THE INCANDESCENT LAMP

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FOREWORD

Deep appreciation is extended for the generous permission of the Callite Products Company, 540 - 39th Street, Union City, New Jersey, in permitting the writer to illustrate this thesis with pictures of their lamp and wire machinery.

CONTENTS

CHAPTER I

A Brief History of the Development of the Incandescent Lamp

Probably no single electrical phenomena has ever been so widely studied as light. Great quantities of data have been collected as the result of wide and varied experimentation to perfect the man-made source of illumination, the lamp. To consider each and every improvement in the making of the lamp we use today, would lead into volumes of research treatises. A lengthy discussion would be impossible; yet, a short history will give the reader an idea of the untiring efforts of lamp engineers and research scientists all over the world in perfecting the source of light upon which we have come to be so dependent.

There are two classes of light source: incandescence and luminescence. The source considered in this paper is produced by heating a substance to a very high temperature which by virtue of this high temperature gives light. The amount of light emitted increases very rapidly. It has been found that the emitted light varies from the 8th to the 12th power of the temperature. Thus, we see, that a small increase in temperature produces a very large increase in the light given off. This fact is the reason for the different efficiencies obtained with different types of lamps and the objective for investigation and experimentation to obtain the greatest possible efficiency; i.e., the least energy drain for the highest temperature.

Scientists soon recognized that an illuminant should be:

1. highly refractory
2. able to withstand high temperatures without softening or deforming
3. able to withstand high temperatures without excessive evaporation
4. mechanically strong
5. highly resistive to give thicker filaments
6. ductile to permit winding
7. inexpensive
8. able to counteract voltage variation by having a high positive temperature coefficient.

Platinum was first used in the earliest lamps. As an illuminant, it did not prove to be serviceable or practical as its melting point is low and it is very costly.

Edison achieved the first practical incandescent lamp in 1879 by producing a filament of carbonized bamboo fibre. Owing to the relatively loose structure of the fibre, the filament could not operate at high temperatures. The efficiencies of the early carbon lamps were low. Great effort was exerted to improve this filament and to find a better material than carbon as an illuminant. A process of squirting the carbon filament from a paste was developed, which gave a more uniform filament than obtained with the threads of bamboo. With heat treatment, the new carbon filament held the illuminant field for about 25 years.

The first real competitor to this improved filament was the Nernst glower. This filament consisted of a mixture of rare earths. As an illuminant, it was not developed to the extent of replacing the carbon filament, but instead, other substitutes were investigated. Two substitutes receiving considerable attention were filaments of osmium and tantalum. Osmium was manufactured and sold in Europe in comparatively large quantities. This metal is very rare and expensive, as it is usually found associated with platinum. It is also a very brittle metal; so that lamps using this material were very fragile. In 1905, tantalum began to replace osmium as an illuminant because of its higher melting point. For six years tantalum lamps were used at the very low efficiency of 7.4 lumens per watt. About the time that the first tantalum lamps were introduced, the use of molybdenum and tungsten were also generally suggested as a filament by such scientists as Drs. Von Bolton, Kuzel, Just, Hanaman, Auer Von Welsbach, Whitney and many others. Each of these scientists developed independent processes for the production of filament bodies of tungsten. A number of advantages were recognized which made tungsten available for use as a filament. These advantages were:

1. the high temperature at which it fuses
2. the whiteness of the light emitted
3. the higher efficiency and longer life
4. the larger number of filaments which could be made from one pound of tungsten.

At first, the tungsten filaments were very brittle and the loss from shock was so great that it was impractical. As a result, many scientists set out to correct this fault by making ductile tungsten. The first process was suggested by Just and Hanaman on

September 8, 1904. This process, known as the "paste method", was analogous to Auer Von Welsbach's method of making osmium filaments. By providing that the tungsten compounds reducible by hydrogen be pulverized, mixed with a binding material free of hydrogen, formed into a paste, and later pressed into a filament form to be reduced in an atmosphere of hydrogen; ductile tungsten was made. Many defects were recognized in the original process with the result that during the years 1905-6, many modifications were rendered. The final process gave a filament of a mixture of carbon and metal coated with tungsten by heating it electrically in a low-pressure atmosphere of hydrogen containing a gaseous compound of the metal.

