HISTORY OF TECHNOLOGY SERIES 3

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A History of Electric Light & Power

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with good wishes,
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There were different opinions about the ideal supply voltages for electric trains, and whether the supply should be a.c. or d.c. In 1920 a Railway Advisory Committee recommended the general adoption of 1500 V d.c., which was in use on some main line railways. The Ministry of Transport accepted this and it remained the standard for some years.

Most of the early electric railways and tramways used direct current, because the series-wound d.c. motor has ideal characteristics (especially a high starting torque). For main lines, however, a.c. transmission was preferable, but no a.c. motors were really suitable for the purpose. The introduction of the mercury arc rectifier in 1928 was a landmark in the development of railway electrification. It permitted a.c. supply to the train with rectifiers on the train feeding d.c. motors. Most of British Rail now uses this system with 25 kV overhead wires. The Southern Region of British Rail uses third-rail d.c. at about 700 V. Other countries have used a variety of systems including a.c. at $16\frac{2}{3}$ and 25 Hz and also three-phase a.c. The three-phase systems, in Switzerland and Italy, had one phase earthed to the track and two overhead wires for the other two phases. Since about 1960 the development of germanium and silicon power rectifiers to replace the mercury arc has simplified the rectifying equipment on board trains.

Fig. 16.5 *Drawing of the City and South London Railway, soon after its opening in 1890*

Although d.c. motors and generators are basically the same machines, some design differences appeared quite early. The main visible difference was that motors, which are often used in dirty surroundings, were more enclosed than generators, used in clean engine rooms.

One of the best known British firms was Laurence, Scott and Co. of Norwich. In the 1890s they were supplying totally enclosed motors for factories. These machines naturally ran quite hot, and were said to be good for warming the workers' tea. The founder of the firm, William Hardman Scott (died 1938) began his electrical career with the Hammond Electric Light Company and went to Norwich in 1883 to instal lighting plant for Colman's, the mustard manufacturers. Scott thought he could make better machines than Hammond's, and with financial backing from Colman's he set up a partnership with a Mr. Paris.

Scott and Paris soon linked up with Reginald Laurence, a mechanical and civil engineer with money to invest, and the firm became Laurence, Scott and Paris. By 1900 the name of Paris had disappeared from the Company's literature: it was Laurence, Scott & Co. Ltd. They specialised in d.c. machines, especially for use on ships. A point of interest to historians is that detailed records and drawings of thousands of machines from about 1900 onwards have been preserved. In 1927 Laurence, Scott amalgamated with Electromotors Ltd of Manchester, which made a.c. machines.[12]

In the United States there were fifteen manufacturers of electric motors by 1887, and more than 10 000 machines had been produced. The most important manufacturer was the C & C Company, which began in 1886. The initials stood for C.G.Curtis and F.B.Crocker, and because they were closely associated also with S.S.Wheeler the firm was also known as the Curtis, Crocker, Wheeler Company. Their first motors were used for driving sewing machines, some being wound for operation from a 6 V battery, others for use on the 100 V mains.

Another American pioneer of electric motors was Frank Julian Sprague (1857-1934), who trained as an engineer in the US Naval Academy. He left the Navy in 1884 to organise his own electrical engineering company. One of his first products was an electric hoist for use on building sites, from which he moved on to electric passenger lifts. His major contributions, however, were in the field of electric traction.[13]

D.C. motors are mainly used in traction, and in other applications where speed control is all important, such as lifts and rolling-mill drives. Such machines may be rated at several thousand horsepower, but the principles of the motor are no different from the smaller machines. Control systems are discussed below, but it is appropriate to consider first the early a.c. motors.

16.2 Induction and synchronous motors

The earliest motors operated on direct current but the advantages of a.c. for transmission and distribution encouraged engineers to develop an a.c. motor. The first practical a.c. motors were the induction and synchronous motors developed by Tesla in 1888.[14]

Nicola Tesla (1856-1943) was born in Smiljan, then in Austria-Hungary but now in Yugoslavia. After studying at Graz and Prague he took up electrical engineering. He made his first invention, a telephone repeater, in 1881 while working at a telephone exchange in Budapest. In 1884 he emigrated to the USA, and became an American citizen. He worked for Edison for a few years, and then joined Westinghouse. Edison was a 'd.c.' man, firmly opposed to a.c.; Westinghouse was the leading American exponent of a.c. systems. In changing employers Tesla was stating his own views on the future direction of electrical engineering.

