19th Century French Scientific Instrument Makers

X: The Richard Family

Paolo Brenni

Fig.1 *Félix Richard (1809-1876). (From: J. Perin,* Jules Richard et la magie du relief, *Paris, 1993, p. 13).*

The story of the firm of the family Richard, which can be considered one of the most important in the history of the French precision industry, can be divided into two distinct periods. The first one, which coincides approximately with the third quarter of 19th century, is marked by the development of Bourdon's tube and aneroid barometers. In the remainder of the 19th century and in the first decades of the 20th century, the firm developed two main types of products: recording instruments both for laboratories and for industry, and stereo cameras and related accessories.

Very little is known about Félix Richard (1809-1876) the founder of the firm (Fig.1).[1] He was born in Lyon, where he first established as a mechanician and instrument maker around 1845. He married Françoise Antoinette Froment (1818-1911), the sister of the famous instrument maker Gustave Froment.[2] They had four sons: Albert, Jules, Max (generally called Félix) and Georges. In 1845 he presented to the *Société d'encouragement pour l'industrie nationale* a special pressure gauge for boilers.[3] This apparatus was composed of a series of interconnected U-shaped tubes partially filled with mercury and water. Thanks to this special design, which reproduced exactly the principle of the multiple tube barometer, it was possible to reduce the size if not the complexity of the gauge. Richard claimed at the time that 261 instruments of this kind were actually sold, and he was awarded a silver medal by the *Société*. In 1849 the French inventor and engineer Eugène Bourdon (1808- 1884), patented his famous manometer as well as a series of thermometers and aneroid barometers, whose key element was the Bourdon tube.[4] In about the same year Félix Richard moved to Paris. Around 1850, Bourdon, who was dedicating all his energy to improving and manufacturing his industrial pressure gauges, sold that part of his patent concerned with barometers to Richard who started to produce and modify this new type of instrument. This activity proved to be very successful and in 1867 Richard described his apparatus as well as the machine-tools needed for producing them in a long article for one of the most famous French industrial publications.[5]

The most important instruments made by Richard at the time were the following ones:

1. The so called 'pendulum-barometer (Fig.2)'. This portable instrument (diameter about 15 cm), cleverly combined in the same cylindrical box a Bourdon's tube barometer and a clock. The axle of the pointer of the barometer was concentrically inserted into the hollow axle of the pointer of the clock, so that this instrument had a single dial with two scales, one for barometric pressure and the other one for time.

2. The 'thermo-barometer' (Fig.3). This apparatus was a combination of a barometer and a thermometer, both working thanks to Bourdon's tube. The tube of the thermometer was in fact filled with alcohol and sealed. The thermal dilatations and contractions of the liquid modified the curvature of the tube. The movement was transmitted to a pointer with a simple lever, rack and pinion system. Here too the axles and two pointers were concentric.

3. The precision barometer. In this instrument the mechanical system for transforming the deformation of the tube into the movement of the pointer was more sensitive and sophisticated than in the above mentioned apparatus. Moreover, a smaller additional pointer, allowed one to read (at last theoretically) pressure variations of 1/10000 of millimeter in the interval between 71 and 80 cm/Hg.

4. The 'monumental barometer'. This type of very large barometer was intended specifically for the façades of public buildings. It had four large Bourdon tubes, which were mechanically connected in parallel, thus producing a remarkable force which could move a pointer of 60-80 cm. The friction was

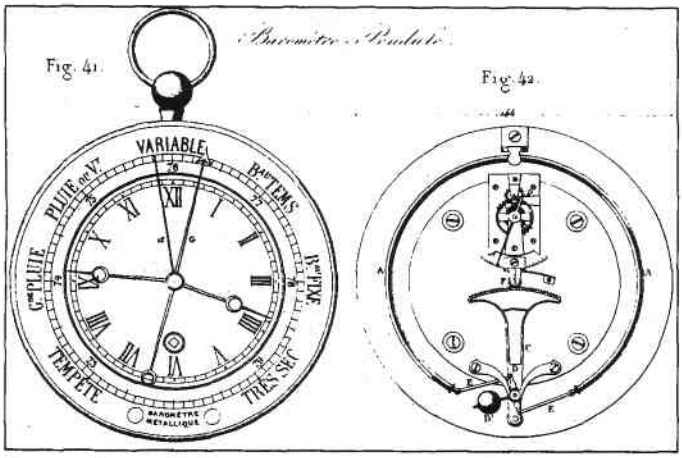


Fig.2 *The so-called 'pendulum-barometer of Félix Richard. (From: F. Richard, 'Construction des baromètres métalliques et de divers instruments multiples', in Armengaud aimé (ed.),* Publication industrielle... *(Paris, 1867), Vol. XVII, detail from Pl. 35).*

