19th Century French Scientific Instrument Makers

XII: Louis Clement François Breguet and Antoine Louis Breguet

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Fig.1 *Louis Breguet. (From: L. Figuer,* Les merveilles de la science *(Paris, 1868), vol. 2, p. 125).*

The name Breguet is synonymous with technical excellence and supreme elegance in the world of horology. In fact, the Swiss-born Abraham Louis Breguet (1747-1823) was one of the most inventive and skilful clock and watchmakers of his time, and his life, as well as his work, has been extensively studied.[1] At the death of Abraham his firm survived and the production of outstanding clocks, chronometers and watches continued, but during the 19th century Abraham's successors successfully diversified their interests and played a new and very important rôle as scientific instruments and electrical apparatus makers in France. In this paper I will outline the history of Breguet's activity in this particular field of industry.[2]

Abraham Louis Breguet was a superb clock and watchmaker but, apart from a few exceptions, he was never really concerned with the construction of scientific instruments. On the other hand it is true that, as far as scientific research and precision measurements were concerned, he produced several magnificent astronomical regulators and marine chronometers, and in 1802 a special chronometric eyepiece for meridian instruments, which allowed one to determine the passage of a star with a precision of 1/10th of a second. At the end of the 18th century the son of Abraham, Antoine-Louis Breguet (1776-1858), started to work in the family workshop, after having spent sometime in London with the clockmaker John Arnold (1736-1799). At the beginning of the 19th century Abraham and Antoine were associated with the name *Breguet et Fils* at the quai de l'Horloge in Paris.[3] Antoine inherited the firm in 1823, but he personally looked after the family business for only 10 years. He was more interested in living in his country house, therefore preferring to supervise the activities from afar, and in 1833 he sold the firm to his son Louis Clément François.[4]

Louis Clément Breguet (1804-1883) was the natural son of Antoine and Jeanne Françoise Venture de Paradis (1774-1813), who married only in 1811. At the age of eight Louis Breguet had been sent to his godfather in Neuchâtel (Switzerland), where he stayed for eight years. Back in France he began to work under the strict supervision of his father. His biographers say that he had to stay in the workshop from 5.30 a.m. to 10 p.m. every day, including Sunday! After an apprenticeship in Versailles with the old mechanic and watchmaker Abram Louis Perrelet (1729-1826), he went to Geneva in 1824, where he worked with the clockmaker Barral until 1827, when he came back to Paris. His father entrusted him with the construction of marine chronometers. Louis (Fig.1) improved the counters for recording *pointage* for astronomical use. At the time he was able to follow the suggestions and the encouragement of a family friend the physicist and astronomer François Arago (1786-1853), and he attended as a day pupil some courses of the *École Polytechnique*, where he improved his physics and mathematical knowledge. In 1833 Louis Breguet married Caroline Lassieur (1815-1889), the daughter of Louis Lassieur (1785-1850), a nephew of Abraham Breguet and director of Breguet's workshop. They had two daughters and a son Antoine (1851-1882), who became assistant and collaborator to his father. In the same year Louis's father retired and sold for about 270.000 francs the *Breguet et fils* to the new company *Breguet neveu et Cie*, a partnership formed by Louis Breguet, Louis Lassieur and a certain Tredos, the accountant.

Louis was able successfully to develop a series of new activities. His scientific curiosity and his interests in the field of electricity pushed him to undertake the construction of physical and electrical instruments, while the production of precision clocks and chronometers was left under the responsibility of a *chef d'atelier*. Louis first improved the metallic thermometer (Fig.2), which had been

Fig.2 *Breguet's metallic thermometer (From:* Catalogue Breguet *(Paris, 1877), p. 49).*

proposed by his grandfather Abraham at the beginning of the century, and were often built in his clocks. This type of thermometer was composed of a helical trimetallic strip (platinum, gold and silver). The different dilatation of the metals produced a rotation of the strip which carried a pointer.[5] In 1841 Louis Breguet proposed a thermometrograph, which combined a metallic thermometer and a clockwork. The instrument punched a hole in a rotating disk thus recording the temperature every hour.[6] One of these instruments was installed in the observatory of Kazan (Russia). In 1843 Breguet was elected *artiste adjoint* to the *Bureau des longitudes*, in the same place occupied by his grandfather Abraham, and he became *artiste* in 1847 after the death of Henry Prudence Gambey (1787-1847).

Louis Breguet's first important and original scientific work was the 1841 research concerning electrical induction phenomena and electrical discharges in rarefied gases, which he carried out together with the physicist Antoine Masson (1806-1860). For their experiments Louis Breguet made a kind of big induction coil and a multiple wheel rheotome.[7] This apparatus was a forerunner of the classical Ruhmkorff coil, which was developed in the 1850s.