The quest of more efficient filamentary bodies continued until in 1910 when the first successfully drawn tungsten wire type lamp was made. By 1912, drawn tungsten filaments had almost completely replaced the squirted type of filament. At first, only pure tungsten was used, but today varying amounts of thorium are added to the tungsten to prevent "crystal growth". This type of filament is very efficient because it can be operated at a very high temperature, 2150^{o} C, without too rapid deterioration.

Remembering that the light emitted by an incandescent lamp increases as the 8th to the 12th power of its absolute temperature, it is obvious that there is still opportunity for increasing the efficiency of tungsten lamps if the temperature can be safely increased. The limiting factor, as previously mentioned, is the volitization or evaporation of the filament. To prevent this action, gas filled lamps were manufactured. The gas used can be either nitrogen or argon or a mixture of both. The most common gas used is a mixture of approximately 86% argon and 14% nitrogen. The nitrogen is added to increase the dielectric strength of the gas mixture; whereas, the argon is used because of its low heat conductivity and inertness. By reason of the gas pressure, about 15 lbs. per sq. in. on the filament, the vaporization of the tungsten filament is reduced. As a result, a higher operating temperature, 2580° C, can be reached safely, with a resultant higher efficiency and whiter light.

And so, continues the work of the lamp engineer. To him we owe the superior lamp we use today. Although far from perfection, we can buy lamps at a great saving of money. An illustration of the progress made by the lamp industry in the last 20 years is shown in the following table:

Lamp Type	Date Measured	Temperature	Efficiency LPW #
Squirted Filament	1909	2310^{o} K	8.4
Drawn Wire	1909	2320^{o} K	8.9
Vacuum	1931	2565^{o} K	10.8
Gas-Filled	1932	2610^{o} K	11.0

These comparative measurements are on 40 watt lamps. Like improvements have been made on other wattage lamps.

At present, superior filamentary bodies for many applications are produced by alloying tungsten with boron nitride, silica, thorium, sodium and potassium silicate, vanadium, etc. With all this endeavor, the problem of producing an efficient lamp is still most apparent.

CHAPTER II

The Manufacture of Tungsten Wire

Before tungsten can be used as an illuminant in lamps, it must pass through several processes which change it from the form of a powder to a metal. The original form of tungsten is a crude oxide, WO_3 (1). This oxide must be purified until it is 99.95% pure, before it is suitable for wire for lamps.

The first step in the purification of tungsten is to place the crude oxide in earthenware vats to be dissolved with an ammoniacal solution (2). The mixture is then stirred with a wooden oar for about one hour and then allowed to settle over night. It is then filtered through paper pulp filters, dried, the paper removed, and the residue sent to the ore reducer. To precipitate the yellow oxide, the residue is passed through steam agitated aqua regia (3). As the steam is passed through the warm acid, the ammonium tungstate is siphoned into the flask, and precipitation results. The yellow acid is allowed to settle, to be decanted and the precipitate washed into vats. The yellow oxide is washed two or three times with water and the supernatent liquid siphoned off. The last of the wash water should have a yellowish colloidal suspension, showing that all electrolytes have been washed out. The yellow oxide is next dissolved in an ammonia solution (4). This mixture is stirred for about fifteen minutes and then allowed to settle for four hours. It is then filtered, the residue being a hydrated tungstic acid. The residue, ammonium para-tungstate, is placed in rubber buckets where it is washed four or five times with water. The white tungstate is now ready to be ignited to oxide after the water has been removed.

The ammonium para-tungstate is broken into small lumps, placed in nickel pans and set in an oven over a direct flame. The temperature of the oven is maintained between 600°-700° C. for two or three hours. In this time, the moisture, ammonia, and volatile salts have been driven from the tungstate. The pans are then removed from the oven and partially cooled. When the yellow oxide is sufficiently cool, it is sieved through an 80 mesh copper screen. At this point, the simple purification yield is 65% and the double purification is 48%.