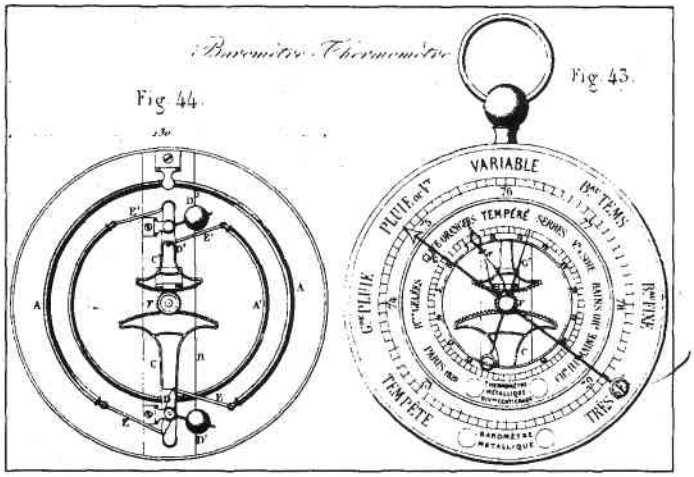


Fig.3 *The 'thermo-barometer' of Félix Richard. From the same source as Fig. 2).*

Fig.4 *Jules Richard (1848-1930). (From. J. Perin,* op.cit., *note 1).*

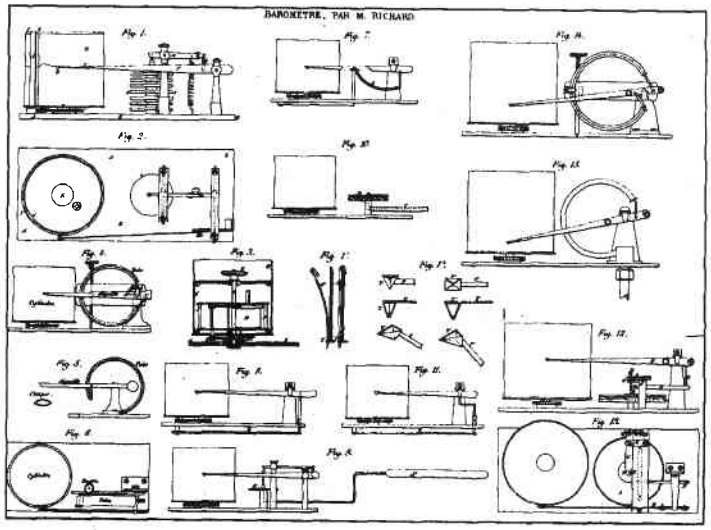


Fig.5 *The engraving illustrating several barometers and thermometers taken from the Richard's patent of 1880. See Patent 139070, 'A M. Richard pour des perfectionnement aux baromètres et autres instruments écrivants automatiquement leurs indictations, dits enregistreurs', in* Description des machines et procédés.., *Paris, 1853), Vol. XXV (II part), Instruments de précision- (A) Appareils divers, Pl. VII.*

reduced by an ingenious type of bearing.

5. Aneroid barometer. Finally, Richard also produced more conventional aneroid barometers, whose essential element was a thin metallic vacuum capsule similar to the one proposed by Nicolas Jacques Conté (1755-1805) at the end of 18th century and subseqently improved by Lucien Vidie (1805-1866). Félix Richard adopted the original idea of enclosing a spring (in fact he employed 3 U-shaped separate springs) in a capsule. The springs had to avoid the crushing of the capsule itself under the action of the atmospheric pressure. The ovement of the walls of the capsule were than transferred to the pointer thanks to a simple mechanism.

The manufcture of Bourdon's tube required a series of special machines. Some of them were conceived by Félix Richard himself and are described in detail in the above mentioned article. Because of the importance of Bourdon's tube in many pieces of apparatus and instruments their manufacture has been described in the **Appendix** at the end of this paper.