In 1844 Breguet constructed, together with the Russian artillery officer Konstantinoff, a special instrument to measure the varying speed of projectiles during their trajectories.[8] It was a special chronograph which was connected to a series of electric circuits and relays. The circuits were subsequently broken by the projectile and the different times were

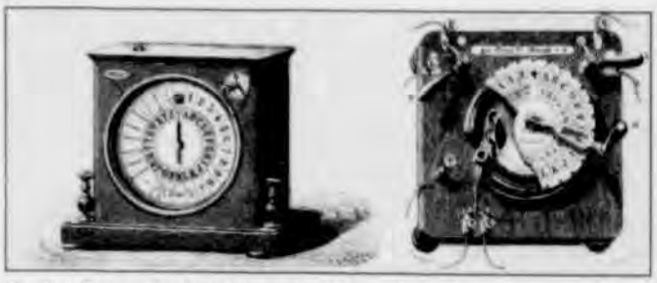

Fig.3 *Breguet's dial telegraph (From:* Interdisciplinary Science Reviews, op.cit., *note 1, p. 158).*

recorded by the special chronograph. This instrument aroused a dispute between Breguet and Charles Wheatstone (1802-1875), who claimed priority. In the same year at the national exhibition held in Paris, the firm Breguet displayed several instruments (thermometers, thermometrographs, psicrometer) together with watches, clocks and chronometers.[9]

In the 1840s Arago, the director of Paris Observatory, conceived an experiment for comparing the speed of light in air and in water.[10] The results would make it possible to determine whether light had a corpuscular or undulatory (wave) nature. In Arago's experiment, a portion of a light beam produced by an electric spark would pass through a tube of water while the other portion would pass through air. Then the rays had to be reflected by a fast rotating mirror and the slower one would be reflected at a greater angle.[11] Arago asked Breguet to build the necessary apparatus. The maker first proposed an instrument with three rotating mirrors which could achieve a speed between 1000 and 2000 r.p.s.(the axle without the mirror could reach 9000 r.p.s.). The mirrors were driven by helicoidal gears which would assure a smoother and more constant running. A special tooth-cutting machine for this kind of gears was devised by Breguet. For this machine tool he was awarded in 1843 a silver medal by the *Société d'encouragement pour l'industrie nationale.*[12] Because of the loss of light due to multiple reflections it was decided to use a faster rotating single mirror apparatus, but because of the declining health of Arago the project had to be interrupted. A few years later in 1849, the physicists Hyppolite Fizeau (1819-1896), who had measured the speed of light in air with his famous toothed wheel system, and Léon Foucault (1819-1868) separately raced to complete Arago's original experiment. Foucault worked with Gustave Froment (1815-1865),[13] while Louis Breguet was the collaborator of Fizeau, who was using the rotating mirror used by Arago. Foucault finished his experiment a few weeks earlier than Fizeau and the result of this research proved to be incompatible with the corpuscular theory of light. But Breguet involvement with this kind of experimental research did not end. In 1874 he built for the physicist Alfred Cornu (1841-1902) an improved toothed wheel apparatus which was used to determine the speed of light between the Paris Observatory and the tower of Monthléry (about 23 km). In this latter instrument the speed of the wheel (about 1600 r.p.s) was electrically recorded on a revolving drum. This made it possible to control small variations.[14]

Louis Breguet, who was extremely interested in electrical phenomena as well as in the practical applications of electricity, was a pioneer in the development of electrical telegraphy in France.[15] France had in the 1840s an important network of Chappe's optical telegraphs and therefore the government tended to support this well established system and showed a certain resistance to adopting a new technology.[16] But in 1844 a special commission stated that it was necessary to build an experimental line of electric telegraphs, which, by this time, was growing faster in England, USA and Germany. At the beginning it was decided to adopt a mixed system of optical and electrical telegraph and in 1845 the *Administrateur en chef des télégraphes* Alphonse Foy asked Breguet to developed a special 2-needles telegraphic apparatus, which could transmit the same kind of signal as the Chappe's telegraph. With this system the operators of the optical telegraph could be directly reemployed, without needing any lengthy retraining for the new electrical apparatus. The first line was installed between Paris and Rouen in the same year and in 1846 the connection between Paris and Lille was opened. But the 2-needles system was not really practical for electrical telegraphy and it was abandoned after a few years. Because of his work in this field Louis Breguet became *Chevalier de la Légion d'Honneur.* In 1846 Breguet improved the dial telegraph (Fig.3), which had been originally introduced by Wheatstone. The transmitter was composed of a crank which was moved around a dial with the

