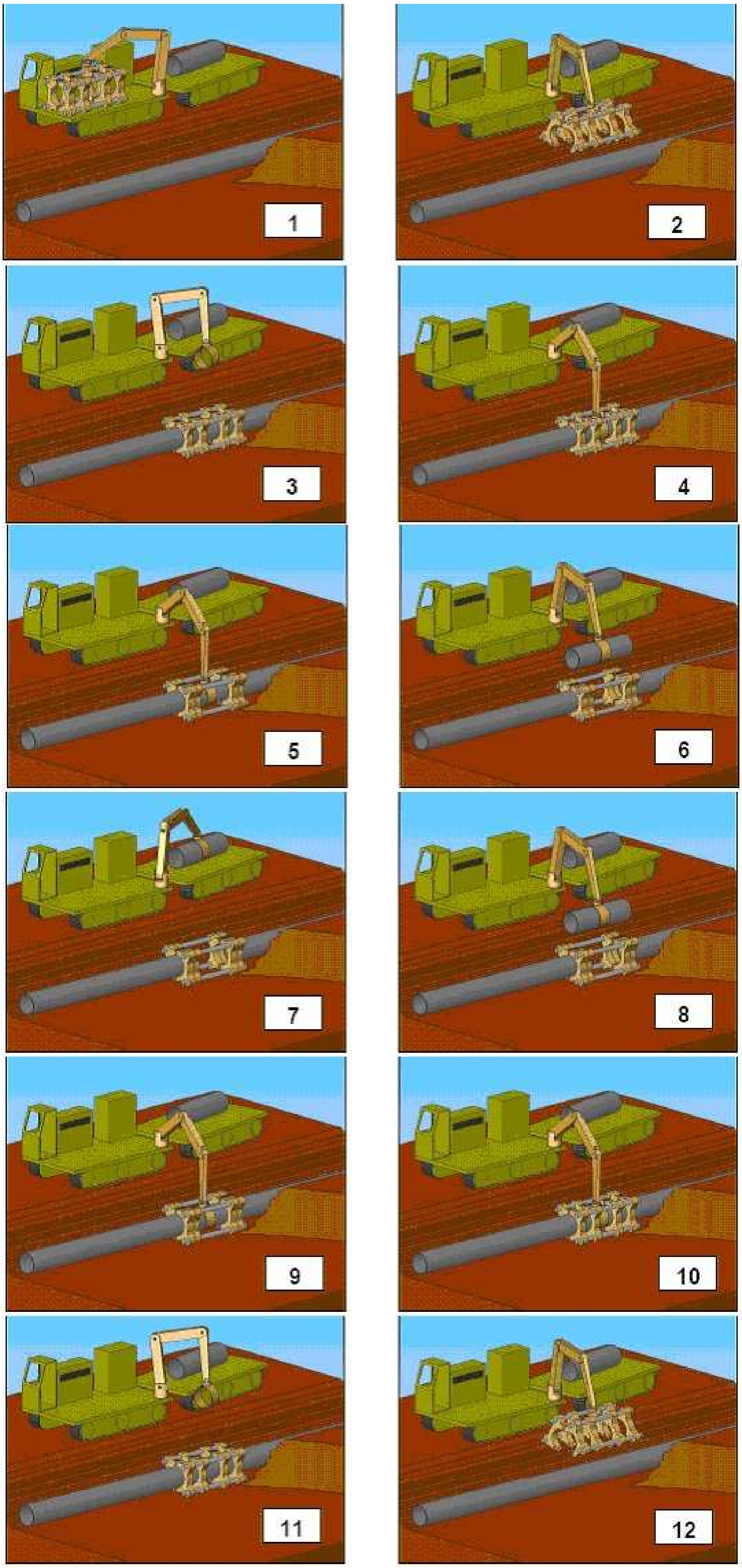

Figure 2-6: Outline Concept

2.5.2 Option Selection

To find the right way for further developments different euipment options were identified and evaluated.

1. PRE-ALIGNMENT		
Givens	Machine will require pre-alignment of the pipe ends Out-of-line tolerance =100mm in any direction. Angular tolerance = 3°	
Options	Notes	For Further Investigation
Cradle/template	Re-usable	Yes
Skilled workforce to Lay accurately	Skill levels What if they get it wrong?	No
Not required - Do it later at tie-in	Large lift capacity required at tie –in	No
Cradle Option	Timber frame	No
	Shape/profile soil	No
	Steel frame or clamp above pipe: Possibly assisted by applying padding under pipe or- Possible air bag arrangement	Yes Maybe Yes
	Steel frame below pipe (needs to be recoverable)	Yes
2. Cutting Back of Coatings		
Givens	Assume that existing pipe coating must be removed in the area where the tie-in machine fits.	
Options	Notes	For Further Investigation?
Do at time of tie-in Machines available	Review available equipment	Yes
Attach to backhoe	Develop concepts	Yes
3. CLAMPING AND FINAL ALIGNMENT		
Givens	The machine and clamps must integrate with any pre-alignment arrangements in place.	
Options	Notes	For Further Investigation?
'Top claw' clamp	2 halves with single central hinge	Yes
'Strong back' clamp	2 hinged sides off central spine	Yes
Double shells	Lose accuracy and precision	No
Double shells in strong frame	Machine would become very large	No
4. CUTTING AND FACING		
Givens	Centreline becomes datum (Referenced to OD). No internal steps. Needs to be flexible to aloe different weld prep profiles to suit different/future welding processes. Final required weld prep profiles will be dependent on the welding process and the methods employed to overcome pipe tolerancing issues.	
Options	Notes	For Further Investigation?
Cutting Systems (including profiling)	Burning	No
	Water jet	No
	Laser	No
	Mechanical - Lathe style	Yes
	Mechanical – Milling style	Yes
	Review existing mechanical systems for incorporation/development	Yes
5. PRE-HEAT		
Givens	Pre-heat is required. Induction systems will be used.	
Options	Notes	For Further Investigation?