After having successfully manufactured and sold these instruments during the Second Empire, Félix Richard died in 1876 leaving his business to his widow. But the economic situation at the time was far from brilliant.[6] In fact Françoise Antoinette Richard stated that the firm, which had sold in the previous years about 30,000 metallic barometers, 500 *baromètres-pendules* and more or less the same number of 'thermo-barometer', was in deep crisis. Nothing was exported anymore, while in the 1860s three quarters of the production had been exported. Furthermore, the number of workers, which had reached a maximum of 40 with Félix Richard, had fallen to 10. Although biographical information concerning Félix Richard is limited we have some hints that can explain this situation. Félix Richard was active in the political arena in the 19th arrondissement of Paris and he had spent a lot of money in politics. During the bloody period of the Parisian *commune*, which followed the 1870 débâcle, he fought with the *communards*. He was imprisoned and sentenced to death. (He was to be executed by shooting). Richard escaped and finally returned to his workshop, but probably his involvement with the rebels did not help his business. Furthermore he had lost money in some ill-fated spaculations, and also because of his extravagant lifestyle. So at the end of his life Félix Richard was badly in debt.

His son (Fig.4), Jules Nicolas Richard (1848-1930) was born in Lyon, and after having studied at the college of Beuvais, he spent three years as an apprentice in his father's workshop. In 1866 he was for some time in the firm of the clockmaker Armand François Collin (1822-1895), who was renowned for his monumental clocks. In the evenings he attended some courses et the *Conservatoire des Arts et Métiers* where he learned the fundamentals of kinematics. Then he spent some time in the *Administration des télégraphes*. In 1876 he was finaly convinced by his mother to join the family firm, which was really in a dramatic state. In fact, we can consider the year 1876 as the year of the rebirth of the firm's activity. Jules and his brother Max-Félix (1856-1949) began to work together[7], the former being the engineer and inventor, the latter being more a kind of public-relations figure. Jules managed to establish an agreement with his creditors and to restart the activity on a new financial basis, before concentrating on the production of aneroid barometers. In 1878 the brothers Richard, together with Madame Richard (Félix's widow) presented their instruments to the Paris universal exhibition.[8] In 1880 Jules patented a series of improvements for the recording barometers and for other registering instruments (Fig.5).[9] In 1882 the cooperation of the two brothers was formalized and they founded the *Société* **RICHARD FRÈRES**. After this date the initials **'RF'** will appear on almost all their instruments. In the same years the brothers Richard presented their apparatus at the *Société d'encouragement pour l'industrie nationale*, where they were were awarded a platinum medal.

Recording meteorological instruments were not a novelty. The first ones were proposed in the late 17th century. During the 19th centuly several pieces of apparatus of this kind were invented but generally they were large, complicated, and often vely expensive.[10] Richard's apparatus represented a new generation of simple, efficient, easy-to-repair and mass-produced instruments which cost only a few hundred francs. It is here necessary to point out some of their most interesting characteristics. All the instruments were mounted on a base and protected by a glass case. The

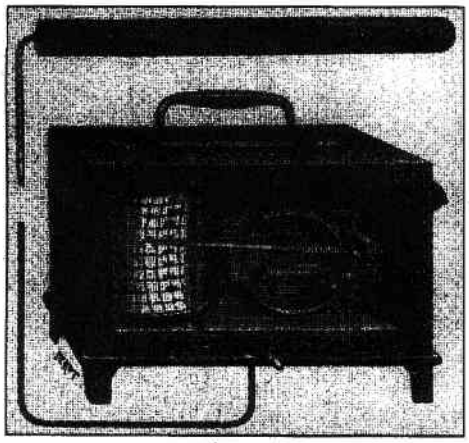


Fig.6 *A Richard industrial recording pyrometer. (From: J. Richard,* Enregistreurs Richard *(Paris, 1913), p. 13/EI).*

recording drum enclosed the clockwork-mechanism and was inserted on a vertical axis. It was thus extremely easy .o replace the clockwork. The Bourdon tube or aneroid capsule was mechanically connected with a long, light and flexible arm thanks to a series of link and levers. The writing pen at the end of the arm consisted of a small and light aluminium box in the shape of a pyramid. In this pen a mixture of anyline ink and glycerine could last for many days of recording as it did not dry up. The recorded trace was clear and continuous. Finally, the simplicity of the mechanical system contributed to reduce the friction. The registering barometric and thermometric instruments were immediately successful and the recording system was soon applied in many laboratory, observatory and industrial apparatus such as anemometers, statoscopes, pyrometers (Fig.6), tachymeters, dynamometers, ampèremeters, voltmeters, wattmeters, mareographs, pressure gauges, cinemographs, chronographs, etc.,[11] At the beginning of the century many others special recording apparatus were made for the needs of the railroad companies (Fig.7) and for different engineering researches.