To improve the working quality of the metal, certain infusable oxides are added to the tungstic oxide at this point of the oxide treatment and reduction. The double purified oxide, which is to be manufactured into filament wire, has added to each kilogram of oxide, 50 c.c. of thorium nitrate solution made by the dissolving of 300 grams of thorium nitrate in a litre of water. This proportion gives a three quarters of one percent thoriated wire. This "doped" wire serves better as a filament wire than pure tungsten wire as crystal growth is retarded.

Before reduction, the oxide is heated in air to give a definite structure to the now greenish oxide. The "doped" oxide is next placed into silica tubes which are heated to a temperature of 1100° C. The tungsten powder remains in this tube for about one hour during which time compressed air is passed through the tube. When cool, the oxide is removed from the tube and sieved through a 120 mesh sieve. The larger lumps which do not go through the sieve readily should be removed and ground in a mortar.

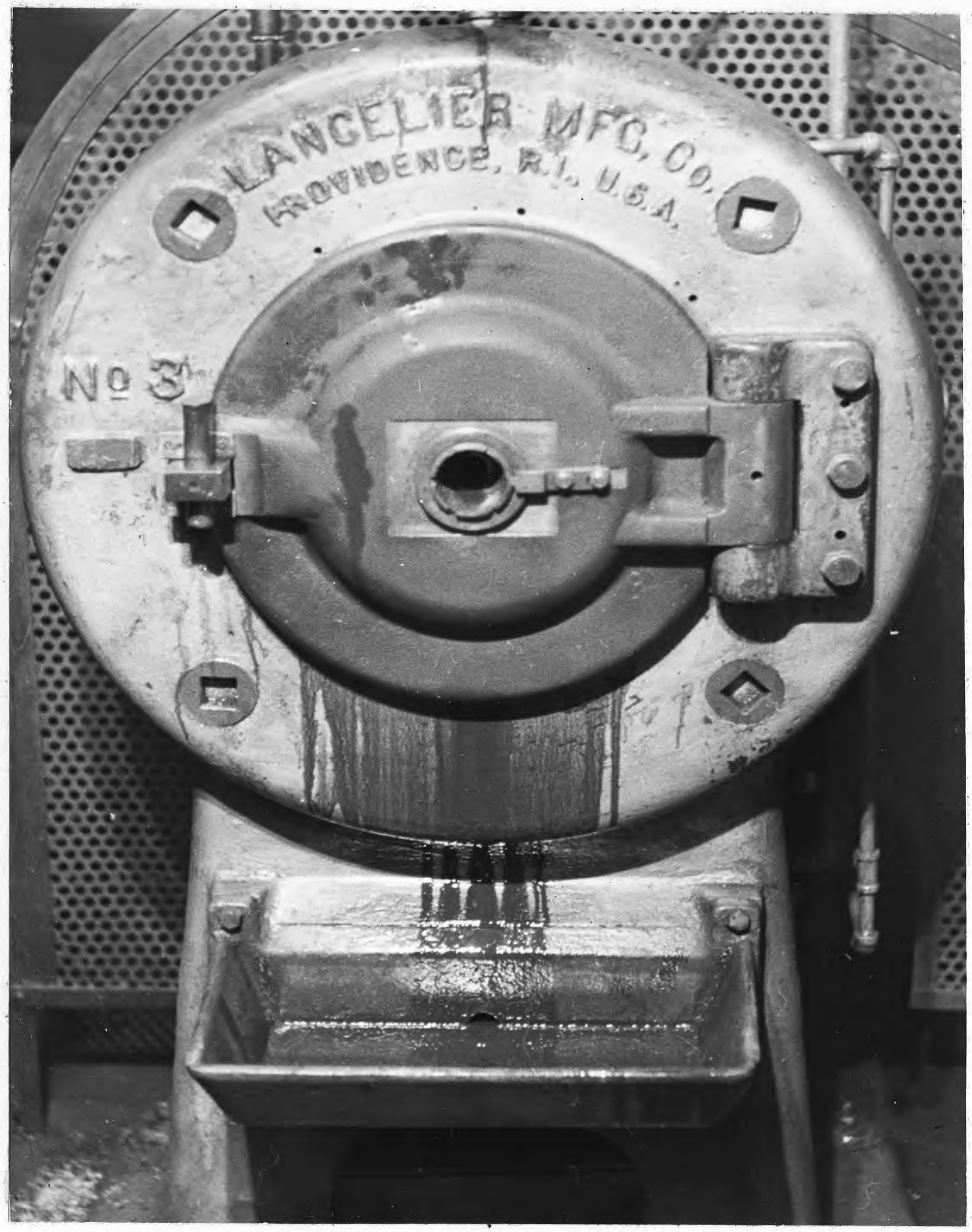
At this point in the making of tungsten wire, the reduced and mechanically sieved metal possesses varying characteristics as to weight and grain structure. Here the metal should be classified to determine what batches will make the best wire. A light, sticky, crystalline metal weighing about 50 grams per cubic inch usually produces the most desirable wire.