The fact that a pivoted permanent magnet or a pivoted piece of magnetic material will follow a rotating magnetic field had been discovered by Arago in 1824 (see Chapter 2). Arago produced his rotating magnetic field by rotating a permanent magnet. Tesla's great achievement was to produce a rotating magnetic field from alternating currents flowing in fixed coils. His first motor had two field coils energised by two alternating currents whose waveforms were 90° out of step (Fig. 16.6). Tesla showed that the resultant magnetic field of the two coils was roughly constant in strength but rotating in direction. He went on to show that three coils spaced 120° apart and supplied with three-phase a.c. would also produce a rotating field.

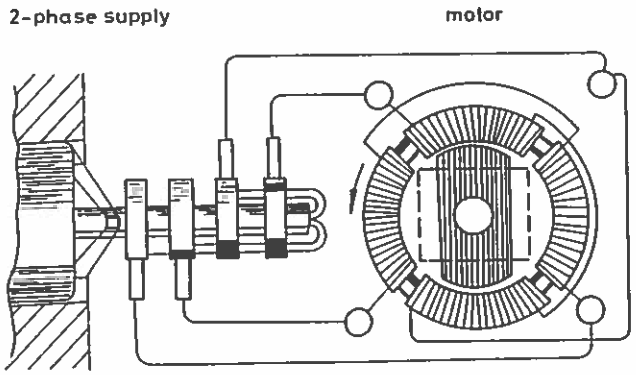

Fig. 16.6 *The principle of Tesla's two-phase induction motor*
A generator (on the left in the drawing) has two sets of coils on its armature, and gives currents 90° out of step. These currents pass through coils arranged at right angles in the motor and produce two oscillating magnetic fields. The resultant of the two magnetic fields is a field of constant strength whose direction rotates. The rotor of the motor follows the rotating magnetic field.

Tesla announced his discovery of how to make a rotating magnetic field at a meeting of the American Institute of Electrical Engineers on 16 May 1888.[15] By 1889 Tesla had obtained ten United States patents, covering two-phase and three-phase induction and synchronous motors, a two-phase four-wire power distribution system, and also split-phase starting of a single-phase motor (see Fig. 16.7).

The synchronous motor corresponds to Arago's experiment with the pivoted permanent magnet. The rotor turns at exactly the same speed as the rotating field although the rotor poles will lag behind the apparent poles of the rotating field by an angle dependent upon the load. The synchronous motor therefore runs at a constant speed, determined by the frequency of the supply and the number of pairs of poles of the rotating field, and has to be run nearly up to 'synchronous' speed by some other means when first switched on. The induction motor corresponds to Arago's experiment with a disc that is not a permanent magnet. The rotating field induces currents in the disc which react with the field to produce rotations. Since the induction motor depends on relative motion between the rotor and the rotating magnetic field in order to induce currents in the rotor, it follows that the rotor speed must always be a little less than the synchronous speed.

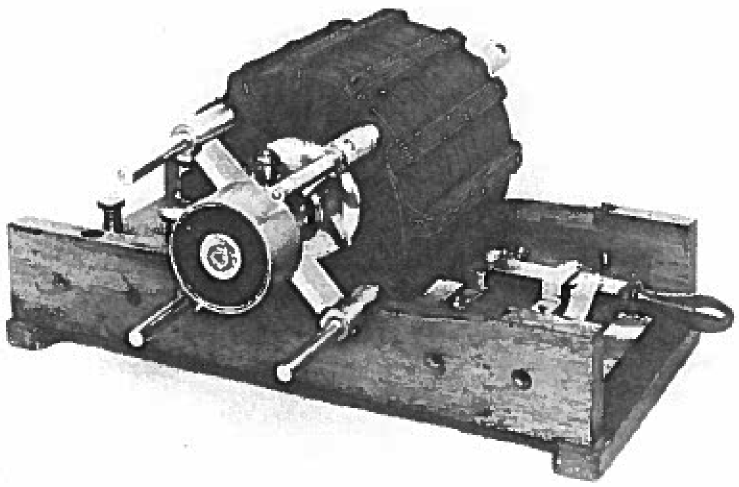

Fig. 16.7 *Experimental induction motor made by Tesla about 1888, and given by him to the Science Museum*