The firm's catalogue of 1886 gave an impressive list of institutions which had adopted Richard's recording apparatus, and stated that at the time about 3,500 of them were installed in different parts of the globe.[12] Around 1900 this number had lisen to 32,000, and to 64,000 in 1913. In 1887 the French Navy officially adopted the instruments made by Richard, thus giving an important momentum to the production.

In 1889, on the occasion of the Paris universal exhibition, Richard's meteorological instruments were chosen by Eleutère Mascart (1837-1908), the director of the *Bureau central de météorologie,* and installed at the top of the Eiffel tower. The instrument readings were transmitted electrically from the top of the tower to a pavillion at the Exhibition (Fig.8).[13]

The year 1891 marked the end of the association of Jules and Max Richard because of a series of problems and disagreements. The firm, which at the time employed 150 workers in a factory of 1500 square metres, now became **'JULES RICHARD'**, but it maintained the initials **'RF'**.[14] The address was the same as at the time of Félix, that is: 8, impasse Fessard. In 1899 the name of the street changed to rue Mélingue. This is the address which appears in the 20th century catalogues. The firm was located here until the 1970s. During the first years of the 20th century, apart from the main building at 25, rue Mélingue with the offices and the workshops, the firm Richard had a retailing shop at 10, rue Halévy, near the Opéra, a permanent exhibition of stereo photographs and apparatus at 7, rue Lafaytte, as well as a branch in London (27, Bond Street) and agents in Geneva, Brussels and Göteborg.

Inspite of the success of the recording apparatus, Jules Richard expanded his activities. In fact, in 1891 he patented his first *Vérascope,* a photographic stereoscopic apparatus (Fig.9)[15] This invention proved to be extremely successful and profitable. At the end of the 19th century stereo cameras and viewers were among the most appreciated scientific amusements commonly found in every bourgeois home. Several specialized firms advertised in their catalogues thousands of stereo slides and pictures which illustrated an incredible variety of subjects. Furthermore, amateur photographers appreciated stereo photography because of its the startling and spectacular tridimensional effects. The *Vérascope* was not the first apparatus of its kind but it was particularly ingenious. It was compact and well made, and the distance between the objectives corresponded to the average distance between the eyes, thus giving the real perspective and tridimensionality of the image.[16] Furthermore, it was reversible as by opening the shutters it could be used as a stereo-viewer.

In 1905 he patented the first model of a new stereoscopic camera, the *Glyphoscope,* which was intended to be a cheaper and simplyfied version of the *Vérascope.* The Vérascopes and the Glyphoscopes were subsequently improved and many different models were produced. They became extremely popular. It can be estimated that between 1894 and 1934 around 52,000 Vérascopes and 68,000 Glyphoscopes were sold. The production of stereoscopic apparatus stopped only in 1957. The firm also developed a series of ancillary instruments and accessories. I shall only mention the *Taxiphoto,* a device for viewing a large number of stereo pictures.[17]

In 1919 the firm employed about 250 workers. In 1924 Jules Richard, who was aware of the difficulties of finding highly

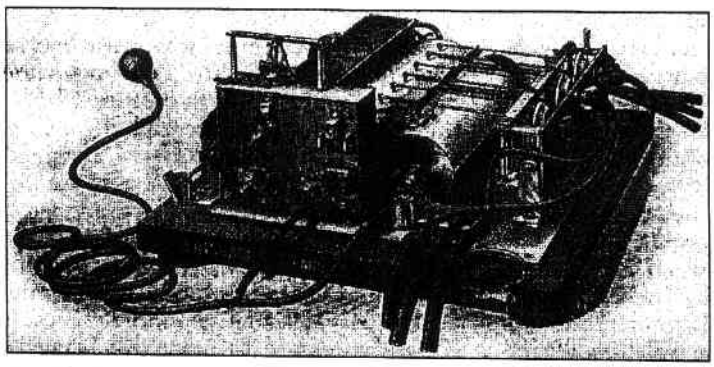


Fig.7 *A special apparatus for recording the vibrations of moving railroad vehicles. (From: J. Richard,* Enregistreurs Richard *(Paris, 1913), p. 4/KI).*

