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INCANDESCENT ELECTRIC LAMPS

AND THEIR APPLICATION

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CHAPTER VI

INCANDESCENT ELECTRIC LAMPS

Carbon Lamps

ONE of the earliest investigators of the incandescent electric lamp was Edison, who appears to have been among the first to appreciate the fact that high-resistance lamps could be worked in variable numbers in parallel on circuits in which the pressure was maintained constant.

At first Edison seems to have concentrated his attention upon high-resistance platinum filament lamps, and succeeded in successfully producing a finished article.

The very high cost of the material, however, coupled with the low efficiency of the lamp and the ever-present danger of an accidental burn-out due to pressure rises, were against the platinum filament lamp from the commencement, and prevented it from ever becoming a commercial success.

In 1879, however, he made the discovery that filaments made of carbonised bamboo yielded a practical lamp, while Swan, having found that the use of low-resistance carbon lamps was a step in the right direction, worked up to high-resistance ones, and arrived at practically the same result as Edison at the same time.

Carbon having been proved a suitable substance for filament manufacture, then held the field until comparatively recent times, and manufacturers appeared to take it for granted that a departure from carbon was an impossibility.

This may have been due to the fact that platinum, a metal apparently held in awe and reverence by all early electricians, having been proved a failure, the use of any other metal was looked upon as a ridiculous proceeding, although, perhaps, the great difficulty attending refractory metal experiments at that time may have had something to do with it.

The early carbon lamps were all practically what would now be called low-pressure lamps—70 to 100 volts being the most usual ratings. The manufacturing processes at the time did not lend themselves to the production of thin, high-resistance filaments, and therefore, of high-voltage lamps, and it was not until the method of producing filaments by squirting a solution of cellulose in zinc chloride had proved itself a success that manufacturers were able to satisfy the demands of users for high-voltage lamps.

Manufacture of Carbon Filaments.—The carbon filaments in use at the present day are manufactured by first dissolving cellulose in a solution of zinc chloride until a viscous solution or syrup is obtained. The cellulose, of course, contains the necessary carbon, and the rest of the process consists in the elimination of the other matter, and the refining of the remaining carbon filament.

The syrup, having been prepared, is purified and then squirted through a die of the requisite diameter, and emerges in the form of a thin thread which is allowed to harden, generally in alcohol, and afterwards wound on drums to dry.

The thread is then cut to the required length, and wrapped on charcoal holders of the correct shape, and finally carbonised by heating in crucibles packed with graphite.

The necessary temperature is about 2000° C., the carbon thereby being rendered exceedingly durable, of increased conductivity and decreased acclusion.

The filaments, however, are far from uniform, and if mounted and placed on circuit would appear patchy, the thinner portions glowing more than the thicker ones of less resistance. It is necessary to reduce the filament to one of uniform diameter, and to perform this operation the flashing process is resorted to.

Flashing.—The filaments after carbonisation are raised to incandescence by electrical means while in an atmosphere of hydrocarbon vapour.

The temperature attained is such that the vapour is decomposed into its constituents hydrogen and carbon, the latter being deposited on the surface of the filament, which is thus provided with a hard coating, and rendered of uniform diameter and resistance throughout.

Flashing further increases the efficiency, and improves the lasting properties of the filament.

Carbon lends itself admirably to the construction of strong filaments.

Its specific resistance, compared with that of metals, is very high, being of the order of 0·004 ohm per centimetre cube, which means that for a given resistance, the length of the filament may

be short, and the diameter fairly large, a strong construction resulting.

By reason of their strength carbon lamps for a long time were recommended for exposed positions or positions of danger from a lamp point of view.

For traction purposes, and for such places as cellars and warehouses, carbon lamps were until quite recent times to be recommended, but as will be seen later, the newest metal lamps are sufficiently strong to warrant their use in all places where economy permits.

Occasionally, however, the cost of the lamp is the main item, the hours of actual service being so few that the energy cost is insignificant. A country hall, for example, may be used perhaps for a few hours monthly, in which case it may be cheaper to instal carbon lamps.

