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# EARLY CONTRIBUTIONS OF ELIHU THOMSON TO ALTERNATING-CURRENT DEVELOPMENT


BY JOHN A. McMANUS

Thomson Research Laboratory, River Works, West Lynn, Mass.

General Electric Company



Reprinted from

GENERAL ELECTRIC REVIEW

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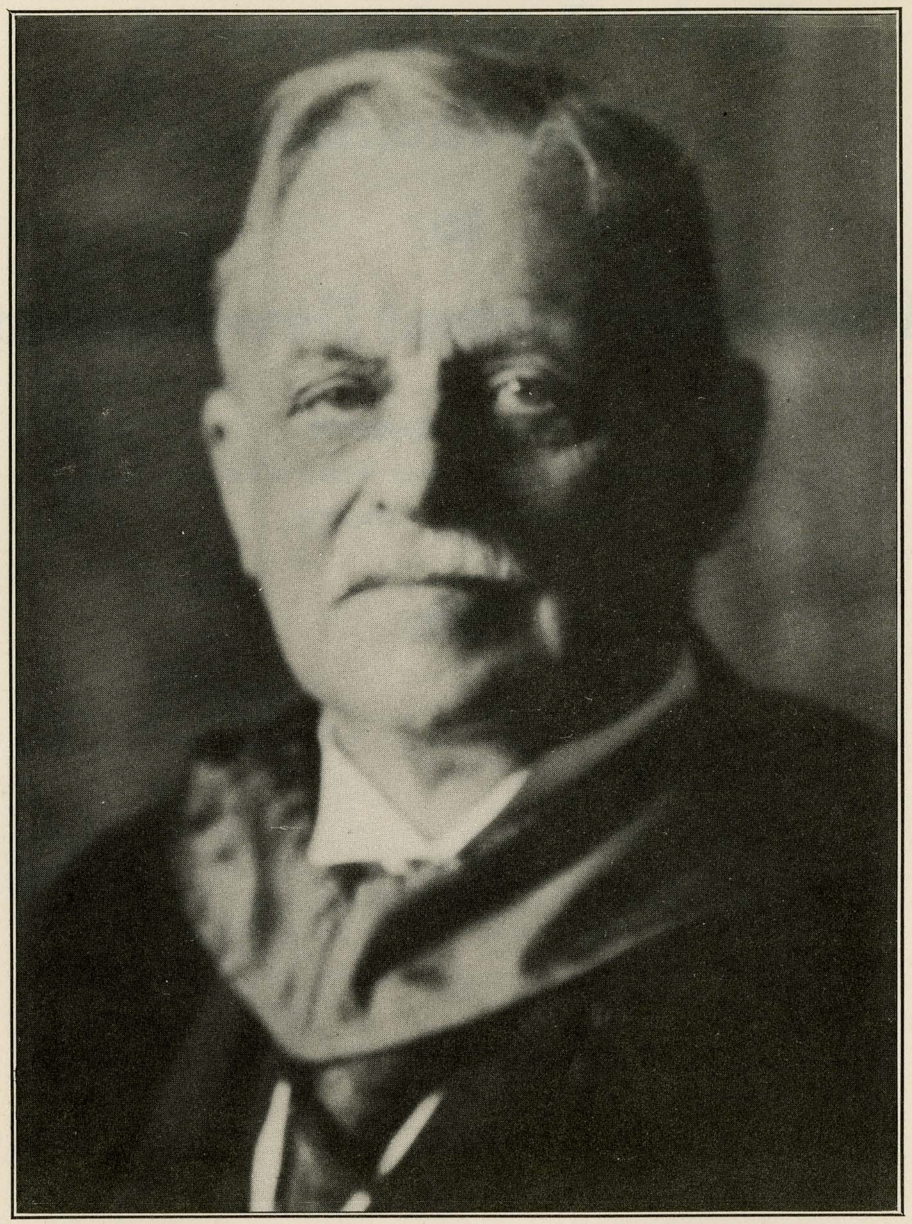

PROFESSOR ELIHU THOMSON

# Early Contributions of Elihu Thomson to Alternating-current Development

**Distribution in parallel transformer circuits – Early work with induction coils – Arc lighting system – Grounding system for protection – Alternators, motors, regulators, and meters**

By JOHN A. McMANUS
Thomson Research Laboratory, River Works, West Lynn, Mass.
General Electric Company

*(This account of some of Professor Thomson's early work is a timely and authoritative commentary on his genius, for Mr. McManus was his secretary for a long period of years, and up to the time of Professor Thomson's death.—Editor)*

AMONG the early electrical engineers to whose imagination the possibilities of the alternating-current system appealed was Elihu Thomson, whose activities in this particular field began in Philadelphia when he was about twenty-five years of age. It was during this period, about 1878–1879, that Professor Thomson was germinating the ideas which were soon to crystallize in the formation of the Thomson-Houston activities, beginning with his association with Professor Edwin J. Houston at the Philadelphia Central High School where they were both professors. One of their earliest activities was the reduction to practice by actual trial of what is today regarded as the fundamentals of the generation and distribution in parallel circuits of alternating current by transformation of voltage by means of transformers, or what were then called "induction coils," the primaries being connected in parallel to the mains and the load taken from the secondary sides of the transformers.

No better background may be had for a clear understanding of the activities of Professor Thomson and his associates in the early days with reference to the alternating-current developments than is found in the testimony in the interferences conducted in the Patent Office involving his patent application (Fig. 1) describing his fundamental system. This application for many reasons was delayed in filing until Nov. 2, 1885, and was not issued until April 22, 1902. It will be noted that the application was in the Patent Office for a goodly portion of the life of a patent, which is seventeen years. The reason for this long delay in issuing was because the application was involved in many interferences in which the work of Gaulard and Gibbs abroad, Charles F. Brush, and a number of other workers in the field were concerned. After this long-drawn-out litigation, priority was eventually awarded to Professor Thomson in the issuing of the patent. The Thomson patent No. 698,156, here referred to, was later declared invalid by the Courts for a number of reasons which would require lengthy explanation, but one of the chief of which was the holding of the Court that Thomson failed to show

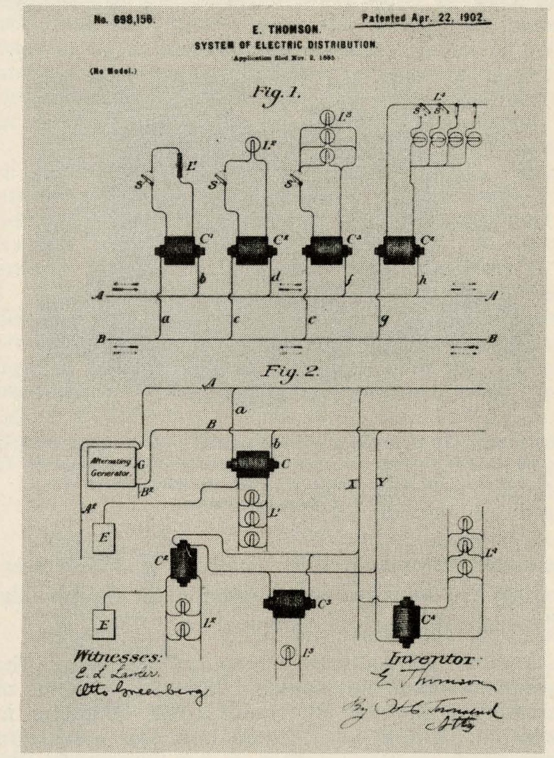


**Fig. 1. Diagram of circuit described in Professor Thomson's pioneer patent for his system of electrical distribution**

This is a broad transformer distribution patent, issued with its sweeping claims after a long contest in the Patent Office in interference with several other contestants. Based on Franklin Institute experiments in 1879.