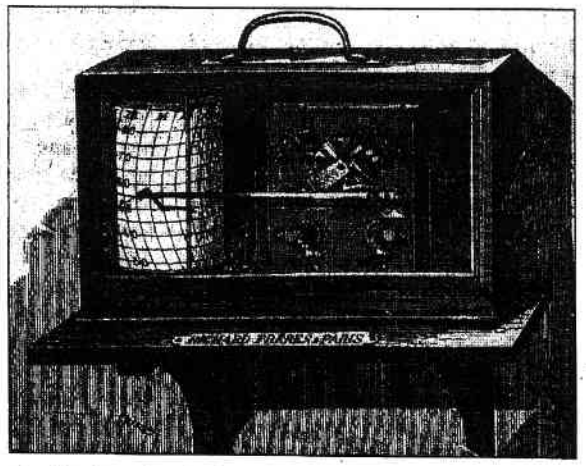


Fig.8 *An electrical registering 'receiver' which could be connected with various instruments. (From: J. Richard,* Enregistreurs Richard *(Paris, 1913), p. 2/FI).*

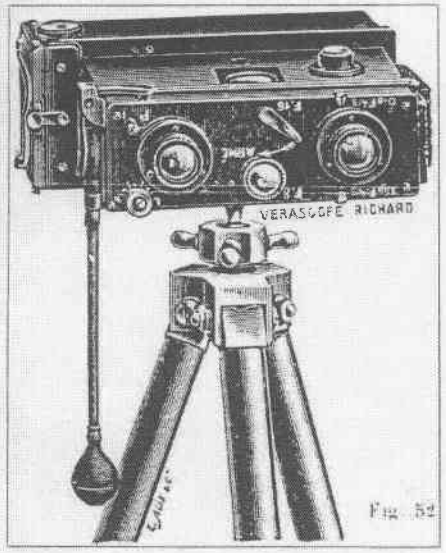


Fig.9 A 1908 Vérascope (Model 6b). (From: J. Richard, Vérascope, Taxiphote, Glyphoscope *(Paris: Richard), 1911, p.14).*

skilled technicians and of the problems related to apprenticeships in workshops, established with the huge sum of 5 millions francs the *École des Apprentis Méchaniciens Précisionnistes*.[18] He was made *Chevalier de la Légion d'Honneur* in 1894 and *Commendateur* in 1925. Jules Richard, who was very active until the end of his life, died in 1930. He was buried in the Parisian cemetery of Père Lachaise. He was succeeded by E. Henard, who was his closest collaborator. The firm now developed a series of apparatus for aerial photogrammetry. In the 1970s and 1980s the firm was reorganized, and ownership and management changed several times. Finally, in 1985 the *Société JRC* (Jules Richard Instruments) under their motto *'Mesure et Enregistrement des Grandeurs Physique de l'Environnement'*, became part of a group of companies specialising in precision instruments for industry. Following a long tradition the JRC was present at the Seville universal exhibition of 1992.

Jules Richard never married and unlike many other instrument makers of his time whose way of life was quite austere, he surely enjoyed himself in the *belle époque* Paris. He liked vaudeville and the *café chantant* atmosphere, and he always appreciated the company of charming women. In fact, he built near his factory a kind of neo-Roman pavillion (called the *Atrium*, with an indoor swimming-pool), where he not only organized discreet meetings with his women friends, but also immortalized their charm in a series of 'artistic' stereo pictures![19] As a manager Jules Richard had a strong conservative streak. He never accepted the motorcar, fought against a 1920 law for the reduction of the working week from 60 to 48 hours, and also opposed other advanced ideas.

Richard's firm, however, marked more than a century of the history of the French precision industry. Félix, the founder, was able to cleverly exploit the potential of a new invention – the Bourdon tube. His son Jules not only could reorganize and revitalize a declining firm but, thanks to a series of new inventions and ideas, create a modern industry. Unlike many other French instrument makers, Jules Richard did not confine himself to the limited production of laboratory instruments. In fact, his industrial recording apparatus as well as his popular stereo cameras contributed to the development of these two new and growing branches of the instrument market. Like his competitor and colleague Jules Carpentier (1851-1921),[20] he transformed a typical 19th century proto-industrial workshop into a modern factory. The fact that still nowaday a precision industry company bears his name is a tangible proof of his success.