Other people were working on the problem of creating a rotating magnetic field, including Michael Osipowitsch von Dolivo-Dobrowolsky (1862-1919), a Russian by birth who spent much of his life in Germany.[16] Another was the Italian Galileo Ferraris, who published his work just before Tesla. Both Tesla and Ferraris described a motor in their initial publications, but Tesla had developed his ideas much further. When challenged on the ground that Ferraris had anticipated him, Tesla's main patents were upheld in the United States' Courts.[17]

Tesla also showed that an induction or synchronous motor could be run from a single-phase supply if part of the field winding were connected through a capacitor or inductor, to produce a second phase. Once started the motor will run satisfactorily on the single-phase supply, and in many motors the starting capacitor or inductor is taken out of the current automatically once the motor is running.

The Westinghouse Company bought Tesla's patents, and from 1892 they began to promote polyphase a.c. distribution systems. They adopted the three-phase 60-Hz which remains the American standard to this day. European engineers preferred lower frequencies, usually 25 or 50 Hz. An experimental single-phase induction motor made in London about 1891 by W. Langdon Davies is shown in Fig. 16.8. By

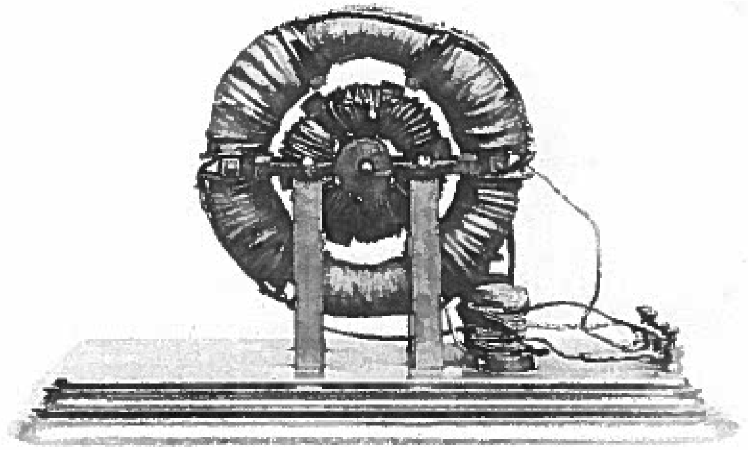

Fig. 16.8 *Experimental single-phase induction motor by W.Langdon Davies about 1891*

1895 Westinghouse had a range of induction motors in production. For motors up to five horsepower the rotor was a 'squirrel cage' construction as used in modern induction motors. The electrical part of the squirrel cage rotor consists of two end rings linked by straight bars. (Squirrels were sometimes kept as pets in the late ninteenth and early twentieth centuries. Presumably the rotor reminded people of the squirrel's cage or, more likely, of the treadmill sometimes placed in pets' cages to amuse the animal – or its owner). For higher rated motors Westinghouse preferred to have the rotor wound with wire. A resistance was connected in series to reduce the starting current, and then cut out automatically when the motor had run up to speed.

The American General Electric Company decided to make a.c. machines, and in 1896 they were offering induction motors up to 150 horsepower.[18]

Most of the world's electric motors today are induction motors. They can only be used where a constant speed is required, but for many industrial applications that is perfectly acceptable. Because it needs no brushgear the induction motor gives reliable service over long periods of time with little or no maintenance. Most domestic washing machines use an induction motor with capacitor start; for other domestic appliances the lighter universal motor is preferred.

An important type of induction motor in low power applications is the 'shaded-pole' motor. As already mentioned, a single-phase induction motor requires a second phase to be introduced for starting, although the machine will then run without it. In the shaded pole motor there is only one field winding but part of the iron pole face is 'shaded' by surrounding it with a thick copper ring. The alternating magnetic flux induces a current in the ring which has the effect of retarding the flux in that part of the pole. In effect the shaded pole motor is a two-phase machine, with the flux in the shaded part of the pole lagging behind the main flux. The resultant flux has a rotating component, so the motor will start. The simple construction of shaded pole motors makes them very reliable. They need no maintenance and are widely used for low power applications where efficiency is not important, such as fans.