Temperature Coefficient.—A point to be noted when dealing with carbon is the fact that its temperature coefficient is negative.

Unlike the metals the resistance of carbon decreases on the application of heat. The resistance of a carbon filament is thus a maximum when the lamp is not on circuit and it decreases as soon as the pressure is applied.

Over-running is, therefore, attended with the danger of a burn-out, as the hotter the filament becomes the lower will be its resistance, the current consequently tending to continually increase.

Vacuum Operation.—Carbon oxidises readily when heated in the air or in an atmosphere containing oxygen, and therefore to protect the filament from oxidation and destruction, it must be operated in a vacuum, or, in other words, the air must be exhausted from the glass bulb in which the filament is mounted.

A good vacuum is of the highest importance, as contact with gas results in conduction and convection taking place with a lowered overall efficiency, the gain, however, being decreased somewhat by reason of the fact that vacuum operation tends to increase vaporisation of the filament with subsequent obscuring of the bulb.

The carbon filament changes in character as vaporisation proceeds, the small particles that leave the surface causing the latter to lose its smooth appearance, and to assume an exterior composed of many projections and depressions.

In consequence of this the radiation surface is considerably increased, which means that for equal energy expenditure a lower temperature of filament and decreased efficiency will result, a further decrease being brought about by the volatilised carbon depositing on the comparatively cool surface of the bulb, which blackens and acts as an absorbing screen.

The efficiency, as will be shown later, can be considerably increased by even a small temperature rise, or, what amounts to the same thing, by over-running, and the question that naturally arises is what is the limiting temperature of operation?

It has been shown above that, owing to being continually subjected to a high operating temperature, the filament gradually changes, losing its hard smooth surface and becoming possessed of one more or less rough. The filament becomes weaker owing to the loss of material which, being deposited on the bulb surface, forms a light-absorbing screen. All these processes of destruction are very considerably hastened by still higher temperature.

It is true that at the same time the efficiency is increased, but this is clearly at the expense of the lamp whose life is shortened by the vaporisation taking place.

The operating temperature must then be such that the greatest output is obtained with the least cost for energy and lamp renewals, and must be found for each particular variety of filament, being about 1800° C. for the average carbon filament.

Filament Mounting.—As regards the actual mounting of the filament, connection is first made to its ends by means of two small pieces of platinum wire, a joint being temporarily made between the filament and metal and then completed by electrically depositing carbon on to it from benzine. This process usually precedes the flashing process, and after the latter has taken place the filament is ready to be mounted in the glass bulb.

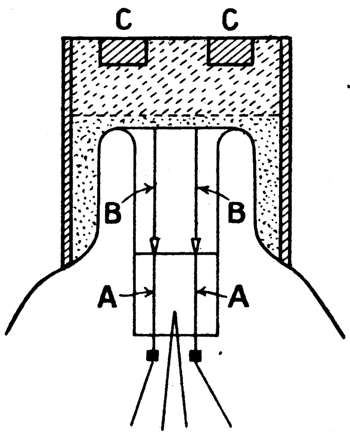

FIG. 20.

The platinum wires are fused through the glass support as shown at A in Fig. 20, platinum, in spite of its high price, being used of necessity for this operation since it is the only known metal whose coefficient of expansion equals that of glass.

The platinum wires are then attached to two copper wires, B, B, which are in turn connected to two contact plates, C, C, embedded in the cap, the inside of the latter being filled with some sort

of glassy slag of good insulating properties, but non-hygroscopic.

Vacuum Production.—The bulb is now exhausted by means of air, and finally mercury pumps, the vacuum being tested by high pressure coils, and when sufficiently good the bulb is sealed off with a blowpipe, and the lamp is ready for testing.

Gem Filaments.—Gem filaments are special types of carbon filaments. They are prepared in the ordinary way, but subjected to additional heating, both before and after the flashing process.