Notes and References

1. The most important source of information concerning the members of Richard's family and their activities is in J. Perin, *Jules Richard et la magie du relief* (Mialet (France), 1993). My thanks here to M. Jacques Perin, whose interesting book concentrates on J. Richard's activities in the field of photography, and for providing me with a series of precious notices for my article. See also: V. Saboure, 'Jules Richard', *Bulletin de la société d'encouragement pour l'industrie nationale* (1930), pp. 898-900 and M.B. (?), *Établissement Jules Richard. Histoire de l'industrie et du commerce en France, Vol. III, l'effot économique contemporain* (Paris, *c.* 1926). Other information on Félix Richard's activities can be found in the report that his widow wrote in 1878 for an enquiry made on the occasion of the 1878 Paris universal exhibition. This report is at the Archives Nationales in Paris (File F^{12} 3363).

2. See P. Brenni, 'Paul Gustave Froment', *Bulletin of the Scientific Instrument Society*, No. 45 (1995), pp. 19-23.

3. See 'Rapport fait par M. le Chatelier, au nom du comité des arts mécaniques, sur le manomètre à air libre de M Richard de Lyon', *Bulletin de la Société d'Encouragement pour l'Industrie nationale*, **492** (1845), pp. 221-228. See also Patent 270 (28th November 1844) in *Description des machines et procédés pour lesquels des brevets d'inventions ont été pris...* (Paris Imprimerie impériale, 1850), Vol. II, pp. 66-72.

4. See Patent 4408 (18th June 1849) and Addition in E. Bourdon, 'Pour un nouveau système de manomètre sans mercure, dont le principe st applicable aux baromètres, thermomètres, etc.' in *Description des machines et procédés pour lesquels des brevets d'inventions ont été pris...* (Paris, 1853), Vol. XV, pp. 280-292, and E. Bourdon, 'Description de manomètres métalliques sans mercure, pour indiquer la pression de vapeur dans les chaudières' in *Bulletin de la Société d'Encouragement pour l'Industrie nationale* (Paris, 1851), pp. 197-200. A typical Bourdon manometer has a curved metallic and elastic tube of elliptical section, which is mechanically connected with a pointer. For example, when the pressure in the tube increases the tube tends to straighten, thus moving the pointer. In a Bourdon thermometer the dilatation and the contraction of the liquid filling the tube modify its shape.

5. See F. Richard, 'Construction des baromètres métalliques et de divers instruments multiples', in Armengaud aîné (ed.), *Publication industrielle des machines outils et appreils les plus perfectionnés et les plus recents employés dans les différentes branches de l'industrie française et étrangère* (Paris, 1867), Vol. XVII, pp. 433-488.

6. See the report by Madame Richard (note 1).

7. They appeared together in the articles and in the exhibitions even if they had not yet formalized their cooperation.

8. In the earliest catalogues of the firm as well as in the report of Madame Richard, it is stated that the firm was also awarded a medal at the 1849 Paris national exhibition and at the 1851 London Great Exhibition. In fact, in the catalogues of these exhibitions the name of Félix Richard does not appear. Probably Félix Richard had made some of the instruments presented in 1849 and in 1851 by Bourdon (who was officialy awarded) and for this reason Richard mentioned these exhibitions in his advertising. In any case they do not appear anymore in the catalogues at the beginning of the century. Since 1878 year the firm systematically partcipated (sometimes *hors concours*) in all universal, international and national exhibitions. A long and complete list is given in the catalogue of 1913. Among the most important ones I will only mention Paris (1889, 1900), Antwerp (1885), Brussels (1888), Edinburgh (1890), Chicago (1893), Brussel (1897), St. Louis (1904), Milan (1906), London (1908), Brussels (1910), and Turin (1911).

9. See Patent 139070, 'A M. Richard pour des perfectionnement aux baromètres et autres instruments écrivants automatiquement leurs indictations, dits enregistreurs', in *Description des machines et procédés pour lesquels des brevets d'inventions ont été pris...* (Paris, 1853), Vol. XXV (II part), 'Instruments de précision- (A) Appareils divers', pp. 36-37.