'Static' Induction Systems	Induction cable blanket (wrap around pipe)	Maybe
	Braced copper clamp/band (very low profile)	Yes
	Larger clamp coil	Yes
Mobile Induction system	Induction head traveling in front of welding head. Review with equipment suppliers	Yes
6. WELDING		
Givens	Laser welding is not an option at this stage. Achieving a root pass is critical. Weld quality, repeatability and reliability are the driving factors, speed is secondary.	
Options	Notes	For Further Investigation
Root pass	Manual (stick) – For prototype only	Yes
	Hand held dun (wire feed)	No
	Automatic STT, TIG Further review latest development	Yes
Hot/Fill/Cap passes	Manual (stick)	No
	Hand held dun (wire feed)	No
	Automatic DMAW	Yes
7. TESTING		
Givens	Testing is required – 100% testing. Ultrasonic Testing – Phased array. Integrated into tie-in equipment system	
Options	Notes	For Further Investigation?
	Talk to specialist companies	Yes
	Investigate remote data transfer	Yes
	Test response speed – Time required for ECA/answer	Yes
	Use E.ON Ruhrgas experience	Yes
8. RE-COATING		
Givens	Tie-in machine must be removed first. Pipe is in trench. System must be flexible.	
Options	Notes	For Further Investigation?
	Talk to specialist companies and review options for Completeness	Yes

Table 2-2: Option Selection

2.6 Results

Line-pipe is traditionally supported and maneuvered using side booms throughout the tie-in operation, or at least until sufficient weld material has been deposited. An automated "Tie-In Machine" must have the capability to effect small pipe positional adjustments for alignment and weld gap adjustment. The principal pipe alignment operation was separated from the marking and cutting process. The most appropriate method of achieving this is to allow a gap between the pipe ends so that the pipe ends can be roughly aligned in advance to within tolerances the tie-in machine could easily handle. This will result in the insertion of a spool piece with two welds, instead of the traditional single weld. The adopting of this standardised concept will also allow the installation of Tee pieces and valves into existing lines.

Another result is that construction contractors require a self contained application that deploys a "machine" onto the roughly pre-aligned pipe ends, or continuous pipe that once in position effects final accurate alignment and then becomes the framework for carrying out all necessary operations to complete the welds and final weld inspection. The tie-in process does not allow the use of internal clamping arrangements. Thus an external clamp will serve to align and squeeze the pipe ends using hydraulic rams to compensate for any relative 'out-of-round' or ovality between the pipe ends, thus allowing for the possibility of automatic welding. At the same time the clamps will grip the pipe to provide longitudinal pipe movement forcing them together, or apart, to the desired tolerance. This is achieved by the use of tapered gripper segments located between a pair of tapered rings that when forced together apply the necessary gripping and centralising force. The gripping force can be applied to the pipe ends forcing them apart to aid the insertion of a spool piece, without over stressing the pipe. tie bars fixed between two such clamps with secondary sliding clamps will carry the tools required for measurements, machining, and welding.

2.7 Conclusions

The objectives of the first project step were to demonstrate the feasibility of a largely automated Tie-In process, confirm the cost reduction expected from the automation of Tie-In and develop a conceptual design ready for detail component design.

The second project step aim at the final design of the Tie-In machine in close cooperation with a manufacturer of pipeline laying equipment, who is prepared to produce, market and use the device.

BP and E.ON Ruhrgas have decided to work openly with suppliers, contractors and other operators to promote innovation and seek technology development opportunities. It was also realised that this objective could not be achieved by a single innovation. It would require incremental change in a number of areas. As a consequence, breakthrough developments in design practices, materials, welding and construction practices formed a portfolio of developments of which the “Automated Tie-In Project” forms part. The work undertaken to date provides significant evidence of cost saving potential, whilst at the same time providing a step improvement in environmental impact and operational safety performance

The study has shown that the automated tie-in process is a feasible option with associated economic benefits. Over the next years, the project will move to a development stage which will include the detail design and manufacture of a detailed prototype, culminating in field trials prior to market commercialization. BP and E-ON Ruhrgas will work jointly on the development if this technology along side selected commercial partners.

3. Authors

Main Author:

Dipl.-Ing. Peter Schwengler

E.ON Ruhrgas AG
Pipelines Competence Centre
Halterner Straße 125
46284 Dorsten
Germany
Tel.: 0049-2362-93-8844
e-mail: Peter.Schwengler@eon-ruhrgas.com

Co-Author:

Graham Freeth

BP Exploration
Building C
Chertsey Road
TW16 7LN Sunbury on Thames
Middlesex UK
Tel.: 0044-1932-764014
e-mail: FreethG@uk.bp.com

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5. List of Tables and Figures

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