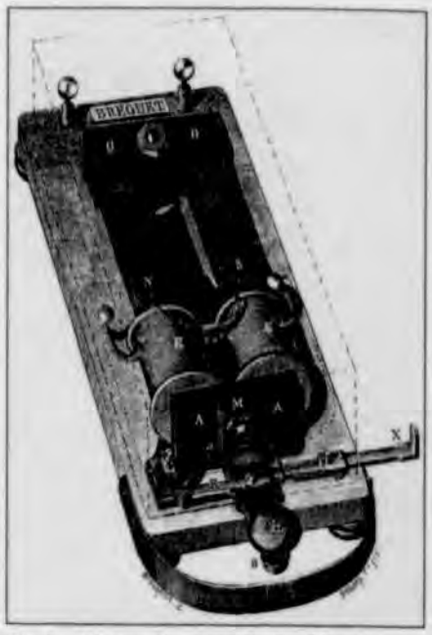

Fig.4 *'Breguet's punch' for blowing up detonators. (From:* Catalogue Breguet *(Paris, 1877), p. 74).*

letters and the number on it. Each step of the crank sent a pulse of current through the line. In the receiver the pulses controlled an electromagnetic escapement which was connected with a pointer rotating on a second dial. Also in 1846 Breguet, who had several apparatus damaged by lightning, invented a special telegraphic lightning protector, which was widely adopted.[17] In 1849 he proposed a portable railroad and army telegraph, which included in a compact box all the elements of his dial telegraph. In the following years many other types of telegraphs (Morse, printing, etc.) were produced by the firm.

Breguet also made various experiments concerning electric currents and signals sent through telegraphic lines and speed of sound in metallic wires.[18] In these years Breguet developed a series of railroad electric signalling apparatus. Among them there was an apparatus to signal the passage of a train near telegraph masts as a means of indicating the position of the train. In 1851 Breguet, published his *Manuel de Télégraphie* which one of the first and most important practical treatises published in France on this topic.

In 1850, with the death of Lessieur the *Breguet, neveu et Cie* became simply *Maison Breguet.* About at the same time Breguet opened a new workshop at 81, boulevard Montparnasse.[19] The firm employed about 55 worker, and in 1854 Alfred Niaudet (1835-1883) a nephew of Louis, who later became one of the most important collaborators of the firm, started to work for Breguet. The con-

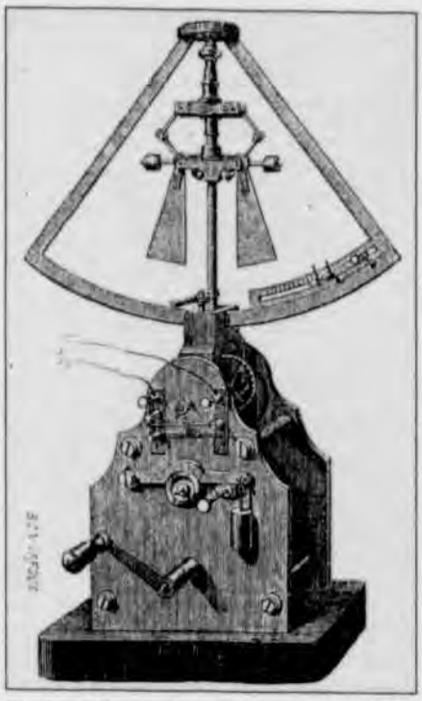

Fig.5 *Villareceau's isochronous regulator made by Breguet (From:* Catalogue Breguet, *(Paris, 1877), p. 130).*

struction of electromechanical apparatus was taking a more and more important role in Breguet's activities, while the production of mechanical clocks was neglected. In fact, in 1867 the manufacture of clocks and watches was sold outright to Edward Brown (1829-1895), who for several years had been Breguet's *chef d'atelier*. Brown's successors continued the horological tradition of Breguet in the 20th century.

In the late 1860s Breguet invented a very powerful apparatus for exploding mines by means of a powerful electric spark.[20] This device (Fig.4), which became known as *coup de poing* or *poing de Breguet*,[21] consisted of a powerful horse-shoe magnet with coils on its poles. A movable iron anchor cold be suddenly taken away from the poles, thus producing a rapid change in the magnetic field which induced a strong high tension current in the coils. With this apparatus it was possible to blow up mines at a distance of several kilometres. An experiment demonstrated the possibility to fire from Paris a detonator which was placed in Bordeaux (about 580 km).