The metal of double purification is now ready to be made into slugs, pressed into a form 9 x 1/4 x 1/4 inches and weighing 115 grams. The pressure used is about eight tons per square inch. The pressed slugs are then placed on a slab and heated in an electrical furnace at a temperature of about 1100° C for 10 minutes. As the slug is heated, dry hydrogen is passed through the furnace at a rate of two cubic feet per hour. The slug is then removed from the furnace and placed upon glass plates to be treated.

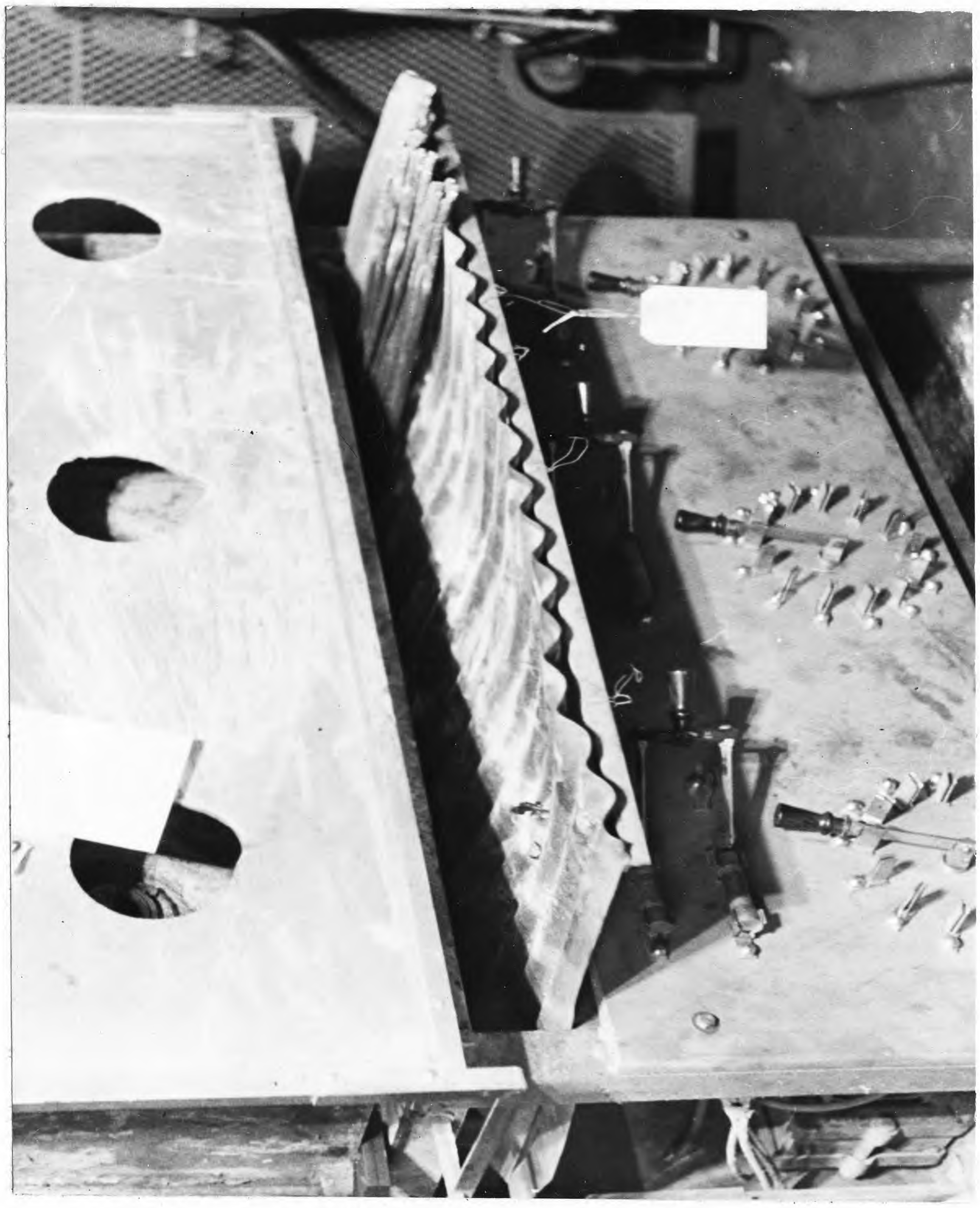
The slug is then treated by passing a high current through it depending upon the maximum fusion current of the material of the particular slug. This current is about 1850 amperes at 10 to 12 volts for the 115 gram slugs. In treating, the slug is grasped in a vertical position between two electrodes. The lower electrode is a copper clip floating in mercury and the upper electrode is two tungsten slabs fastened to a copper arm. A spring in both electrodes permits the grasping of the slug without crushing it.