reasonable diligence in the filing of his patent application, doubtless having in mind the time which had elapsed between 1879 until the late 80's when he began to exploit the system commercially. An excerpt from the Court opinion in declaring the patent invalid is interesting. The excerpt is as follows:

"The patent in suit rests fundamentally upon the connections of the primary coils of transformers in multiple to the supply main of a reversed or alternating-current circuit. If the patent be sustained, almost all lighting systems and the major part of the industry of the country, to the extent to which electricity is necessarily used therein, would be monopolized by the plaintiff. So useful and valuable is the system described and claimed by Thomson that he ought to give some satisfactory reason for the delay of 27 years from the date of his application to the time of testing the validity of the patent on final hearing in this court."

Regardless of the question of validity of the patent, Professor Thomson's parallel distribution system occurred in 1879. It is true that Professor Thomson's reduction to practice of the invention in 1879 was not a commercial operation, but it was of a character to show that he had, by actual trial, comprehended the fundamental requirements of what is today the system of alternating-current distribution in universal use.

The most authoritative and interesting account of this work is to be found in the words of Professor

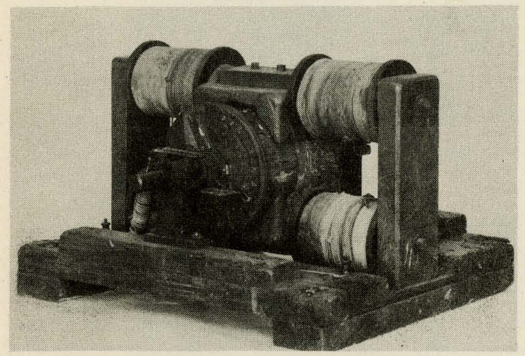

**Fig. 2. Early bi-phase dynamoelectric machine made in 1878 in Philadelphia, and having both alternating- and direct-current characteristics, used in the Hall of Franklin Institute early in 1879 with step-down transformers**

Thomson's own testimony involved in these interferences and which is here presented in reply to the following question by Counsel:

*Question.* "Please state what part you had in the conception and development of the system of distribution covered by these issues, detailing in narrative form if you choose how the inventions came to be made, whether or not you made any drawings, sketches, machines or apparatus, and how far the system or systems have been reduced to commercial form and introduced into practice by yourself?"

*Answer.* "I spent part of the summer of 1878 in Paris, particularly in examining the objects at the Exhibition. Before going there I had been engaged with Professor Houston in testing dynamos in Franklin Institute, the tests being completed in the early part of 1878. In 1877, in preparing a lecture on electricity, I had used a Ruhmkorff coil passing a Leyden jar discharge through the fine wire secondary and noticing the heavy current induced in the primary which thus became the secondary. I had also been interesting myself in the construction of electric apparatus, dynamos and motors from about 1874. On my return from Europe in 1878, Professor Houston and I discussed the great future which was in sight for electrical development and in October of that year we began to prepare to take out patents on systems of working which had occurred to us—I think we had applied for one or two patents before that time on electrical devices which were our joint work, but I remember distinctly that in October just before the winter of 1878–9 we spent a good deal of time in devising and discussing the various probable developments in the electric field. Among these was the idea of employing induction coils to feed lamps from secondary circuits, the primaries of the coils being supplied with alternating, intermittent, or currents reversed by commutating devices.

"This resulted in our filing on November 8, 1878 an application for a patent on a system of electric lighting, the main feature of which was the employment of induction coils connected to the main line and delivering low-pressure currents to the lamps in the secondary circuit. Our idea was to render the lamp circuit, namely the secondary circuit, independent of the main line or the pressure of the main line and constitute the lamp circuit a low-potential circuit whose potential would be just sufficient to run the lamp at the same time that the primary line might through a number of secondaries in which currents were induced feed a number of separate lamps. The construction of the induction coils was discussed between us and in our application both what are now called open magnetic circuit cores and closed magnetic cores were shown. Also the arrangements were such that by coupling the secondary circuits in series or in multiple the potentials might be changed as well as the effective sections of wire on the secondaries. We realized that for economy the resistance of the secondary circuit must be low in order that the whole of the potential there developed or nearly the whole should be expended on the lighting device.

"Soon after this application was filed we made preparations to put our ideas into practice and during the progress of these preparations—I think about the latter part of November of the same year—it occurred to me personally that if the induction coils were connected to the primary circuits in multiple so that each primary formed a branch from the circuit, the secondary currents would be obtained under more favorable conditions inasmuch as the cutting off of current in one induction coil or one secondary would have but little effect on the work of the other coils fed in multiple. I began the construction of a dynamo electric machine [FIG. 2] capable of exciting its own self and yielding alternating currents at the same time. I personally made the wood patterns, got the castings and built the machine, assisted in some parts of the work by Professor Houston. This machine was finished I think about the end of the year '78. Meanwhile I had constructed a pair of induction coils of the open-core type and the commutating apparatus driven by a belt for reversing the current at rapid intervals, of a continuous-current dynamo so as to be able to pass reversed currents through the primary coils of the induction coils. Early in January '79 this commutating apparatus was operated by Professor Houston and myself at the Franklin Institute Building, Philadelphia, the commutator being driven by a belt from a steam engine which stood on the floor of the lecture hall, the same engine driving a Brush dynamo, the currents from which were carried as continuous currents to the commutator and taken therefrom as alternating or reversed currents to the primary or primaries of the coils which had been constructed. The secondaries were made up so as to be coupled up in series or multiple and the vibrating lamp



[FIG. 3] was put in the circuit of the secondary coil. These vibrating lamps had meanwhile been made in two or three forms, and differed from ordinary arc lamps largely in the rapid vibration of one of the carbons towards and from the other and in the fact that free access of air to the carbons was prevented, with the object of preventing their combustion to a large extent.