Clock making was not the main interest of Louis Breguet, but he did develop the use of electricity in time keeping.[22] In 1856 he proposed an electric *remontoir* clock. In it, a spiral spring connected with the escapement wheel and with a ratchet wheel was periodically stretched by the action of an electromagnet. At the same time he installed in the town of Lyon a series of electric slave clocks connected with a master clock in the *Préfecture*. These clocks were set on gas lanterns so that their dials were lit up at night. Around 1859 he also invented an electrically controlled hour-setting system for synchronisation of distant clocks. Finally, in the second half of the 1870s Breguet contributed to the setting up of a public time distributing system, which from a master-clock in the observatory in Paris controlled a series of pendulum clocks in different series of *centres horaires*. The latter were driving a larger number of slave clocks in the town.[23]

Around 1870 Louis Breguet also made the first isochronous governor (Fig.5), which had been proposed by the engineer and astronomer Antoine Joseph François Yvon Villareceau (1813-1883). These were used in the driving mechanism of large equatorial telescopes.[24] At the same time Breguet was improving and manufacturing several pieces of apparatus, which were conceived by the physiologist (and later 'moving images' pioneer) Etienne Jules Maray (1830-1904).[25] Among them, were sphygmographs, kymographs, cardiographs, various recording instruments and the pneumatic sensor and reception mechanisms based on a capsule closed by a rubber membrane. At the 1873 Vienna Universal Exhibition the firm Breguet displayed for the first time Maray's instruments together with his more typical products. Breguet, who between 1830 and 1880 was granted about 80 different patents, also made and improved a large series of laboratory instruments (such as special electromagnets, a sinus galvanometer, and a rheostat) and industrial apparatus such as an electromechanical manometer and a gas flow regulating system. As far as domestic uses of electricity were concerned Breguet's firm produced a series of bells, switches, signal system for the domestic staff, and even an electric billiard pool point marker! Finally in 1874 Louis Breguet, like his grandfather before him, entered the French *Académie des Sciences* and four years later he became *Officier de la Légion d'Honneur*.

Antoine Breguet, always worked in strict collaboration with his father Louis. After having attended the *Lycées Saint-Louis et Bonaparte* he enrolled to volunteer in the army in the Engineers Corps and he participated in the siege of Paris. At the end of the Franco-Prussian war he entered the *École polytechnique* and finally in late 1874 he started to work in the family business. Full of energy in spite of poor health, Antoine was not only interested in scientific research but was keen to modernise and transform the products of the firm. He , too, had a deep

Fig.6 *The Headquarters of the* Maison Breguet *in quai de l'Horloge (From:* Le Génie Civil, op. cit., *note 1, p. 334).*

interest in electricity and its applications, which led him to develop several apparatus.[26]

In 1877 Antoine Breguet presented in Paris the first telephones of Alexander Graham Bell (1847-1922) and he soon started to experiment and to manufacture these new devices.[27] It seems that the first working telephonic apparatus in France was installed at the quai de l'Horloge, which was the headquarters of the firm (Fig.6) as well as the workshop for the production of scientific instrument and measuring apparatus. In the 1880s this workshop was equipped with a 2HP gas engine, which powered a series of light machine-tools.

Breguet also manufactured several other types of telephones, which were used in France at the end of 19th century. In October 1880 Antoine met Bell in Paris. The American inventor proposed a new apparatus to Breguet, the photophone, which he had invented together with Charles Sumner Tainter (1854-1940). Immediately Antoine made several experiments with the photophone.[28] The apparatus (Fig.7) was based on the peculiar proprieties of selenium, whose

Fig.7 *Bell's photophone made by Breguet. (From:* La Nature, op. cit., *note 28, page 345).*

Fig.8 *Laboratory ring armature dynamo with Jamin magnet made by Breguet (From:* Catalogue Breguet *(Paris, 1877), p.139).*

electrical resistance varies with illumination. A beam of light was reflected by a membrane vibrating under the influence of sound. The modulated rays were then directed to a receiver with a selenium photocell connected with a microphone. But in spite of the successful experiments the photophone never had any practical use.[29] In the late 1870s Breguet's firm was also producing the capillary electrometer. This instrument had been invented by the physicist Gabriel Lippmann (1845-1921), who had studied the influence of an electromotive force on the capillary forces between two liquids.[30] In 1879 Antoine Breguet proposed a special mercury telephone, which was based on the above-mentioned capillary effect.[31]

In the 1870s Antoine became interested in the dynamo of the Belgian inventor Zénobe Théophile Gramme (1826-1901).[32] Because of its ring armature it was the first practical and efficient generator. This machine was also reversible and therefore could be used as an electric motor. Antoine carefully studied the theory of Gramme's dynamo and was able to acquire a licence for its manufacture.[33] The firm started the industrial production of this machine in connection with electric arc-light. For laboratory use he developed a special Gramme demonstration machine with a Jamin laminar magnet (Fig.8). These machines were produced in a new workshop on the rue Montmartre.