A hood fits over the device in which an atmosphere of hydrogen is maintained as the slug is heated. Both the electrodes and the hood are water cooled. When treating time has elapsed, the current is rapidly lowered to zero. The slug is allowed to cool for about two minutes before it is removed from the hood. The treated slug is now ready for the swaging department.

The slug which is to be swaged from a rectangular form to a round form must be quite straight. Often times it is necessary to heat the slug and straighten it in a vice before it can be passed through the first swager. The tungsten slugs handled in the swaging department must be worked while hot. When the slug is warm enough it is passed through the first swaging die to its center point. The slug is then quickly removed and the unswaged end introduced through the die. Great care must be taken that the swaging action should be continuous. To stop for one instant is to spoil the wire. The slug now has a diameter of 0.240". It is then retreated before being passed through the next die of 0.220". The swaging process is continued at the first swager in steps of 0.020" until the slug has a diameter of 0.160". As the slug, which is now a rod, is long enough to be engaged in rollers instead of



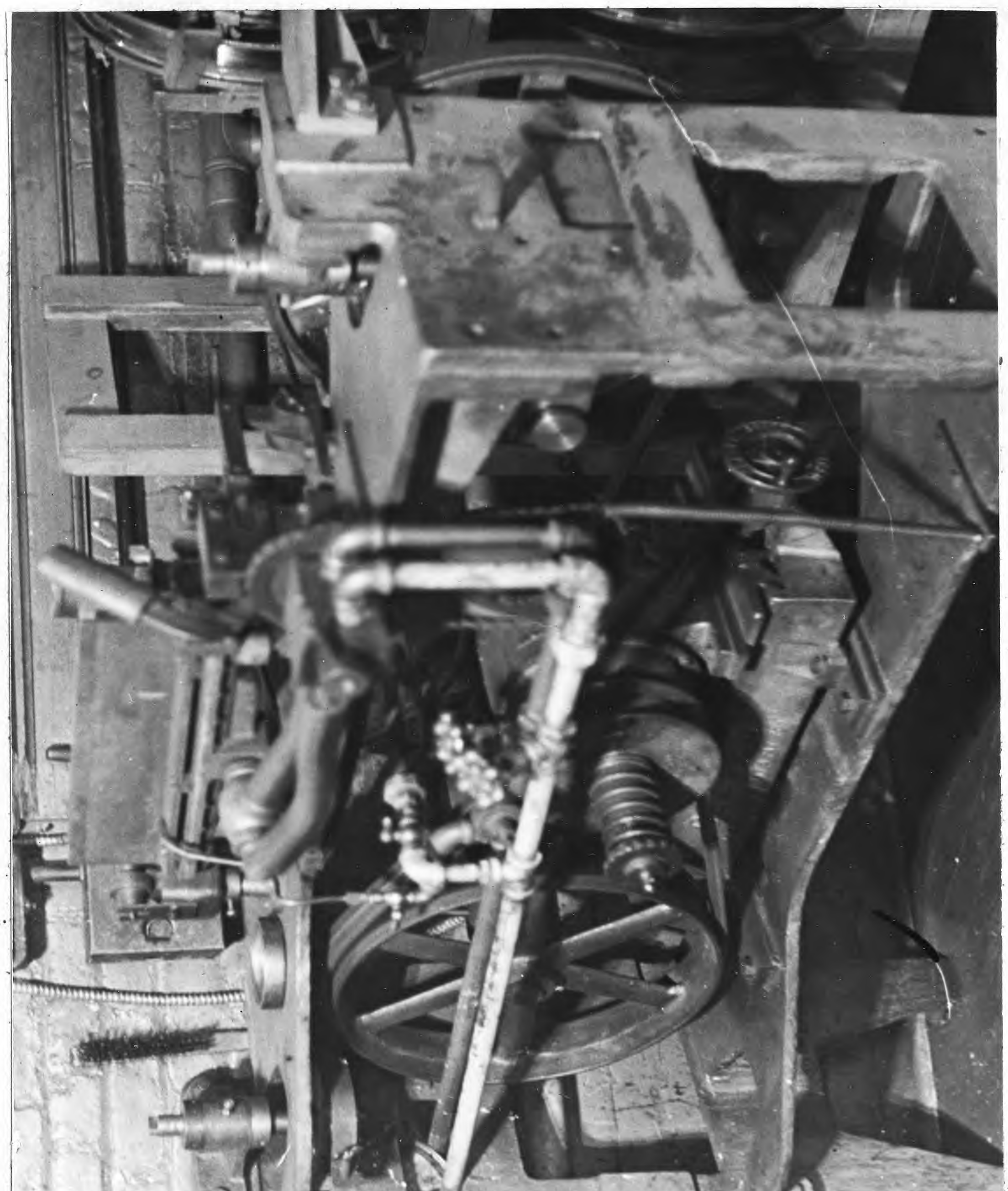
A SWAGING MACHINE



SWAGING OVENS

being pulled through the die by hand, it is sent to a second swager where the rod is swaged to a diameter of 0.060" in successive steps of 0.010". Before being passed through the successive dies of this swager, the rod is passed through a gas furnace having a temperature of 1300° C. The 0.060" rod is now sent to a third swager where the die steps are 0.050", 0.042", 0.038", 0.034" and 0.030". The temperature of the wire at the first die is about 1200° C and is reduced to 1000° C at the last die. With these last two swaging machines it is necessary to use "aquadag" (5) for lubricating the wire as it is passed through each die. This lubricant is applied by laying the wire or rod in a trough filled with the emulsion and then led into the die.

After the wire reaches a diameter of 0.032", it is ductile enough to be wound. As the wire progresses through the first coiler, which has dies of 0.029" and 0.026", the wire which has a temperature of about 1000° C is passed through a "dag pot" containing a carbonacious emulsion. The wire is now passed through a second coiler having die diameters of 0.024", 0.022", and 0.020". The third and last coiler reduces the wire to a diameter of 0.013" in steps of 0.001". The 0.014" and 0.013" dies are used