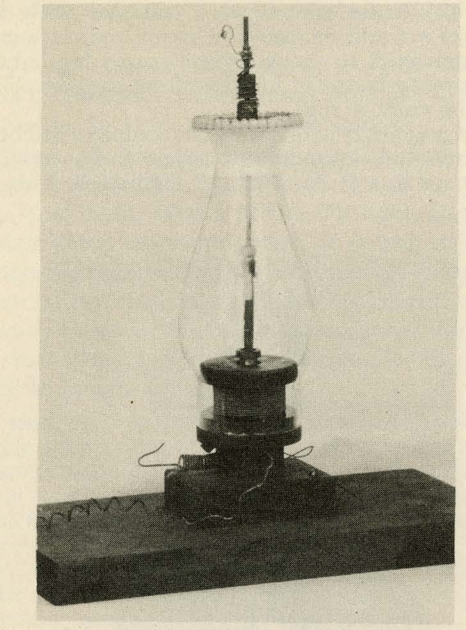

**Fig. 3. One of the two vibrating lamps used in connection with shell-type transformers in pioneer a-c trials of January and February 1879**

These lamps were used as a load in circuit operated by Professor Thomson's bi-phase dynamo and the current supplied to them was through the shell-type transformers used with that dynamo, no incandescent lamps being available.

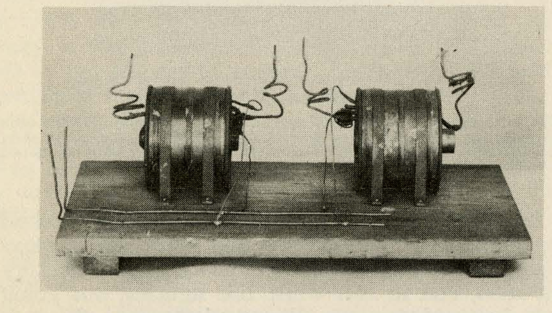

**Fig. 4(*a*). First pair of shell-type transformers as used at the Franklin Institute in January and February 1879 in pioneer a-c trials**

These transformers were used with Professor Thomson's bi-phase dynamo of 1878 to reduce to practice his transformer system invention. Primaries of fine wire in parallel from a-c dynamo, secondaries, coarse wire stepping down to local load.

"These experiments were followed by the construction of a pair of induction coils incased in iron [FIG. 4] which gave another type of coil now known as the closed-core type and late in January or very early in February a pair of these coils was used with the dynamo which had been constructed to give alternating currents for this work. The apparatus run by the Franklin Institute engine and the coils were tried with the primaries in multiple and in series on vibrating lamps chiefly, our idea being to so use the apparatus as to reduce to practice the various ways of working which had suggested themselves to either of us. I remember particularly that I was desirous of practicing the connection of the coils by their primaries in multiple and that in doing so I connected the long fine wire of the coil with the dynamo mains and used the coarser secondary as the source of current—the two iron-cased coils being used for this connection. The dynamo machine was of sufficient size to use about three horsepower in driving it. In the meantime a description of the apparatus had been made in the form of a specification for a patent and in the form of a short article in the Journal of the Franklin Institute for January, 1879. Immediately after this work, however, we were approached by Mr. Thomas H. McCollin of Philadelphia and Mr. George S. Garrett who were desirous that we should undertake the manufacture of arc lighting machines for which there was then an increasing market. I was asked whether I could produce machines capable of running a number of arc lights by continuous currents and on my statement that this could certainly be done according to our methods we began the manufacture. We soon had machines of the continuous current type in operation running eight arc lights in series and my time was largely taken up in the work of this development in addition to my duties as professor at the High School.

"This work finally culminated in the organization of a manufacturing company in New Britain, Conn. and demanded a great deal of my time during the latter part of 1879 and early part of 1880 and it became plainly evident that to pursue the work actively one of us must devote his entire time to it. I then resigned my position at the Central High School and removed to New Britain where my time was devoted to perfecting the details of our arc lighting system, in instructing men in devising methods and means for carrying out the work (all of which was of a novel character), and in general in looking after the affairs of the new Company. It took us until about the early part of 1881 to get well under way manufacturing dynamo machines, arc lamps, regulators, etc. While at New Britain, I think in the year 1881, as the first occasion, I went over with Mr. Rice, who was then my assistant in the electrical and mechanical work, the subject of the application of induction coils as distributing appliances for electric lighting, stating what I had done and what I thought the prospects would be of the eventual development in the direction of my early work. I remember particularly dwelling upon the naturally high economy which could be obtained by proper designing and the great ease with which the potential could be adapted to the work by simply selecting the proper windings for the coils. This general subject was discussed on other occasions during the New Britain period, but we had no time to turn aside from the regular work of the company which was limited to arc lighting machines and lamps.

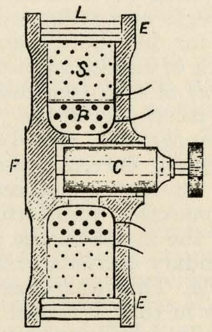


**Fig. 4(*b*). Cross-section of one of the coils of a shell-type transformer**

The primary coil *P* which surrounded the core *C* was provided with a secondary coil *S* adjacent to it. The ends *E* and *F* of the bobbin were disks of iron concentric with core *C*, slit from center to circumference. The outer extremities of the disks were connected by the laminated structure *L*, thus forming an induction coil encased in iron. The strength of the current developed in the secondary coil was greatest when the core was inserted so that its extremities were in contact with *E* and *F*.

"The affairs of the company were not in a satisfactory state in 1882 and for some months I had disconnected myself from it, while a majority of the stock had been purchased in the interest of the Brush Electric Company of Cleveland with the idea, no doubt, of shelving the business. Through my efforts and those of my associates at a great cost of time and labor this control was purchased by a Lynn syndicate who immediately made preparations to extend the business and finally removed it from New Britain. It took a very large portion of my time in instructing the new management in correspondence with those interested, who were resident in Lynn chiefly, and in traveling from New Britain to Boston during the major part of 1883. The removal to Lynn took place in the fall of 1883 when for the first time we had a well-equipped factory and were encouraged to develop our work in various directions. There was little need of transformer systems or converter systems for anything like arc lighting and the transmission of power as a field for work had not developed to any extent. Our company began, however, to turn its attention to the possibility of supplying incandescent lights from high-potential

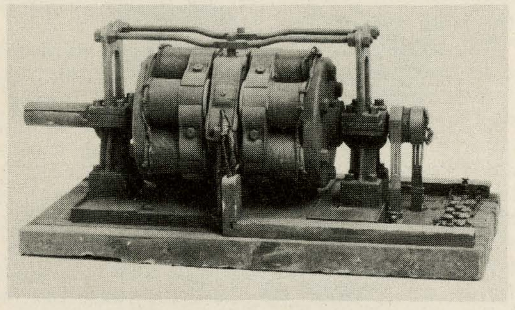

**Fig. 5. First a-c dynamo built in Lynn. Used on "Jew's-harp" welder and in other early applications of alternating current**

circuits in 1884. This led me to work out a number of ways using high-pressure currents and reduction of said currents to low potential for distribution and I again took up actively the work of employing induction coils, constructing a number of such coils during the year 1884 and towards the latter part of the year building alternating-current apparatus, namely a small dynamo yielding alternating currents and a motor-generator, also using alternating currents. I repeated my experiments connecting transformers or converters in multiple from the mains on the primary side and taking the secondary currents to feed incandescent lamps in multiple. This was done in about the year 1884, and early in 1885 I turned my attention to the use of such coils in still another direction. Sketches were made from time to time and in March 1885 I remember a sketch and description was made in a notebook which was kept by Mr. Rice as a sort of memorandum book and in which both he and myself made records from time to time. I prepared also in the fall of 1885 to put into practice an old idea of mine using converters or transformers whose potentials were to be high in the primary and low in the secondary for electric welding. Machinery [Figs. 5 and 6, and cover illustration] was built and operated about February, 1886, followed by the construction of other and larger machinery for the same purpose. I had before this time built an alternating dynamo of about four or five horsepower capacity and after beginning the welding work constructed another such machine and a pair of closed iron-core transformers which were finished in the summer of 1886 and used by me in September in carrying on some experiments and beginning the same month the same apparatus was used in the regular lighting of what is known as Factory B at the Lynn Works, which was then just being completed. In this case the alternating-current dynamo was driven by power in Factory A, the original factory building and the lines were led to Factory B, the potential of which lines was about 300 volts. In Factory B the two transformers were installed with their primaries in multiple from the mains and the secondaries connected to incandescent lamps for lighting, about twenty lamps in multiple from each secondary being the number run.