10. See for example R.P. Multhauf, 'The Introduction of Self-Registering Meteorological Apparatus', *Bulletin 228: Contributions from the Museum of History and Technology*, Smithsonian Institution, Washington D.C., Paper 23, pp. 96-116 and Middleton W.E.K., *The History of the Barometer* (Baltimore 1964); id., *The Invention of the Meteorological Instruments* (Baltimore, 1969); id., *A History of the Thermometer and its Use in Meteorology* (Baltimore 1966).

11. See Richard frères, 'Notice sur le thermomètre sous-marin', *Association française pour l'avancement des sciences Comptes rendus* (1884), part II, pp. 186-188; Richard frères, 'An improvement in anemometers', *Meteorological Magazine*, **23** (1889), p. 176; Richard frères: L'observatoire météorologique au sommet de la tour Eiffel', *Association française pour l'avancement des sciences Comptes rendus* (1889), part II, pp. 367-368; J. Richard, 'Chronographe astronomique Régulateur isochrone Plume enregistrante', *Congrès intérnational de chronométrie* (Paris, 1889), pp. 201-204 and 'De la mesure de la vitesse Nouveau indicateur absolu', ibid., pp. 205-213; J. Richard, 'Description d'appareils enregistreurs de météorologie', *L'Aéronaute* (1890),

pp. 226-230.; E.M. Richard, 'Application du système enregistreur Richard frères aux appareils de mesure électrique', *Annales télégraphiques*, 17 (1890), pp. 32-39; Richard frères, 'Nouveau anémomètre', *Association française pour l'avancement des sciences Comptes rendus*, 1891, I, pp. 195-196; J. Richard, 'Nouveaux appareils enregistreurs', ibid. (1892), part II, pp. 317-326; J. Richard, 'Nouveaux appareils enregistreurs Statoscope', ibid. (1893), part I, p. 209; J. Richard, 'Anémomètre à indications electriques multiples et orientation automatique', *Comptes rendus de l'Académie des Sciences*, 120 (1895), pp. 121-122.

The descriptions of many of these of Richard's instrument can be found for example in the following articles in *La Nature*: 'Manomètre extra sensible' (1877), part II, pp. 371-372; G. Tissandier, 'Baromètre enregistreur' (1881), part I, p. 220; G. Tissandier, 'Thermometre enregistreur' (1881), part II, pp. 385-386; G. Tissandier, 'Hygromètre enregistreur' (1884), part II, p. 84; 'Indicateur de vitesse absolue' (1884), part II, pp. 394-396; G.Tissandier, 'Le statoscope' (1890) part II, pp. 411-412.

12. Richard published several illustrated catalogues of scientific instruments (for example in 1886, 1889, in 1913, etc.) but they are not mentioned in R.G.W. Anderson, J. Burnett, B. Gee, *Handlist of Scientific Instrument-Maker's Trade Catalogues*, National Museums of Scotland Information Series N°8 (Edinburgh, 1990). Other catalogues dealt specifically with the photographic equipment.

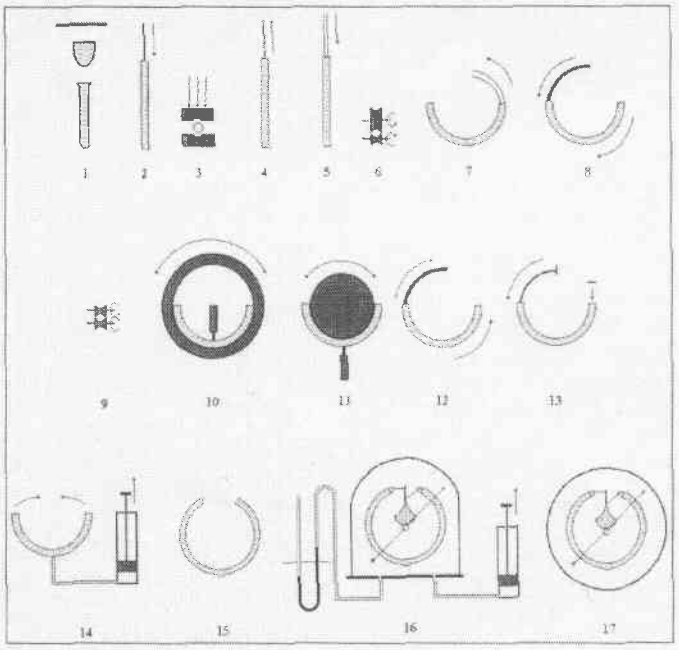
13. See G. Tissandier, 'La tour Eiffel, la station météorologique', *La Nature*, 1889, II, pp. 71-74. The recording apparatus of this type were awarded with two prizes in 1887 and in 1890 by the *Société d'encouragement pour l'industrie nationale*.