In 1881 a large electricity exhibition took place in Paris. The old Louis Breguet was on the organising committee but his son Antoine as very active *Chef du service des installations* was one of those responsible for the success of this event. For his work Antoine became *Chevalier de la Légion d'Honneur.* It was a triumph for Breguet's firm, which displayed a large number of apparatus in almost every class and group of the exhibition. Telegraphs and ancillary equipment, electric signals, electrical measuring instruments, electrochemical piles and accumulators, dynamos, telephones, chronographs, electric clocks, fire alarms, and several other pieces of apparatus on Breguet's stands were among the most important in the exhibition. At the end of the same year Louis Breguet sold the firm to Antoine for 330,000 francs, and the *Société Anonyme Maison Breguet* (always at the 39, rue de l'Horloge) was founded. Antoine was the director of the new company which started to expand by building two new factories in rue Hippolyte-Maindron and in rue Didot (Fig.9) (at the time the workshop in rue Montparnasse had become too small for the industrial production of heavy electrical machines). After 1880 Antoine became director of the *Revue Scientifique,* at the time he was also a leading member of the *Société de Physique,* highly appreciated for his brilliant public lectures.[34]

But Antoine, whose weak health was probably endangered by his help with organising the 1881 exhibition died of tuberculosis in June 1882. His father Louis died a year later aged 79, and because of these losses and also because of a general economic crisis, the firm had to survive a difficult period. But at the end of the 1880s the production of lighting systems and electric projectors for the navy (Fig.10) and of dynamo machines became more and more important. The prosperity of the firm at the end of the century was assured by the construction of turbines Laval-Sosnowski. At the end of the 1880s the workshop of the rue Didot, which was devoted to the production of telegraphic, telephonic and signalling apparatus as well as of dynamos and lighting equipment, had a surface of 3500 square metres. The main steam engine had a power of 180 HP and moved about 130 machine tools of various types. A woodwork and a coil winding workshop completed the factory. At this time about 250 peoples worked for the *Maison Breguet.*

Fig.9 *Breguet's factory in rue Didot at the end of the 1880s (From:* Le Génie Civil, op.cit., *note 1, p. 347).*

In the second half of the century the firm successfully participated in the most important national and universal exhibitions both in France and abroad, exhibiting the best of its products not only in the fields of electricity and telegraphy, but also their physics, meteorological instruments and experimental physiology instruments.[35] As usually happened with firms which distinguished themselves with the excellence of their products, they often participated to the exhibitions *hors concours*. Breguet's firm published at least three large illustrated catalogues (1875, 1877, 1883) and several leaflets in the second half of the 19th century. The fact that they are trilingual (French, English and German) indicates the international importance of the company, which exported at least 30% of its production.

In 1898-99 a new factory in Douai (in the north of France) was built, and the firm also presented several large and powerful machines (turbines, dynamo, etc.) to the 1900 Paris exhibition.[36] The production of telegraphic, telephonic equipment and electrical instruments continued for a few years but the most important activities of the firm were more and more directed to the heavy electromechanical industry. In the 20th century two sons of Antoine Breguet, Louis (1880-1955) and Jacques (1881-1839), played a major role in the development of the French aircraft industry, but that is another story.

The work of Louis and Antoine Breguet in the field of scientific instruments and electrical technology had been really impressive. Not only did they invent or improve a large number of devices, but they were also able to transform several laboratory instruments into practical and efficient apparatus which became part of every-day life. Breguet's constant activities both in scientific research and in industrial development (with telegraphs, telephones, dynamos, etc.) made the firm one of the most important links between science and electrical technology in France. The story of Breguet's family (which I have only traced for the period between *circa* 1840 and 1890) from clock making to electromechanical (and later the aeronautic) industry, is therefore also an illustration of the evolution which transformed a craftsmanship tradition into engineering and entrepreneurial activities. This often difficult transformation was largely due to the inventiveness, energy and restless enthusiasm of the Breguets.

Today the richest collection of instruments and apparatus made by Breguet can be seen in the collections of the *Conservatoire nationale des Arts et Métiers* in Paris.