"Just previously to this work the company had begun to manufacture incandescent lamps and a supply of such lamps was at hand as a consequence. This had

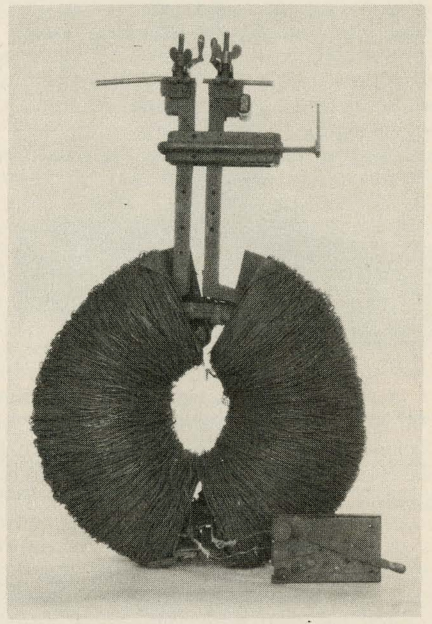

**Fig. 6. Welding transformer of early type with single-turn secondary, built in 1886**

The business which has grown as a result of this invention has been world-wide, and electric welding is used widely today in the metal parts and especially in the automobile industry. (The welding transformer shown went by the name of the "Jew's-harp" coil.)

not been the case previously as what lamps we had were odd lamps obtained here and there, not in regular supplies. Immediately after the lighting of Factory B in 1886, and in fact while this lighting was going on I designed for the Thomson-Houston Electric Company alternating-current dynamos and transformers or converters for regular commercial use and sale. Factory B was continued to be lighted by the same system and active preparations were made to put the apparatus developed on the market. There followed in 1887 a considerable extension of alternating-current distribution with transformers [Fig. 7] or converters as part of the regular work of the Thomson-Houston Company in connection with its other manufacture of electrical apparatus and this progress has continued on an increasing scale since that time—until at present very many plants are equipped and thousands of lamps supplied through the medium of transformers.

"The electric welding work which was started in 1885 has also resulted in a large expansion of the application of converters in accordance with the original plan. In addition I may also mention the fact that numerous plants have been installed by the General Electric Company, successors to the Thomson-Houston in this business for transmission of power on a large scale and in recent years such work has been going on in a continuously expanding manner."

It will be seen from the history thus recounted by Professor Thomson himself that while other engineers were contemporaneously developing alternating-current application, (notably William Stanley in this country, and Ferranti in England) the 1879 demonstration by Professor Thomson was from five to seven years earlier. In 1886, Stanley was working at Great Barrington at his commercial application while Thomson had actually lighted a portion of his plant at the West Lynn Works of the Thomson-Houston Company about the same period. It is true that the Thomson-Houston Company did not go into the commercial exploitation of alternating-current apparatus at this time for the reasons such as the following, which have been well stated by Professor Thomson, himself, from time to time:

"It may be proper to remark here that for a considerable time I was opposed to the introduction of transformers for lighting houses, etc., where it was possible that by leakage of the primary high-voltage current to the secondaries, a person might receive a dangerous, if not fatal, shock by touching a lamp fixture, while standing on ground or touching a metallic object, such as a heating radiator connected, as it would naturally be, to the ground.

"I set to work to provide effective safeguards, and several were invented. The best of these was the grounding of the secondary of the transformer itself, as in my U.S. Patent 322,138. I tried for years to convince people that such a procedure eliminated all danger, writing technical articles about it, etc. Some years went by after 1887, at which time my house in Lynn, Mass., and that of Mr. E. W. Rice, Jr., were provided with this protection. Gradually after these years, it was pronounced *permissible* by the authorities to use the safety ground. Some years later, the procedure was *recommended*, and years after that, it was made *mandatory*, and the practice was thus firmly established. I have a handsome set of resolutions of the Western Society of Electrical Inspectors, in which I have been unanimously called "The Father of Safety Grounding."

It is quite important to note with emphasis that the so-called "induction coils" used by Professor Thomson in the 1879 demonstration were constructed with a closed magnetic circuit as well as with the open magnetic circuit commonly employed. In other words, Professor Thomson had in this system not only the fundamental modern parallel distribution system by means of transformers, but also a transformer which itself involved the principle of the closed magnetic path.*

The following statement by E. W. Rice, Jr., in an address before the Stanley Club at Pittsfield in 1929 is interesting:

"The commercial introduction of the constant-potential alternating-current system with transformers followed promptly upon Stanley's demonstration in Great Barrington in March, 1886. This may be said therefore to mark the beginning of the commercial development and practical use of that system in this country.

"It is true that Thomson and his co-workers knew nothing of the Stanley rule for design of transformers, above quoted, until the issue of his patent several years later, in March 1892, yet meanwhile they had made many thousands of commercial transformers."

Upon the occasion of the presentation of the medal of the Verein Deutscher Ingenieure of Germany on Professor Thomson's 82nd birthday, John Liston wrote:[1]

"The presentation of the VDI medal of honor occurred in the 50th year after the filing of Thomson's epoch-making patent entitled "System of Electric Distribution," in which, for the first time, there was depicted and described a system which incorporated the fundamental elements of our present transmission lines and networks and which also included the humane provision of the grounded transformer circuit.

"As early as 1879, he had constructed and demonstrated in his laboratory the elements of this system; but it was not until 1885 that a patent was applied for, and subsequent litigation delayed until 1902 the granting of the patent.

"We who live in the era of gigantic central-station systems transmitting current over long distances for innumerable applications of electricity in industry and the home find it difficult to visualize the conditions under which the pioneers of the central-station industry labored in their efforts to make electric service broadly available.

"Despite the ingenuity and perseverance of the early inventors of the direct-current system, its limitations were such as to restrict its use to comparatively small areas immediately surrounding the power station; and this in turn compelled the industry to develop along the lines of a large number of small isolated plants whose sphere of service was definitely limited by the distance over which direct current could be economically transmitted.

"The invention of the alternating-current distribution system with its flexibility of voltage control liberated the central station from the limitations of the direct-current system as it then existed and made possible for the first time the practical utilization of power sources distant from the point of power utilization.