14. After the separation Max Richard founded with the brother Albert (1844-?) the *Comptoir photographique*, where he also commercialized a photographic apparatus of Jules Carpentier, a competitor of his father. Max was accused by Jules of unfair trading and he had to pay 84,000 francs damages. Max finally found with Léon Gaumont (1863-1946) the famous Gaumont-Photo-Cinema company. About the troublesome relationship between Gaumont and Jules Richard see Perin (note 1). Albert on the other hand went first to Nice and then to Menton where he opened a photographic shop. Georges (1863-1922) the youngest of the brothers, after having done his military service, opened in Paris a bicycle and mechanical workshop. He than became involved in the automobile industry, first with Henri-Charles Brasier and later, thanks to the financial support of Henri de Rothschild, he found the *Société des automobile UNIC*.

15. I am giving here only a little information concerning the optical and photographic apparatus, which were conceived and manufactured by Jules Richard. A complete description of the various models, patents as well as a detailed story of this branch of Richard's scientific and commercial activity can be found in the recent book of Perin (see note 1).

16. For this reason it was called *Véroscope* (true-vision, from a combination of latin words).

17. See also J. Richard, *Véroscope, Taxiphote, Glyphoscope* (Paris: Richard 1911).



18. This school is today the *Lycée technique privé Jules Richard* and has about 350 students.

19. Some of these amusing photographs still exist and they are reproduced in the book by Perin!

20. Carpentier reorganized and enlarged the famous but old-fashioned workshop of Heinrich Ruhmkorff (1803-1877). See P. Brenni, 'Jules Carpentier', *Bulletin of the Scientific Instrument Society*, No. 43 (1994), pp.12-15.

Appendix

The production of Bourdon barometers was a delicate and complicated process. Félix Richard described it as well as the necessary machine-tools in a detailed article of 1867 (see note 5). I illustrate here schematically the most important phases of this manufacture:

1. A straight, cylindrical tube is obtained by stamping and reheating a brass disk.

2. A metal mandrel with rounded edges is introduced into the tube. It avoids the squeezing of the tube in phase 3.

3. The section of tube is partially ovalized by two concave wooden blocks, which are submitted to the action of a press.

4. The mandrel is then extracted from the tube.

5. Two metallic and parallel springs are introduced longitudinally into the tube. They will keep its surfaces separate during phase 6.

6. The tube is forced in small rolling mill, with a couple of slightly concave rolls of different diameters. The combined action of the wheels curves the tube and tends to give to its section the definitive shape.

7. The parrallel springs are extracted from the curved tube.

8. For rolling and burnishing the tube it is first necessary to introduce into it a solid arc made of steel. This arc will stand the pressure which is applied to the tube during the following operations. A special tool is utilized for forcing the arc into the tube. The same too is necessary for extracting it (phase 12).

9. The tube is laminated by a small flatting mill, whose finishing rolls have the same diameter.

10. and 11. The concave and the conve surfaces of the tube are burnished thanks t a special kind of lathe. The strong pressure which is exerted by the fixed burnishing tool polishes and hardens the brass of the tube.

12. The steel arc is extracted by the tube which has now the right shape and the desire pseudo-elliptical section. At the same time i shows a remarkable flexibility. (The sam result was obtainable by using a steel tube but for Félix Richard it was much easier t work brass instead of steel.)

13. A compensating steel spring, whic increases the elasticity and the resistance o the tube, is inserted into it. The tube is now carefully closed by soldering two little metalli caps to the ends of it. The spring is fixed to th caps.

14. A small pipe is soldered to the tube and i connected with a vacuum pump. The evac uated tube increases its curvature under th influence of athmospheric pressure. Féli Richard used a multiple cylinder pump of hi own design. This pump had 4 or 8 glas cylinders, wich were connected in series. Onl the first one communicated with the Bourdo tube and only the last one with the open air.

15. The connection pipe is closed and cu away.

16. The barometer is tested and calibrate under a vacuum bell. A mercury gauge give the right pressure. The definitive length of th arms which connected the Bourdon tube wit the rack and pinion system had to b determined separately for each tube.

17. The mechanical system is adjusted an the barometer is ready.

Next to come: Brunner.