THE HISTORICAL DEVELOPMENT OF THE INDUCTION COIL AND TRANSFORMER.

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(*Continued from Vol. XXVI., page 417.*)

§ 7. **Callan's Further Researches.**—In the *Philosophical Magazine* for December, 1836, Prof. N. J. Callan made further mention of his auto-induction coils, giving also a description of an improved form of galvanic battery. He wound, on an iron bar about two feet long and an inch thick, two coils of insulated wire, each about 200ft. long. These insulated wires were joined together in series, and the extremities of one wire were put in connection with a battery of 14 cells; on taking hold of the ends of the whole length of 400ft. of wire and breaking the battery circuit, a very sharp shock was felt. He concluded that if about 2,000ft. of wire were so coiled on a bar, and the first 200ft. of this wire connected to a battery, a still greater shock would be received if the ends of the whole 2,000ft. were touched, and the battery contact broken. Twenty-one years afterwards he returned again to the subject of induction apparatus, and in a long Paper, communicated to the British Association at its Dublin meeting in 1857, and reprinted in the *Philosophical Magazine* for November, 1857, Callan described many experiments he had made in his efforts to improve the induction coil and exalt its power. Referring first to the induction coil made at Maynooth College in 1836, and to one like it sent to Mr. Sturgeon in the summer of 1837, he establishes his claims to priority in the matter of the invention of an induction coil, having two *separate* wires, one thick and the other thin, by means of which a *quantity* current could be made to produce an *intensity* current. This 1857 Paper is occupied chiefly in advocating the use of an induction coil, with a secondary circuit made of insulated iron wire, and such a coil he showed to the British Association, in which the secondary circuit consisted of 21,000ft. of iron wire, about ·01in. diameter. His arrangement apparently consisted in using a secondary circuit of insulated iron wire rolled up tightly into a cylindrical form, and which formed not only the secondary circuit, but also the iron core of the primary. The primary circuit, consisting of insulated copper wire, was wound over and outside of the iron wire secondary, and the secondary circuit thus fulfilled at once the functions of core and secondary circuit. In one form of coil described the circuits were alternately overlaid. First an iron wire secondary circuit, then a copper wire primary; then over this another iron wire secondary, and a further copper wire primary. The primary circuits were to be joined in series, and the iron wire secondaries in parallel, with the object of obtaining "considerable quantity" in the secondary currents. It is suggested that in this way it would be possible to procure current enough to operate an arc light between carbon poles. One form of induction coil suggested consisted of an iron wire secondary coil wound up tightly into a helix; and on this, considered as an iron core, the copper wire primary was wound; over this copper circuit another iron wire circuit was coiled, and the two iron wire circuits were joined up in series, so that the copper wire primary acted inductively on both, and generated induced currents in each in the same direction. Reasons are given in this Paper which led the writer to consider that this insulated iron wire secondary circuit had advantages over a secondary circuit of copper wire, and an independent longitudinally divided iron core, as introduced by Backhoffner. Callan explained with great clearness that the principle of joining together the secondary circuits of a number of coils in parallel is the right method to adopt to obtain a secondary current of sufficient strength and electromotive force to produce an arc light, and he may, therefore, be credited with the knowledge at that date of the mode of adding up either the electromotive forces or the currents in the secondary circuits of a number of distinct induction coils. It is not quite equally clear whether he ever arranged his coils with primary circuits in parallel also. The same Paper also contains suggestions as to mode of manufacture of condensers for induction coils, and certain advantages are claimed for condensers made of iron plates rather than of tinfoil sheets. Callan's mode of insulating the wires of his coils was ingenious. He dragged the bare iron or copper wire through a hot bath of melted resin and beeswax, and this, when set, formed a highly insulating and sufficiently flexible varnish on the wire, which appears to have rendered silk or cotton covering unnecessary. The secondary circuits were wound on the plan, previously suggested by Poggendorff, of building up the secondary circuit of flat or vertical coils, so connected that no contiguous parts of the wire were at great differences of potential when the coil was in action.