"In 1887 before the American Institute of Electrical Engineers, Professor Thomson read a paper entitled 'Novel Phenomena of Alternating Currents,' in which he made evident to his contemporaries the practical possibilities of his system. The effect of his disclosures at that time can hardly be over-estimated. They furnished inspiration to many whose names were later associated with the design and construction of apparatus to meet the growing needs of expanding central-station systems and by a logical sequence of development also made possible the present-day electrification of American Industry."

The first alternators sold by the Thomson-Houston Company and installed for furnishing lights to customers were built early in 1887. Two of them were tested and shipped in May of that year, one to the Lynn Electric Lighting Company and the other to New Rochelle, New York. The latter was first in operation, having been started up by Mr. A. L. Rohrer, engineer at the Thomson-Houston Works.

*The original dynamo, transformers, and vibrating lamps are now part of a permanent Thomson exhibit at the Franklin Institute, Philadelphia.

(1) Editorial, General Electric Review, vol. 38, no. 5, p. 209.

The alternator was of the revolving-armature type, was single-phase, of about 900 volts, had six poles occupying a horizontal position, and ran at a speed of 1200 rpm. It was self-excited, the excitation being furnished by a separate winding connected to a six-part commutator on the same shaft. Its capacity was two hundred 16-candlepower lamps and it was known as the "A-2." Several of them were built and sold. Various modifications and improvements of this type of alternator followed, such as A-4, A-6, A-12. About 1889 the numerical designation was changed to indicate kilowatt rating, such as A-18, A-35, A-70, A-165, etc.

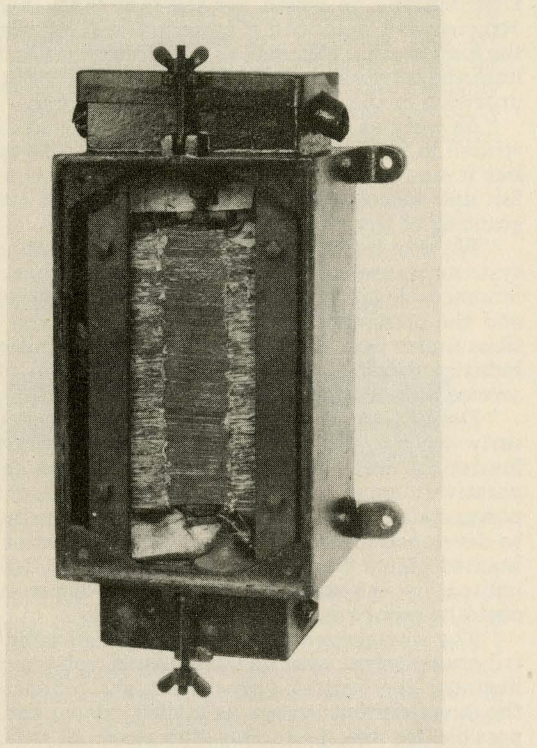

**Fig. 7. Interior of one of the earliest commercial transformers of the Thomson-Houston Company**

This transformer (which is now in possession of the Lynn Historical Society) was used for house lighting purposes in 1887 and was installed by the Lynn Electric Lighting Co. in the house of Mr. E. W. Rice, Jr., at 75 Washington Street, Lynn, Mass. A few years ago the transformer was taken from the house by Mr. I. F. Baker, the present owner of the house. The installation at Lynn was one of the first, if not the first, of the commercial alternating-current systems of the Thomson-Houston Co.

This particular transformer was provided with film cutout grounding protection. A similar transformer which was installed in Prof. Thomson's house at 26 Henry Ave., Lynn, about the same time was protected by the actually grounded secondary.

A very interesting commentary on early work in the field of a-c development is found in a compilation of the history of the General Electric Company, reading as follows:

"A generator may be designed to produce single-phase, two-phase, or three-phase alternating current. A single-phase circuit requires two wires, or conductors, whereas two-phase and three-phase circuits are operated with either three or four wires.

"As far back as 1879, Thomson's dynamo fulfilled the elementary requirements of an alternating-current generator, and he had devised two induction coils in a working circuit that were perfect counterparts of the modern transformer. But he did not utilize alternating current, because of the greater simplicity of direct current. In 1885 he foresaw that the day of alternating current was near; and he set up an experimental system at the Thomson-Houston plant, sending current from Factory A to Factory B, during the building of the latter (in 1886) and making use of transformers for so doing. This of course was not a commercial installation.

"Stanley meanwhile was working in the same direction independently of Thomson; and what he did had in the beginning no relation to the General Electric Succession. It was an outgrowth of his association with George Westinghouse. The latter had founded, in 1886, the Westinghouse Electric and Manufacturing Company, which has become one of the large electrical manufacturing units of the present day.

"Westinghouse saw the possibilities of alternating current, and the need of such a device as the transformer to give the current utmost utility. He bought the American rights to the patents of a Frenchman, Gaulard, and an Englishman, Gibbs, who had worked out transformers. Then he commissioned Stanley to experiment with Gaulard transformers, whose principal drawback was in their series connection so that they were dependent upon each other in operation and could not work independently.

"Stanley's notable contributions were two. First, he connected the transformers in parallel, giving independent operation, such as Edison obtained by connecting incandescent lamps in parallel; and second, he used the counter electromotive force in the transformer coils to make each transformer automatically regulate itself, thus permitting independent control of the devices supplied by the transformer.

"Thomson in 1879 had already accomplished the same things. He, too, had connected induction coils in parallel and had designed those coils to utilize the counter electromotive force, which he termed the 'reactive-kick.'

"Stanley obtained a patent covering the method of designing his transformer, rather than the method of connection in circuit. Thomson made application for a patent in November 1885, but it was stubbornly contested by several opponents, one of whom was the Gaulard-Gibbs combination. It was nearly twenty years before Thomson's patent was granted, only to be declared invalid in its first court test.

"Thomson, Stanley, and Westinghouse all perceived that the transformer was the key to a new door in electrical progress. Up to this time men generated electric current with great success. They distributed current after it was generated and utilized it in ways that were expanding every year. But they could not transmit the low-voltage current employed for incandescent lighting farther than three miles, without excessive line drop. To send it over greater distances requires large conductors and the incurring of a prohibitive expense for copper wire.

"The arc-light systems had an advantage due to the higher voltages used. Brush had used his forty-light dynamo to operate thirty lights at full brilliance ten miles away. This restriction of transmission was the serious limiting factor of Edison's system. An Edison generating station could not economically supply a territory greater than 16 square miles. The scheme became feasible only when the transformer was made practical.

* * * * * * * * *

"But the transformer would remain commercially valueless were it not for parallel connection and the proper use of the 'reactive kick.' The latter is in effect like an automatic valve, permitting the transformer to draw from electrical conductors as much current as is needed by the 'load'—that is, lamps or other devices in use. There is little waste current, the transformer never draws off more than it needs.

"In Stanley's historic installation at Great Barrington, current was sent from his laboratory in an old rubber mill on the outskirts of town into the town proper, a distance of four thousand feet, the voltage being transformed from 500 volts to 3000 volts and back again.