Next to come (last but not least): Soleil, Duboscq, Pellin

Notes and References

1. A modern and very detailed book concerning Abraham Breguet's work is G. Daniels, *The Art of Breguet* (London, 1975).

2. The most important sources concerning the life and work of Louis and Antoine Breguet are: L. Breguet, *Notice sur les travaux de m. L. Breguet* (Paris, 1847); G. Tissandier, 'Antoine Breguet Nécrologie', *La Nature*, II semestre (1882), p. 102; H. Delsandres, 'Antoine Breguet', *Revue Scientifique*, III série. **3** (1882), pp. 129-132: G. (Cloué. 'Discours prononcé sur la tombe de M.Breguet'. *Bulletin de la Société d'encouragement pour l'industrie nationale*, III série, **9** (1884), pp. 20-22, E. De Jonguières, 'Notice sur la vie et le travaux de Louis François Breguet', ibid., IV série, 2 (1887), pp. 404-411; E. Ferret, *Les Breguet* (Paris. *circa* 1910). C. Breguet 'La maison Breguet', *Annuaire pour 1962 de la Société historique de XIX Arrondissement*, pp. 6592; C. Breguet, 'The Breguet Dynasty', *Interdisciplinary Science Reviews*, **5**, no. 2 (1980), pp. 149-164. C. Breguet, 'Louis Breguet constructeur de télégraphes électriques'. *Dilegence d 'Alsace*, **28** (1983), pp.20-31. Several bits of information about Breguet's workshop can be found in A. Soubeyran, 'Exposition universelle de 1889. La maison Breguet'. *Le Genie civil*, Premier semestre, **14** (1888-1889), pp. 334-341.

3. During the 19th century several makers had their workshops in quai de l'Horloge (Ile de la Cité).

4. Nevertheless Antoine did not abandon his scientific interests, but he followed his son's activities and it seems that he continued his experiment in his private scientific 'cabinet'.

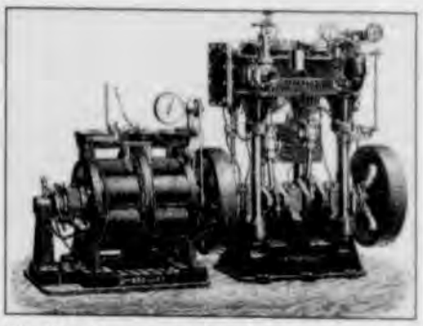

Fig.10 *Steam engine and dynamo made by Breguet for the French Navy (From:* Le Génie Civil, op.cit., note *1, p. 341).*

5. W.E. Knowles Middelton, *A History of the Thermometer and Its Use in Meteorology* (Baltimore, 1966), p. 171; Breguet (père et fils), 'Nouveau thermomètres métalliques', *Annales de chimie et de physique*, **5** (1817), pp. 312-315, Prony, *Instruction sur le thermomètre métallique de MM Breguet père et fils* (Paris, 1821); L. Breguet, 'Phenomène de dilatation observé sur le thermomètre Breguet', *Annales de Chimie et de physique*, III série, **3** (1841), pp. 506-507. The trimetallic strip was better than the bimetallic one because it could cope better with the deformations.

6. 'M.Breguet fils presente un thermomètrographe de son invention', *Comptes Rendus de l'Académie des Sciences*, **11** (1841), p. 24.

7. A. Masson and L. Breguet, 'Mémoire sur l'induction', *Annales de physique et de chimie*, III série, **6** (1842), pp. 129-152 and also by of the same authors 'Recherche sur l'induction', *Comptes Rendus de l'Académie ds Sciences*, **13** (1841), pp. 426-427. This original apparatus is nowadays preserved in the historical collection of the *Lycée Louis le Grand* of Paris.

8. L. Breguet, 'Note sur un appareil destiné à mesurer la vitesse d'un pojectile dans différents points de sa trajectoire', *Comptes Rendus de l'Académie des Sciences*, **20** (1845), pp. 157-162 and 'Rapport sur un passage qui se rapporte à cette communication, dans une note de M.Wheatstone sur le chronoscope électromagnétique', ibid., pp. 1712-1713. See also Th. Du Moncel, *Exposé des application de l 'électricité*, 3rd ed. (Paris, 1872- 1876), vol . 4, pp. 211 -213.

9. See *Produit de la maison Breguet Neveu et Cie-Exposition de 1844* (Paris, 1844).

10. The experiments concerning the measurements of the speed of light in the mid-19th century as well as a large bibliography on the subject can be found in W.Tobin, 'Toothed Wheels and Rotating Mirrors: Parisian Astronomy and Mid-nineteenth Century Experimental Measurement of the Speed of Light', *Vistas in Astronomy*, **36** (1993), pp. 253-294 and also in 'Comment on a reussi à mesurer la vitesse de la lumière', *Les Cahiers de Science et Vie*, 25, February 1995.

11. The rotating mirror for measuring speed of electricity was first proposed by Charles Wheatstone in 1834.

12. See Calla, 'Rapport sur un appareil propre à tailler les dents en engranages hélicoïdes, de MM Breguet fils et Bouquillon', *Bulletin de la Société d'encouragement pour l'industrie nationale*, **42** (1843), pp. 331-337; 'Extrait d'un mémoire de MM Bréguet fils et Bouquillon sur de nouvelles dispositions mechaniques ayant pour objet l'execution des engranages hélicoïdes de White, sous tous les angles et pour toutes les formes de denture'? ibid., pp. 457-464.