Prof. Francis Lennon has given* the following details of the remains of Prof. Callan's apparatus, which are still preserved at Maynooth College as valuable relics. The large electromagnet constructed by Callan in 1836, consisting of a horse-shoe of iron, about 13ft. in length, and weighing 210lb., is still in existence (*see* Fig. 12), but it has been deprived in course of time of one of its circuits, so that it now remains as a simple and not a compound electromagnet. A somewhat smaller horse-shoe magnet, constructed by him on the same principle, with two wire coils, one thick and one thin, was the one presented

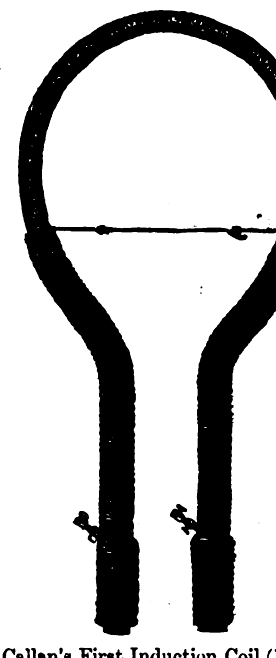

FIG. 12.—Dr. Callan's First Induction Coil (1836), with thick and thin wire Circuits.
Still preserved at Maynooth College.

to Mr. Sturgeon. In the Physical Laboratory at Maynooth also exists one of Callan's Electromagnetic "Repeaters," which was one of the first rapid contact breakers ever made.

§ 8. **Callan's Great Induction Coil.**—The most valuable relic is, however, the large induction coil, which may be regarded as the completion of Dr. Callan's labours. Although constructed 30 years ago, it is still one of the largest coils in existence. The representation of it in Fig. 13 is from a photograph recently made. The core is a cylindrical bundle of annealed iron wires 42in. in length, and 3·5in. in diameter. The thickness of each wire is $\frac{3}{16}$in. The primary coil is a copper wire, ·25in. in diameter, covered with cotton thread, and wound in three layers. For insulation the primary coil is covered with several layers of thin sheet gutta-percha, cemented by a paste, formed by dissolving gutta-percha, resin, and wax in boiling oil. The secondary coil is of *iron* wire ·01in. diameter, and consists of three separate coils or rings. The inner diameter of each coil or ring is 5·75in., and the outer diameter is 21in. Two of the rings are 3in. in thickness, and one is 4in. The rings are so arranged on the primary coil as to divide its entire length into four equal parts, the planes of the rings being perpendicular to the axis of the coil. In each ring both ends of the wire are

* See *Electrician*, March 6, 1891, Vol. XXVI., p. 554.

left projecting, so that the separate coils can be joined in series or in parallel. The contact breaker is an automatic mercury break, worked from one extremity of the core. Two condensers, so arranged that they can be used together or separately, serve to reduce the spark at the break. With six cells of the Maynooth or cast iron battery, sparks 15in. long in air can be still obtained, the rings or secondary coils being joined in series. Prof. Gerald Molloy states* that the construction of this coil was commenced by Dr. Callan some years before his death, which occurred in January, 1864, and that it was then left in an unfinished condition. It was probably his intention to add more secondary coils to it. It remained one of the most powerful coils down to the time of the construction of Mr. Apps' large coils for the Polytechnic and for Mr. Spottiswoode. A long Paper by Dr. Callan on the induction apparatus, describing his latest researches, is printed in the *Philosophical Magazine* for 1857, Vol. XIV., 4th series, p. 323. This Paper is full of valuable suggestions and facts.

A description of the large induction coil, and experiments with it, will be found in the *Philosophical Magazine* for June, 1863 (Vol. XXV., Series 5, p. 413). Dr. Callan says that about three years and a-half before the date of writing he made an induction coil of considerable power. The secondary coil was of iron wire, No. 34 gauge, and consisted of three parts, two of which were each about two and a-half inches, and the third three inches long. The entire length of the secondary coil was about eight inches, and it contained 150,000ft. of secondary wire. He used thin sheet gutta-percha in insulating

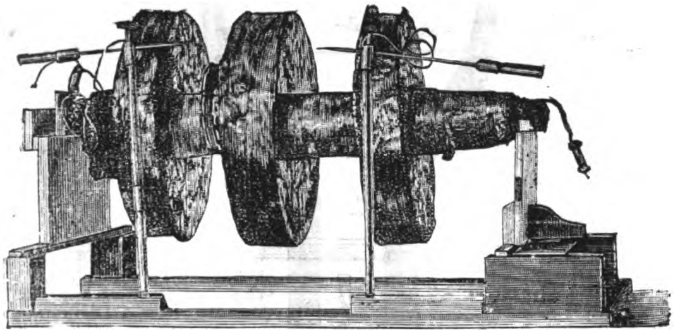

Fig. 13.—Dr. Callan's Large Induction Coil completed in 1863. Still preserved at Maynooth College.