"Thomson did not place an alternating-current dynamo upon the market until the spring of 1887. His policy in one regard was distinct from that of Westinghouse and Stanley.

"He believed that high-voltage systems, which would obviously grow up as alternating current came into extensive use, required protective devices to safeguard customers. In 1885-1886 he devised such protective equipment and incorporated it into his first commercial transformers. Until he had done this, he would not allow the Thomson-Houston Company to exploit the alternating current commercially. His feeling on this point was inflexible and won the endorsement of both Coffin and Rice. Thomson told his colleagues that he would not permit an alternating-current system to enter his own house without protection and therefore he would not sanction its use in the houses of others.

"Westinghouse and Stanley were in open disagreement. They recognized the latent danger in a high-voltage line, but they held that it was exaggerated. So they went ahead, while the Thomson-Houston Company refrained from entering the field though at no time did it condemn or criticize its competitors.

"Not so the Edison Electric Light Co. which assailed alternating current and kept up the attack against competitors that ventured to advocate it. At first the Company trained its guns upon th Westinghouse people. When the Thomson-Houston Company put transformers in the field with a Thomson protective device it was also included in the attacks. Sales agents had no trouble convincing customers that its transformer was now perfectly safe. But the Edison Company remained adamant toward the alternating current, regardless of whether protective devices were in use or not.

"In a printed pronouncement, the famous 'Red Book,' bound in scarlet covers and under the glaring title of '*A Warning from the Edison Electric Light Company*,' it sought to show that the alternating current was a menace to life and limb. And this attitude persisted despite the obvious electrical advantages of utilizing that kind of current.

"The clash of opinions was intensified by the decision of the New York State prison authorities to adopt electrocution for capital punishment and to employ alternating current for the purpose. That was ammunition for the direct-current artilleries. What could be more convincing, they demanded, than the official selection of this current as the most efficacious means of executing men?

"So there grew up this curious conflict known as the 'War of the Currents.' The Westinghouse group frequently struck back at the Edison camp, and these became the principal antagonists. Coffin never permitted the Thomson-Houston contingent to participate in the skirmishing. He insisted that his men keep quiet and 'saw wood.'

"As a matter of fact there was never quite the protective advantage in the direct current that its protagonists supposed. At equal voltages, alternating current, as Thomson said, is less deadly than direct. The danger in alternating current is that the primary coil in the step-down transformers, from which circuits enter houses and offices, may accidentally come in contact with the secondary coil, allowing the high voltage of the former to enter the secondary circuit. Should that occur, any person touching the secondary was likely to receive a serious shock. Under prevalent methods of manufacture and installation Thomson believed that the two coils might readily short-circuit.

"To take care of such a contingency, he invented three methods of protection, each of them effective. The one finally adopted, because of maximum reliability and simplicity, was to ground the secondary wires of the transformer with a metallic conductor. Once adopted, the Thomson-Houston Company did not hesitate to exploit the alternating current. A complete commercial system was planned at once, using Thomson alternators and transformers. The latter raised the current pressure for transmission to a thousand volts, which was for some years the standard Thomson-Houston transformer voltage.

"The Thomson alternator was a dynamo with six magnetic poles, producing current at approximately 60 cycles. The first of these units was ready for shipment May 11, 1887, and was installed in the Stewart Street generating station of the Lynn Electric Lighting Co.

"Strangely enough, opposition was encountered in the fire underwriters, who persuaded themselves erroneously that the grounded secondary was a fire menace. This prejudice lasted no less than 20 years, despite continued successful installations of the system with the grounded secondary included. There came a day when the fire underwriters opposed it a little less vigorously, then they tolerated it. Soon they actually favored it, and last, they made it mandatory in the interests of fire protection. This was in 1902, when the Thomson-Houston Company had gone out of existence and the General Electric Company held the patent.

"The Thomson-Houston Co. had realized the limitations of the direct-current system back in 1885 when a direct-current line of 110 volts was run from the Stewart Street Station to the old Lynn Armory, only 1200 feet away. The amount of copper wire required for the distance was surprising.

"In the same year one of their 'experts,' Charles B. Burleigh, installed a direct-current incandescent system at Montpelier, Vermont, where he put in two dynamos. Two years later he went back to Montpelier to replace the direct-current system with alternating current. When he got through with the work, he had a large reel of wire previously a part of the system but not needed for the new system. Upon calculating the value of the surplus wire he discovered that it equalled the entire cost of making the change-over.

"Experienced construction men had to undergo an initiation when it came to alternating-current work. Burleigh's curiosity about the new principle was so overwhelming that he was led to take a transformer apart to find out how it worked. The original transformer was about the size of a nail keg. When he put it together again, he found to his bewilderment that it had swollen to the dimensions of a flour barrel. No one doubted the accuracy of his statement when he shipped it back to the factory labeled: 'Struck by lightning.' "

Another outstanding achievement of Professor Thomson during his Philadelphia days was the construction of the first three-phase winding on any dynamo, which appears in his Patent No. 223,557 of

January 13, 1880, filed October 4, 1879. The dynamo involving this principle was known as the three-coil arc dynamo (FIG. 8), which with its automatic regulator and other novel features formed the basis of the successful lighting system put out by the Thomson-Houston Electric Company beginning in 1880. The three-coil dynamo was one of the first three-phase machines and was shown as an alternator in the original patent papers.

Although originally used for direct current, the principle of this three-phase armature is now embodied in practically all power generators of large or small capacity using alternating currents. Even the motors used in toys, such as toy trains, have all along embodied examples of the three-phase armature winding. Professor Thomson related that the original specification filed in the Patent Office contained claims for alternating-current generation, and with collector rings for the phases, but these claims were cancelled at the time upon advice of the patent solicitor in order to facilitate a quicker allowance of the application. The machine was known as the famous "Bakery machine" because of its use for lighting a large bakery in Philadelphia in 1879 and is now preserved at the Smithsonian Institution in the National Museum at Washington.

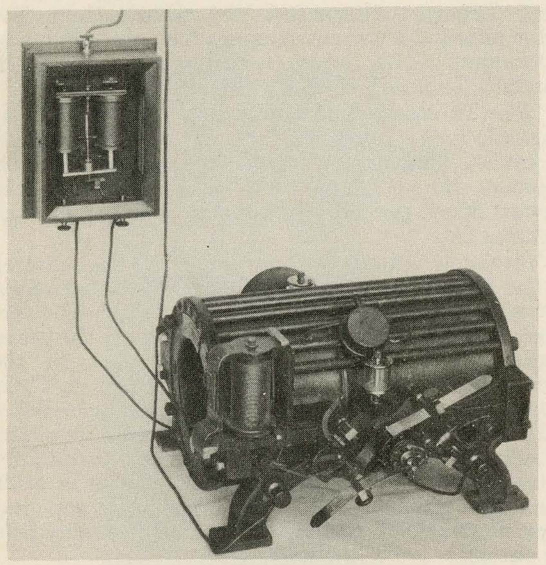

**Fig. 8. An early commercial form of the arc machine, with wall controller and automatic brush-shifting regulator**

This machine was of the consequent-pole type, and the armature was one with three coils, the commutator being of three segments only. It is believed that this was the first dynamo having a three-phase winding. By suitable movements of the collecting brushes on the commutator, it was possible to employ a regulating system whereby under any variation of load from full number of lamps in series to none, the current in the circuit could be maintained constant. It was also possible to run successfully a series of arc lamps with perfect success, even though the engine speed was irregular or subject to considerable fluctuation.