13. P. Brenni, 'Paul Gustave Froment', *Bulletin of the Scientific Instrument Society*, no. 45, 1995, pp. 19-23.

14. A. Cornu, 'Determination de la vitesse de la lumière entre l'Observatoire et Montlhéry', *Annales de l'Observatoire de Paris-Mémoires*, **13**, pp. A.l-A.315; A.Cornu, 'Expériences nouvelles sur la vitesse de la lumière', *La Nature*, I sem., (1875), pp. 182-186.

15. It would be here far too long to give a detailed list of references concerning the several Breguet's telegraphic and electric apparatus. They are well described in the most important 19th century treatises of telegraphy and applied electricity. See for example Du Moncel (*op.cit.*, note 8), vol. 3; F. Moigno, *Traité de télégraphie électrique*, 2nd ed., (Paris, 1852); E.E. Blavier, *Nouveau traité de télégraphie électrique* (Paris, 1865-1867); F. Moigno, 'Un de nos grand maîtres en télégraphie électrique, une des gloires françaises ds de l'horlogerie. Télégraphes électriques et montre merveilleuse de M. Bréguet', *Cosmos*, **7** (1855), pp . 212-220.

16. About the beginning of electrical telegraphy in France see C. Bertho, *Télégraphes et téléphones da Valmy au microprocesseur* (Paris, 1981), pp. 59- 174; P. Flichy, *Une histoire de la communication moderne, espace public et vie privé* (Paris. 1991), pp. 60-86.

17. L. Breguet, 'Sur un accident arrivé au télégraphe électrique de Saint Germain'. *Comptes Rendus de l'Académie des Sciences*, **24** (1847), p. 980-981.

18. L. Breguet, 'Sur la télégraphie électrique'. *Comptes Rendus de l'Académie des Sciences*, **21** (1845), p. 61; L.Breguet 'Experiences faites au télégraphe électrique de Rouen', ibid., **22** (1846), pp. 743-744; L. Breguet, *Télégraphie électrique, son avenir...* (Paris 1849); L. Breguet, 'De l'induction par différents métaux', ibid., **23** (1847), pp. 1155-1157; Wertheim, L. Breguet, 'Expériences sur la vitesse du son dans le fer', ibid., **32** (1851), pp. 293-294.

19. It was a difficult period for Louis Breguet who was not very good as far as financial and administrative matters were concerned. The bankruptcy of two bankers as well as the breach of confidence of one of his collaborators (a certain Mouillon), created many problems for the firm.

20. L. Breguet, *Notice sur les appareils magneto-électriques brevetés par Breguet et sur leur application à l'explosion des torpilles et des mines en général* (Paris, 1869).

21. It was called this because the handle which separated the anchor from the magnet had to be violently struck by a punch.

22. Du Moncel, *op.cit.*, vol. 4 and A. Favarger, *L'électricité et ses application à la chronometrie* (Neuchâtel, 1924) .

23. J. Mascart, *L'heure à Paris* (Paris, 1907).

24. A. Breguet, 'Régulateur isochrone de M.Yvon Villareceau', *La Nature*, I semestre (1878), pp. 187-190; J. Darius and P.K. Thomas, 'French Innovation in Clockwork Telescope Drives', in C. Blondel, F. Parot, A.Turner (editors), *Studies in the History of Scientific Instruments* (London and Paris, 1989), pp. 144-154.

25. F. Dagognet, *Etienne Jules Marey La passion de la trace* (Paris, 1987) and M. Braun, *Picturing Time The World of Etienne Jules Maray (1830-1904)* (Chicago and London ,992), pp. 8-41.

26. This interest is demonstrated also by the historical article: A. Breguet, 'Aperçu historique sur la lumière produite par l'électricite', *La Nature*, I semestre (1878), pp. 230-231, 289-291 and 394-396. See also: A. Breguet, 'Radiomètre de Crookes' ibid., II semestre (1876), pp. 60-62.

27. A. Breguet, 'Téléphone de M.Graham Bell', *Comptes rendus de l'Académie des Sciences*, **85** (1877), pp. 776-777; A. Breguet, 'Sur quelques modification nouvelles apportées au téléphone', ibid., **86** (1878), pp. 31-32; A. Breguet, 'Sur le téléphone de Bell et les téléphones à ficelle', ibid., **86** (1878), pp. 469-470; C. Breguet, 'Antoine Breguet du téléphone Bell au photophone (1880-1882)', *Diligence d'Alsace*, **30** (1984), pp. 2-23.