the layers of wire. The primary coil was nearly three feet long, and the soft iron wire core three feet six inches long. This long primary coil was probably intended to be overlaid with more secondary wire, and as left at Dr. Callan's death the coil was incomplete. With three cells of the Maynooth battery this coil would give sparks 15in. in length.

Dr. Callan discovered that an increase in length in the spark is produced by connecting a large plate of any metal to the negative terminal of the coil, and that, in order to get the longest spark, the outer end of the secondary coil should be positive, and the inner end the negative. He states (see *Philosophical Magazine*, June, 1863) that when a pointed wire is connected with the positive end of the secondary a plate connected with the negative end lengthens the spark considerably, but when the point is connected to the negative end and the plate to the positive one the sparks are much shorter. Sparks 15in. long, when the first arrangement is made, are reduced to 11in. with the second. Sparks did not pass at all between positive plate and negative point until the plate was brought within eight and a-half inches from the point.

A ball, three inches in diameter, connected to the positive terminal shortens the spark as much as a 12-in. plate. He noted also that sparks from a positive point to a negative plate never went to the circumference of the plate, and scarcely ever struck the plate at a greater distance from the centre than three inches. But sparks between a negative point and positive plate always went to the circumference until the plate was brought to within two and a-half or three inches of the point; even when a rectangular plate 20in. by 28in. was used as the positive terminal the sparks flew to the edge of the plate.

* See *Electrician*, February 13, 1891, Vol. XXVI., p. 465.

§ 9. C. G. Page's Researches in Electro-Magnetism.—Very nearly at the same time that Prof. Callan, of Maynooth, was assiduously engaged in England in experimental inquiries on the induction coil, Dr. C. G. Page, at Salem and at Washington, in the United States, prosecuted with the greatest zeal and ingenuity similar researches on the other side of the Atlantic. Reference has already been made to his experiments with the ribbon coils of Henry, and which are described in *Silliman's American Journal of Science*, Vol. XXXI., for 1837, in a Paper dated Salem, May 11th, 1836, and entitled "Method of Increasing Shocks, and Experiments with Prof. Henry's Apparatus for obtaining Sparks and Shocks from the Calorimeter." In a second Paper, dated April 24, 1837, Page describes the construction of a large auto-induction ribbon coil, such as has already been described in § 2, which he now calls a "Dynamic Multiplier." This last coil consisted of a single ribbon of copper, 320ft. in length and one inch in width, wound into a flat spiral, the successive turns being insulated with strips of varnished cotton cloth. It had ten mercury cups soldered to the strip at various distances. With this apparatus he repeated all his former experiments on a larger scale. At this stage Page made an important contribution to the subject by inventing various forms of self-acting contact breakers to interrupt the primary current. One of the first of these (made in 1837) was a copper spur, or star wheel, the points of which just dipped into mercury contained in a little gutter or excavation in the base board which supported the wheel. He made this self-acting by placing a horse-shoe magnet so that its poles lay on opposite sides of the wheel, as in the experiment known as Barlow's revolving spur wheel. The electro-magnetic action of

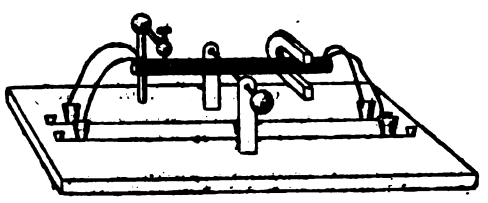

Fig. 14.—Page's Automatic Contact Breaker.