A motor which is easy to confuse with the induction motor is the repulsion motor. The confusion is compounded by the existence of mixed action motors which start as repulsion motors but run as induction motors.

The repulsion motor is largely due to J.A.Fleming and Elihu Thomson. Fleming, who was professor of electrical engineering at University College London, is best known for his work in connection with radio. Fleming made a study of the forces between conductors carrying alternating currents. In 1884 he showed that a copper ring suspended within a coil carrying an alternating current tends to twist so as to be edge on to the magnetic field. This is the basis of the repulsion motor. Fleming presented a survey of much of his work in a Discourse at the Royal Institution on 6 March 1891.[19] He demonstrated the 'jumping ring' experiment in which a copper or aluminium ring dropped over a vertical iron bar is thrown off when alternating current is passed through a coil on a bar. By cutting the ring and inserting a lamp he showed that a current flowed around the ring and that the repulsion of the ring was due to this current. Fleming then described the action of induction motors and of repulsion motors, which were being developed from his ideas by Elihu Thomson in America. For the latter he had demonstration equipment sent him by Thomson.

Thomson's repulsion motors had a single field winding and a wound multi-coil armature with a commutator. Two brushes which are connected together act on opposite sides of the commutator and short-circuit the armature coil which is positioned across the magnetic field. There is then a turning force on that coil, and the armature rotates.

More complex repulsion motors were soon made. Some had two sets of field windings placed at right angles and connected in series. The motor could be reversed by reversing the connections of one winding. Some had two sets of short-circuited brushes, or one set of short-circuited brushes and another set connected to the secondary of a transformer whose primary is in series with the field winding. The advantage of this complicated arrangement was that the machine had a very good power factor.

Repulsion motors are mainly single-phase, though can be made for polyphase supplies. They give a good starting torque and have been used extensively for electric traction with speed control obtained by shifting the brushes. In practice large repulsion motors require more maintenance of the brushgear than d.c. machines, and for lower power applications the capacitor-start induction motor or the 'universal' motor is preferred.

16.3 Control of motors

In many applications motors are 'controlled' simply by switching them on or off.

The two potential applications of linear motors that have attracted most attention throughout the twentieth century are driving shuttles in a loom and railways. Emile Bachelet set up a company to work on both applications in 1914. Eric Laithwaite was first interested in the linear motor for use in a loom, and turned later to its use in transport. The loom requires a means of projecting the shuttle at high speed across the width of the cloth. Conventionally, this is done by striking the shuttle very hard and catching it on the other side, a process which wastes energy and requires considerable mechanical strength in the shuttle. Despite many attempts linear motors have still not taken over in this application.

The story of linear motors in transport is one of promising but unsuccessful ventures. Readers interested in this theme are referred to Professor Laithwaite's book in this series.

One application where linear motors have achieved considerable success is in pumping and stirring liquid metals. In the 1930s pumped liquid metal was used for heat transfer in special circumstances, where the high thermal capacity of the metal was useful, and where direct contact with the liquid metal was to be avoided. The liquid metal itself acts as the moving part of the motor, and all that is necessary to pump the metal is to fix a wound stator onto the wall of the container holding the metal. Such devices are now commonly used for stirring aluminium and other metals in furnaces, and for assisting the transfer of metal to moulds for casting. A very specialised application is for pumping the liquid sodium coolant in some nuclear reactors. Reliable operation and complete isolation of the metal being pumped are vital requirements, and the linear motor provides these.

16.7 The versatility of the electric motor

Electric motors are now made in a vast range of types and sizes. Large motors drive trains, ships, or rolling mills and may be rated at thousands of horsepower. At the other end of the scale an electric analogue watch has a motor that takes so little power it can run for a couple of years on a tiny cell. These small machines are electromagnetic engines, the direct descendants of the machines described in Chapter 4 and of the motors in the ABC telegraph receivers.

Nowhere is the versatility of electric power seen better than in the electric motor. The reader is invited to count the electric motors in his or her home, then to add the electric motors in the factories that made the things in the home, and the electric motors in the vehicles that bring things to the home. Most gas or oil-fired central heating systems have an electric pump, and every petrol or diesel vehicle has an electric motor for starting, and usually others for operating windscreen wipers, blowers etc.

Electric motors make the world go round!

16.8 References

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