During the years 1887 and 1888, Professor Thomson built the first experimental induction motors including a single-phase motor having a commutator. The first induction motors built by the company with reference to commercial use were brought to test early in 1892. As a result of this test, it was decided to proceed with the development of motors of two or three sizes.

The necessity then sprang up for polyphase generators or some system of operating polyphase motors from single-phase circuits. The monocyclic generator was conceived by Dr. C. P. Steinmetz as something that would supply the want, and was a dynamo from which could be obtained single-phase and polyphase potentials. Many of these generators were built in the years 1894 to 1900 in both belt-driven and direct-connected units.

The demand for generators for power purposes increased so rapidly during the period from 1894 to 1900 that numerous two-phase and three-phase generators and motors were developed. As a result, lighting circuits were run more and more from polyphase circuits.

It became apparent during this period that revolving-field alternating-current machines had decided advantages over those of the revolving-armature type, as higher voltages and greater capacity were thus made practicable. Power applications were chiefly through induction motors, consequently the power factor of the generator was so low (because of the low power factor of motors running at less than full load) as to make unsteady the potential on lighting circuits, however alert the operator at the switchboard may have been. The situation was relieved by the development of field regulators that controlled the excitation and maintained a constant voltage by regulating the field of the exciter. And, thus, by evolution, we have come to the more modern changes and application of alternating-current machinery and design, by what has been herein referred to as important landmarks in the process.

One of the outstanding inventions of all time insofar as the industrial arts are concerned, and more particularly associated with the applications of alternating current was that of electric resistance welding (Patent No. 347,140 of Aug. 10, 1886). Professor Thomson described this invention in his own words, as follows:

"While preparing a lecture on Electricity (one of a course of five) at the Franklin Institute at Philadelphia, early in 1877, I had the temerity to pass the discharge of a Leyden battery through the fine wire secondary of a Ruhmkorff induction coil, while the primary coil of quite coarse wire had its terminals resting together in contact. As the Ruhmkorff was my own, one I had made, I could take the risk of breaking down the insulation. On the passage of the condenser spark of about 35 mm length, a bright flash appeared at the ends of the heavy primary in contact, and I afterward found them firmly welded together.

"This suggested to me the possibility of electric welding, and later, about 1885, as soon as opportunity afforded, I built the first electric welder,* using a transformer to step down to a very short and heavy secondary between the terminals of which, by suitable clamps, the pieces to be welded were held in juxtaposition or contact. The first trials of this apparatus were highly successful, and welds were made, not only between pieces (bars) of the same metal, but many different metals were so united.[2]

"In the development of this very valuable means of uniting metals, it was necessary to devise special types of electric welders for a great variety of work, and this led to the making of a series of inventions during years of effort. The applications of electric welding by the Thomson process, now called 'the resistance method,' are already innumerable and are constantly increasing. As an example, it is now noted that in the forming of such a structure as a Ford automobile, more than two thousand electric resistance welds are made. Of especial interest is the application of the method to the production of steel pipes, as one definite example, and of steel chain by electric chain welding machines, as another."

*The first electric welding transformer with single-turn secondary (illustrated on cover page) is now lodged in museum exhibit, Franklin Institute, Philadelphia.



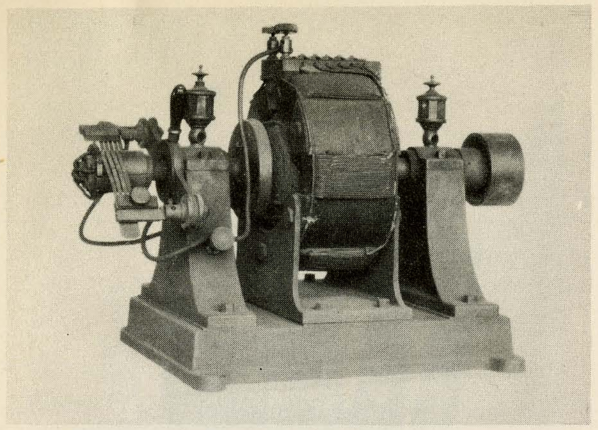

**Fig. 9. Early form of repulsion motor (1889)**

This type of motor was an outcome of Professor Thomson's discovery of the principle of electro-inductive repulsion.

In 1885, when working on certain properties of transformers, Professor Thomson made an observation, the result of which when followed up led to the discovery by him of electro-inductive repulsion. This was unique, a pioneer discovery, upon which were based many new applications in alternating current, such as repulsion motors (FIG. 9) designed upon the principle of electro-inductive repulsion, and the repulsion-induction motor. A motor running by alternating current on this principle was probably the first motor actually designed for alternating current alone.

In a year or two these were supplemented by the discovery of the effects of what is known as the "shaded pole." These shaded-pole effects (FIG. 10) were embodied in alternating-current motors (FIG. 11) and in meters. They are still fundamental. Repulsion-induction motors have been built by many thousands, while meters for measuring and recording the energy supplied to consumers also employ the principle of the shaded-pole application. This is also true of fan motors.

The induction regulator for alternating currents was another outgrowth of this discovery; it was disclosed in Professor Thomson's fundamental Patent No. 465,078 of December 15, 1891, and other patents followed. This device is now very extensively used and has been subject to many modifications of design by others as a standard part of the equipment of alternating-current systems.

In 1889 there was an exhibit at the Paris Exposition of this electro-inductive repulsion apparatus of Professor Thomson which is now lodged at the Royal Institution at London as supplementary to the Faraday apparatus. It was also used by Dr. J. A. Fleming in a famous lecture before the Society of Arts (London), May 14, 1890.

The Thomson recording wattmeter (as this commutator type of watthour meter was then called) is so well known that it requires but very little mention except to say that this meter was universal for both a-c and d-c applications and that many millions of them have been made. The first of this type of meter was produced in 1889, and in 1890 the Paris prize of 10,000 francs was divided between the Thomson meter and Dr. Aron's original meter which was a much more expensive and complicated meter and has seen but a small amount of use.

In the field of alternating-current measuring instruments, Professor Thomson invented the so-called "inclined-coil instrument" patented in 1895, and a patent on the wattmeter of the same type was issued in 1896 (FIG. 12). This inclined-coil principle was used in ammeters, voltmeters, wattmeters, etc., especially adapted for alternating-current measurements. The instruments went into very extensive use.