the radial current in the wheel on the fixed magnetic field caused rapid rotation of the copper spur wheel, and, hence, interruption of the current, as the tips of the stellate projections of the wheel passed into and out of the mercury. He found this arrangement to answer well for interrupting a current when powerful currents were used. Such an arrangement, however, failed with feebler currents, and he accordingly devised a rocking magnet interrupter, which he describes in this same Paper, published in 1837, and which was afterwards reproduced almost identically by Golding Bird as his own invention in 1838 (*see* Golding Bird, *Phil. Mag.*, Vol. XII., 1838). Page's contact breaker and Bird's reproduction of it consisted of a small electro-magnet (*see* Fig. 14) made of a piece of soft iron wire, one-eighth of an inch in diameter and three inches long, wound over in opposite ways with two separate insulated wires, the ends of one coil projecting at one end, and the ends of the second coil at the other. This small electro-magnet was balanced beam fashion on pivots, and so arranged that the projecting ends of the wires wound on it could dip in pairs of mercury cups at the two ends of the supporting board, according as the beam was tilted one way or the other. A permanent horse-shoe magnet was fixed so that one end of the beam electro-magnet could play between the poles. The mercury cups on the board were connected together, as shown in the figure. If a battery and coil were connected in series with one pair of mercury cups at one end of the board, it is obvious that matters could be so arranged that the reversals of polarity of the beam magnet as it was caused to tip its connections backwards and forwards into one or other set of cups, could not only maintain the rocking motion, but also interrupt the circuit of the coil. In the following year, 1838, Page had completed new and more perfect induction coils, consisting of two separate circuits, a thick wire primary, and a thin wire secondary, and he describes these coils in a very able Paper, published in June, 1838, in *Silliman's American Journal of Science*, Vol. XXXIV., July, 1838, p. 364.

He calls iron cores wound over with two separate circuits "compound electro-magnets," in the use of which phrase he followed Prof. Joseph Henry. These compound electro-magnets, or induction coils, were made with cores, consisting of bundles of fine soft iron wire, or strips of soft hoop iron. The cores were either straight or U-shaped. Dr. Page evidently arrived by independent investigations at a knowledge of the advantage obtained by using such divided iron cores, but whether before or after Backhoffner it is impossible to say. Page himself states that he used them before February, 1838, when Backhoffner first used them in England. These compound magnets were, however, induction coils of the form employed by Callan, and by their use Page obtained visible sparks from the secondary circuits, as well as very severe shocks, and produced secondary sparks by the help even of a primary current derived merely from one or two thermo-electric couples. In this same Paper, Page describes a remarkably interesting and ingenious induction coil which he called a "magneto-electric multiplier." He arrived by experiment at the conclusion that when an armature of soft iron was applied to one of his U-shaped compound magnets, the induction, as we now call it, through the secondary circuit for a given current strength in the primary, was much greater than when the armature was not present. Also so as to break the circuit of the primary current when the soft iron armature was just leaving the position in which it magnetically completed the iron circuit of the magnet. Hence the primary electric circuit and the magnetic circuit were opened, one immediately after the other. The result was a very considerably greater production of electromotive force in the secondary circuit. Page got brilliant sparks from the ends of the secondary circuit of this coil, and unbearably severe shocks. He was also able to get a small arc when carbon points were used as terminals for the secondary, and he found the tension at the ends of the secondary was great enough to enable him to charge a Leyden jar. The same Paper which contains the description of this "electro-magnetic multiplier" also contains some very clear remarks on the use of divided iron cores, and on the magnetism of soft iron. Page employed sometimes cores made of very soft hoop iron, wrapped together, in making his compound magnets or induction coils. He knew very well that soft iron is capable of retaining a considerable amount of magnetism, provided it is not shaken or twisted. He illustrates this by an experiment in which a very soft iron wire was magnetised by being drawn once across the poles of a permanent magnet. It contains a considerable amount of magnetism if handled gently, and will lift up another piece of soft iron wire equal to itself in weight. If, however, it is given a flip with the finger and thumb, it immediately loses nearly all its magnetism. Page also was aware of the depolarising effect which a number of magnetic filaments, such as magnetised soft

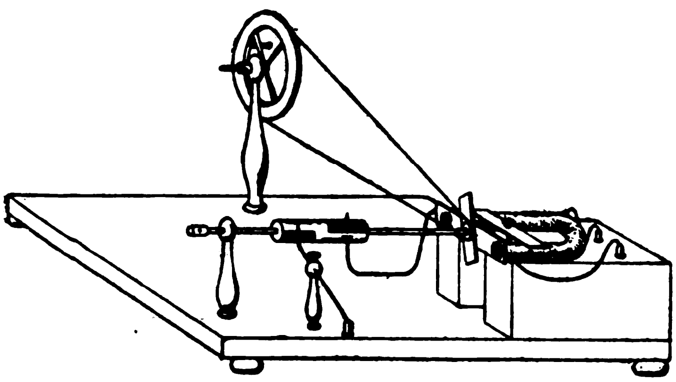

FIG. 15.—Page's "Magneto-Electric Multiplier."