This treatment, besides removing impurities and reducing the filament's acclusion, or gas-retaining powers, appears to modify its construction, imparting to it properties similar to some of those possessed by the metals employed in lamp manufacture.

Metal Lamps.—To achieve success in filament form a metal must possess several very important properties. To permit of its continuous running at very high temperature it must be refractory, and it has long been known that many metals can withstand much higher temperature than carbon without excessive disintegration taking place.

Carbon is the most refractory material known, and what may be called its melting point, or the temperature in the arc crater, is given by various authorities as varying between 3600–4000° C.

Yet, in spite of this fact, carbon, in comparison with such metals as tungsten and tantalum, is an unsatisfactory material from a filament point of view. The metals have a much lower melting point than the carbon, but possibly by reason of their high atomic weights they can be operated continuously at a higher temperature, their rate of evaporation from the solid state being much lower.

The temperature limit of the filament is then not so much the melting point as the temperature at which evaporation is such that the life of the filament is unduly shortened.

Again, to produce filaments of reasonable length and of sufficient diameter to afford strength to withstand vibration, handling, etc., the resistance constants of the material must be satisfactory. Here it may be remarked that the metals have one great point in their favour, and that is, that they possess positive temperature coefficients.

An increase in temperature produces an increase in resistance, the current tending to remain constant, and automatic regulation practically taking place. It is possible to run a metal filament lamp at twice its normal voltage for a short time if the latter be raised gradually from normal.

Metal filament lamps on a varying voltage circuit, the variations being other than mere voltage flickers, will yield a much steadier output than will carbon ones on the same circuit, for the changes in the filament resistance of the former will be such as to damp out current fluctuations to a great extent, while as regards the latter an increased temperature results in a decreased resistance and immediate current increase.

At the present time the metals employed in the manufacture of lamp filaments to the practical exclusion of all others are tantalum and tungsten.

Tantalum.—Tantalum is an exceedingly hard metal of great strength, ductility, and conductivity. The wire is prepared by melting tantalum in an electric furnace, heating the ingots red, hammering them into sheets and then drawing the sheet down into wire.

The melting point is stated to be about 2000° C., while the atomic weight is 183, permitting of high temperature operation without undue evaporation of the filament.

The specific resistance of tantalum when cold is some ten times that of copper, namely 15·5 microhms per centimetre cube, and this increases to 83 microhms at the running temperature.

Compared with that of carbon the specific resistance is seen to be exceedingly low, and this means that filaments of great length and small diameter are a necessity, a 25 C.-P. lamp designed to run on a 110 volt circuit, for instance, requiring a filament over 2 feet, or 25 inches to be exact, in length, the diameter not exceeding 0·05 millimetre or about 0·002 inch.

It is a triumph to draw wires down to this exceedingly small diameter and yet be able to handle them sufficiently to mount them without breakage.

From information obtained from the makers, the method of doing this is as follows: The metal is first formed into fairly thin rods, and then drawn through diamond dies of decreasing diameter until the required cross-section of filament is obtained. The remainder of the manufacturing process, apart from the fact that the filament has to be wound on supporting arms, by reason of its great length and small diameter, proceeds much in the same manner as does the manufacture of the ordinary carbon lamp, the only difference being that in the case of the metal lamp, a higher vacuum is required and the flashing process is not resorted to.

Tungsten is an exceedingly hard metal with electrical properties similar to those of tantalum, but differs from the latter ductile metal in being very brittle.

In the early days of Tungsten lamps the filaments were made by squirting tungsten powder that had been mixed with some suitable material through a diamond die.

Manufacture of Pressed Filaments.—The early "Osram" or tungsten lamp had filaments prepared by what is known as the paste process, the principle of which consists in preparing, usually from the metal itself in a finely divided form, a paste with a binding agent such as gum. This paste, with a consistency of putty, is then forced through a fine hole in a diamond by a pressure of several tons to the square inch.