Professor Thomson made important contributions to the design of transformers, particularly his constant-current transformers and several patents taken out by him in 1889 showed the first examples of this kind. These involved magnetic leakage shunt on constant-current systems and the constant-current transformer with movable coil was patented by him on March 20, 1894 (Pat. No. 516,846). This transformer was based on the principle of electro-inductive

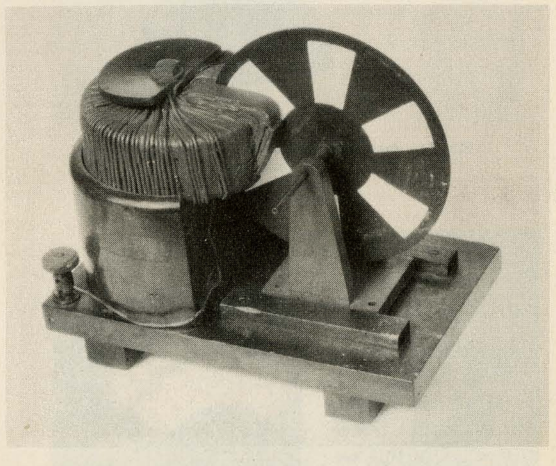

**Fig. 10. A device illustrating the principle of "shading" the pole by closed circuits**

A laminated ring is wound over with wire, but has a slot cut through it, dividing the ring and causing it to present two pole faces opposite to each other at the air-gap. Each pole is "shaded" by a set of closed copper bands. A copper disk, free to turn on a shaft, is introduced by one edge into the air-gap in the magnet and turns rapidly when the magnet is excited by an alternating current. A silver coin held just at the edge of the air-gap in such an alternating magnet with a shaded pole is drawn into the interpolar space and propelled with some force through it. A lead disk or coin of base metal is acted upon by a smaller force, owing to its inferior conductivity.

(2)"Electric Welding," by Prof. Elihu Thomson, *The Electrical World*, vol. VIII, no. 26, Dec. 25, 1886, pp. 307-309.

repulsion previously mentioned. This gave rise to the so-called "tub system" for series street lighting. The core of the transformer had a fixed primary and a movable secondary (Fig. 13), for generation therein of constant alternating current. This invention went into very wide and extensive use both here and abroad and is still in use.

Other transformer contributions were:

(*1*). Immersion of transformers in heavy oils for conserving insulation and for cooling.
(*2*). Casings for transformers with expanded external surfaces for cooling.
(*3*). Casings with internal projections to pick up heat from the oil.
(*4*). Cooling channels for circulation of air in cooling.
(*5*). Ducts or tubes for circulating cooling water, so as to cool the oil in which the active elements, primary, secondary, and iron core are immersed.
Patent No. 428,648 of May 27, 1890 relates to this development.

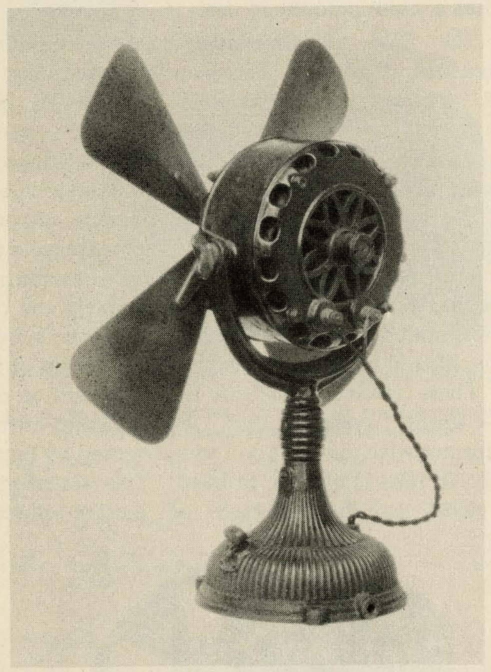

**Fig. 11. An a-c fan motor of the shaded-pole type with 16-in. fan**

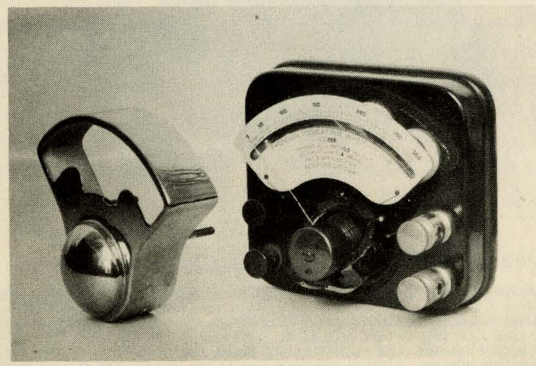

**Fig. 12. Thomson inclined-coil indicating wattmeter (1895), a type of instrument extensively used with alternating currents**

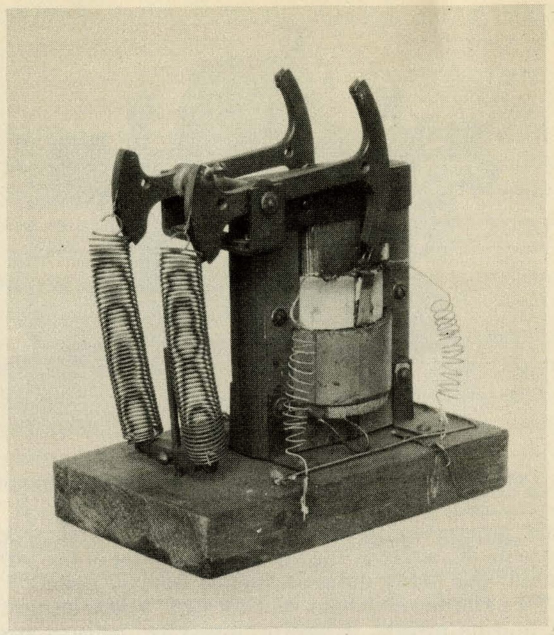

**Fig. 13. Constant-current transformer (1891)**

This is a transformer with a movable secondary properly supported and counterbalanced to supply constant current. This type of transformer has been extensively employed in operating circuits of street lights, and went by the name of the "tub" system. It enables constant-current service to be supplied from alternating-current sources, thus supplanting, especially when used with a rectifier, any need for a special arc dynamo.

The utilization of these principles is now practically universal procedure. There was a prior patent to David Brooks, showing the method of insulating cables and induction coils in oil, but Professor Thomson's work was constructive in the use of oil for insulating and cooling transformers on a commercial scale.

The so-called "reactive coil" or theater dimmer and welding regulator was invented by Professor Thomson and is still in use in modern power plant installations.

Professor Thomson filed a patent application on August 17, 1891 which resulted in Patent No. 471,155, March 22, 1892, relating to condenser starting motors for alternating current work in which portions of the stator winding are shunted by condensers for advancing the phase of that part and so assisting starting on displaced phase principles for single-phase operation. At the same time the power factor is much improved by the condenser. The condenser compensator used on early a-c self-starting motors embodied this principle.

Many arc lamps of varying design adapted for alternating-current circuits were made by Professor Thomson and his associates at Lynn. Professor Thomson also contributed prolifically to the development of high-frequency applications of alternating currents. These contributions embodied not only the study of novel phenomena of high-frequency currents, but also the production of electrical apparatus utilizing the principles studied by him in this connection.

From the time Professor Thomson began his pioneering activities in alternating current, and through years of its later development, he contributed many important engineering and scientific papers and addresses bearing on various divisions of the subject.