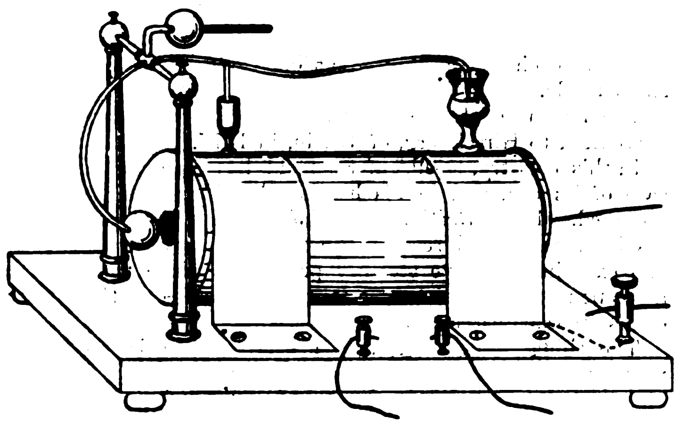

FIG. 16.—Page's Induction Coil (1838).

that the depolarising power of the magnet was much greater when the armature was removed, so as to break the magnetic circuit. Hence it occurred to him that if he could first of all make his iron core a closed magnetic circuit *before* starting the primary current, and then break the primary circuit and open the magnetic circuit by detaching the armature directly afterwards, the combination of these two actions would put in and take out of the secondary circuit many more lines of force in the same time, and hence produce a greater electromotive force in the secondary circuit than if the primary circuit of a straight coil were simply opened and closed. This reasoning shows that at this date Page had acquired a great grasp of the true principles of electro-magnetism. The apparatus with which he put his ideas to the test is shown in Fig. 15. It consisted of a horseshoe shaped induction coil, or a U-shaped compound magnet, the core being made of 500 soft iron wires, 12 inches long, and bent into the shape of a U. The primary coil consisted of five layers of No. 16 copper wire, and the secondary of seven layers of No. 26 copper wire, both being well insulated. This horseshoe magnet was fixed on a wood block, so that its poles projected horizontally, and a soft iron armature fixed to a spindle, so adjusted that it could revolve in front of the poles. This spindle also carried a cylindrical wooden piece, having brass strips on parts of its circumference, and which had contacts made against it by a couple of brass springs. This was the primary current contact-breaker. By shifting the angular position of this cylinder relatively to the armature, it was possible to break the primary circuit at an instant corresponding to any defined position of the soft iron armature. It was normally set iron wires, exert on one another when bound into a bundle with similar poles adjacent. On this account, he says, a bundle of fine steel wires will act almost as well as a bundle of fine soft iron wires when used as a core for an induction coil. Page proceeded still more to improve the coil, and in *Silliman's American Journal of Science*, Vol. XXXV., 1839, he communicates another Paper, dated from Washington, Nov. 13, 1838, in which he describes a large induction coil closely resembling modern models. This last coil had a straight core consisting of a bundle of soft iron wires, and the coil wires were wound on a bobbin, having wooden cheeks. The primary wire was a thick copper wire, and the secondary a very fine copper wire. This coil was provided with an automatic hammer break which broke and made a mercury contact (*see* Fig. 16). The hammer head was a ball of soft iron, which was operated by the magnetism of the core. The hammer head was prevented from sticking to the end of the core when attached by the interposition of a small piece of brass. The vibrations of the hammer worked a mercury cup break placed on the coil and which interrupted the primary currents. Page noted the fact that the deflagration of the mercury at the point of break had the effect of prolonging the contact because the primary current continued to flow in the mercurial vapour. Hence, it occurred to him to prevent this by putting oil or alcohol on the top of the mercury to quench the spark and increase the suddenness of the break. This device was revived many years after by other inventors, particularly by Foucault, but it seems first to have been used by Page, in 1838.

(To be continued.)