The filaments so formed are heated away from air, and are then sufficiently strong to be clamped in holders, in order that they may be subjected to the passage of an electric current which raises them to a high temperature causing the filaments to sinter. The sintering process is carried out in gases which chemically attach all the constituents of the binding agent, the result being that a filament of pure metal is obtained.

The diameter of the filament is exceedingly small, that of a 25-C.-P. 110 volts lamp not exceeding 0·03 mm. Tungsten filaments so manufactured are elastic but brittle, and require very careful mounting, and a single loop of metal for each support.

There are many disadvantages of the pressed filament type of lamp, and the problem of drawing down the metal tungsten and so producing a drawn wire tungsten filament in one continuous length has only recently been solved.

Drawn Tungsten Wire.—It was known that the tungsten filament, brittle at ordinary temperature, became soft and flexible at the operating temperature of the lamp, but that it lost this property as soon as it had cooled down again. Coolidge discovered that it had the property of softening, even below red heat, and he was able to work tungsten at relatively low temperatures. He further discovered a process by which it is possible to render tungsten ductile by a mechanical treatment of the material in the heated state, and to also give it a permanent ductility while in the cold state. According to this process pure tungsten powder is pressed into rods, then rendered coherent by heating, hammered while hot, and finally drawn out into wire through diamond dies.

Lamps manufactured from such wire show not only the great economy, long life, and constancy in candle-power of the old tungsten lamps, together with automatic regulation, but are equally strong, being one continuous length of drawn wire, with the carbon lamp.

After the discovery of this process a further important success was obtained, as it was found possible to draw down filaments of even finer diameters, so that lamps are now obtainable of even 10 C.P. for pressures of 200 volts and over. In the case of the latter lamp, the filament is no greater than 0·012 mm. in diameter, a marvellous result when the properties of the material are taken into account.

The mounting of the wire now is a very simple process. It is wound in a continuous length, in a zigzag manner, round a glass carrier, as shown in Fig. 21, and which carries, at the top and bottom, a star-shaped carrier consisting of a number of metal supports.

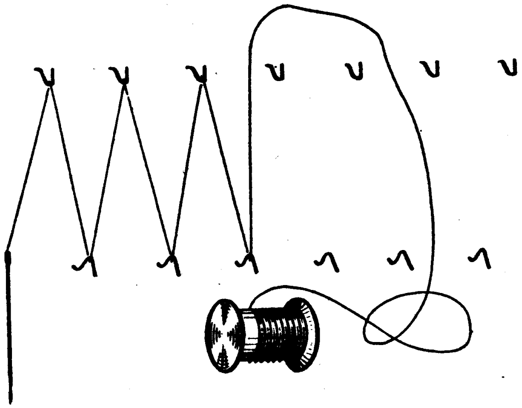

FIG. 21.

One carrier consists of strong, stiff material, whereas the other is made of very fine refractory wires, molybdenum being used in the Osram lamps of the present day. These fine supports act as springs, and keep the filament in its original position, no matter at what angle the lamp is supported.

The importance of this feature will be rendered evident when the large amount of sag resulting, when many of the cheaper metal lamps are used, is observed. The filament, in some cases, sags so much as to touch the glass, breakage resulting, or even if this is avoided, the appearance of the lamp suffers considerably by the misplacement of the wire.

The drawn wire lamps are completed, as far as sealing in and exhaustion are concerned, in much the same way as are the pressed filament lamps previously described.

The metal wire lamp, as now manufactured, means a success over all other types of electric lamp, and is, to quote Dr. Geisel, definitely superior even to gas lighting.

It has been the means of introducing extension of electric lighting, and of popularising electricity generally, and as such has rendered great service to the whole electrical industry.

Users of such lamps as the Mazda, Osram, Wotan, to name only the best known of the tungsten drawn filament makes, need

have no fear of the fragility of the filament. The pressed filament lamps almost superseded all other makes by reason of their great economy, and this, in spite of the fact that the filaments were brittle and fragile, and the invention of the tungsten wire finally established the superiority of this form of incandescent lamp over all others.