28. A. Breguet, 'Les récepteur photophoniques de sélénium', *Annales de chimie et de physique*, 5 série, **21** (1880), pp. 560-563; A. Breguet, 'Le photophone de Bell', *Journal de physique théorique et appliquée*, I série, **9** (1880), pp. 369-375; R.V. Bruce, *Bell. Alexander Graham Bell and the Conquest of Solitude* (Ithaca and London, 1973), pp. 335-343; A. Breguet, 'Sur les experiences photophoniques du professeur A.G.Bell', *Comptes Rendus de l'Académie des Sciences*, **91** (1880), pp. 595-598, and A. Breguet, 'Sur le photophone de MM.G.Bell et S.Tainter', ibid., pp. 652-654; E. Hospitalier, 'Le photophone', *La Nature*, II semester (1880), pp. 341-346.

29. In the 1880s the French physicist Ernest Mercadier (1836-1911) improved and modified the photophone, which he baptised *radiophone*, see E. Mercadier, 'Sur le radiophone', *Jounal de physique théorique et appliquée*, I serie, **10** (1881), pp. 53-68 and 147-154.

30. G. Lippmann, 'Expériences électrocapillaires', *Annales de physique et de chimie*, I série, **3** (1874), pp. 41-43, Breguet (Maison), *Notice sur l'emploi de l'électromètre capillaire de G.Lippmann* (Paris, 1884). Breguet's firm also manufactured Lippmann's mercury galvanometer, see 'Sur un galvanomètre et un électrodynamomètre à mercure', *Annales de physique et de chimie*, II série, **3** (1884), pp. 384-388.

31. A. Breguet, 'Sur un nouveau téléphone dit téléphone à mercure'. *Comptes Rendus de l'Académie des Sciences*, **86** (1878). 711-715; A. Breguet, 'Téléphone à mercure'. *La Nature* (1878) II semestre. pp. 83-84.

32. Z. Gramme. 'Sur une machine magnéto-électrique produisant des courants continus'. *Comptes Rendus de l'Académie des Sciences*, **73** (1871), pp.175-178. The Italian physicist Antonio Pacinotti (1841-1912) had proposed a ring-armature about ten years before Gramme. In 1865 Pacinotti travelled to Paris, where he bought some apparatus and he tried to industrially develop his dynamo. Pacinotti visited the makers Breguet and Froment. At the time, Gramme was one of the technicians in Froment's workshop so he had the opportunity to discuss this device with Pacinotti. It was probably after this meeting that Gramme started to elaborate his own dynamo. A detailed account of the Pacinotti-Gramme controversy can be found in D. Manetti, 'Scienza, tecnologia e economia: l'invenzione della dinamo', *Annali di storia dell'impresa*, **4** (1988), pp. 279-367. However, if Pacinotti discovered the principle of ring armature, Gramme was able to improve the dynamo and to transform a laboratory device into an efficient industrial machine.

33. A. Breguet, 'Sur la théorie des machines du genre de celle de Grammes', *Comptes Rendus de l'Académie des Sciences*, **87** (1878), pp. 746-748; A. Breguet, 'Recherches sur la théorie de la machine de Gramme', *Annales de physique et de chimie*. 5 série, **16** (1879), pp. 5-48; A. Breguet. 'Sur les machines magneto-électriques du genre de celle de Gramme'. ibid., 5 série, **17** (1879), pp. 282-288; A. Breguet, *La machine de Gramme* (Paris, 1880); L. Breguet, *Eclairage par la lumière électrique* (Paris, 1876); L. Breguet, *Lumiere électrique par les machines magneto-électriques de Gramme* (Paris, 1876); L. Breguet, *Instruction pour l'emploi de la pile Bunsen et du régulateur Serrin* (Paris, 1876).

34. Among the article that Antoine Breguet wrote in the *Bulletin de Séances de la Société de Physique* and which were not published elsewhere we should note: 'Téléphones à courent de pile' (1878), pp. 13-15; 'Différentes formes d'appareil de rotation électromagnetique, et déplacement des frotteurs dans la machine de Gramme' (1878), pp. 180-184; 'Solutions d'enroulements électromagnétiques' (1879), pp. 104-107; and also: 'Sur le potentiel électriques', *Revue scientifique*, II série, **19** (1880), pp. 443-447.

35. We only point out: Paris (1855, 1867, 1878, 1889, 1900), London (1862), Vienna (1873), Philadephia (1876), Chicago (1893).

36. A detailed description of Breguet's apparatus and machines at the 1900 exhibition can be found in R. Hospitalier and J.A. Montpellier, *L'électricité à l'exposition de 1900* (Paris, 1902).