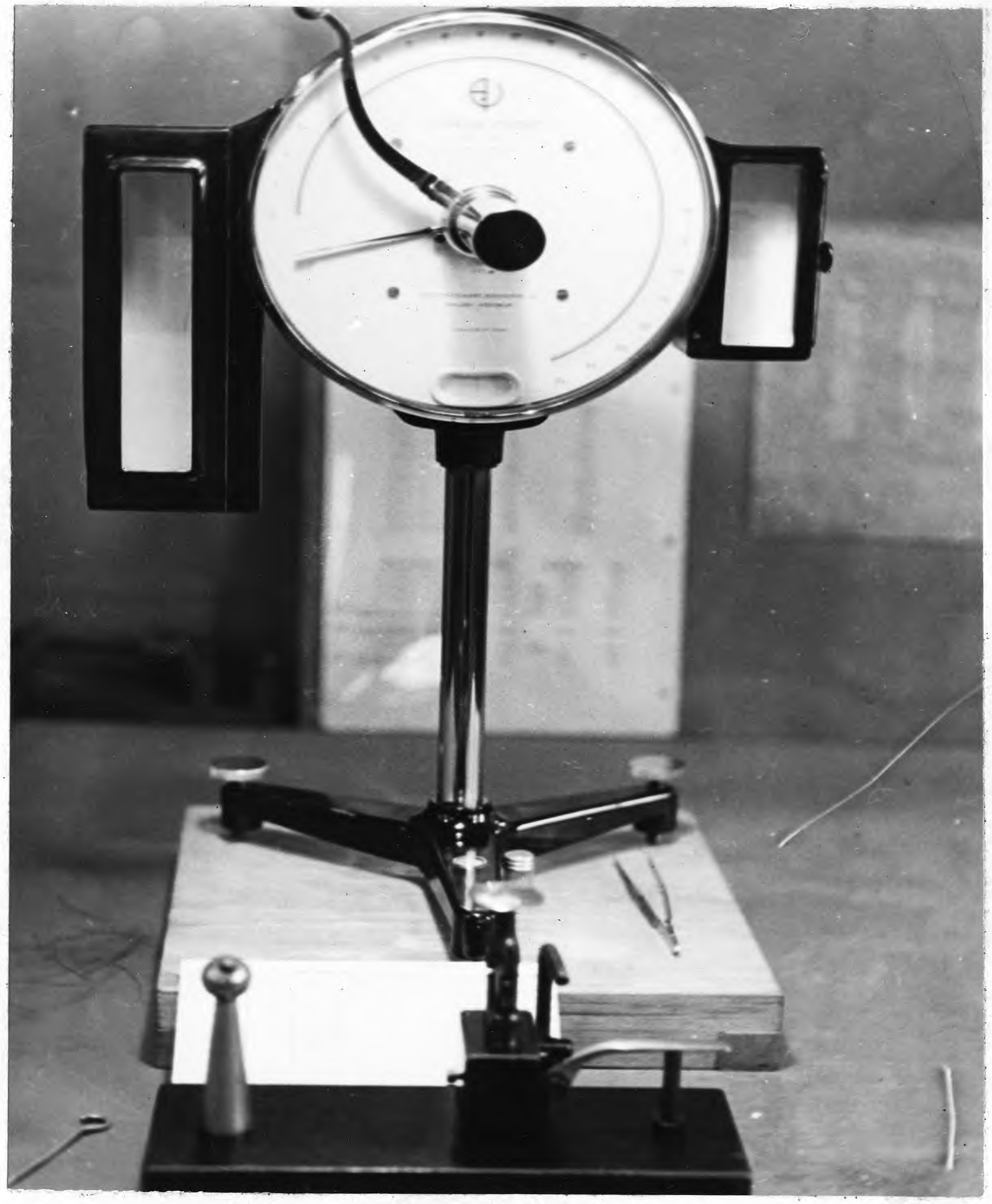


WIRE DRAWING MACHINE

(Large Wire Diameters)

for finishing the wire. At the last coiler, the temperature of the wire is about 700° C. Considerable trouble may be experienced in passing the wire through the smaller dies. This may be overcome by pointing the wire simply by dipping it in a container of molten sodium or potassium nitrate.

The 0.013" wire is now sent to the wire drawing department. Here the first operation is to remove the wire from the drums on to another drum which fits over the spiders of the heavy wire drawing machines. As the wire is being rewound, it is passed through a gas flame to anneal it at red heat. The first die through which the wire is passed is 0.0125". Before the wire is passed through each die it is pointed and lubricated (6). The wire is passed through dies of decreasing diameter of about 0.0015" until it is 0.008" in diameter. At this point the wire is too small to be measured correctly, so the "diameter" is expressed in milligrams per 200 millimeters of wire. The wire drawing process is continued to whatever size wire is desired. Wire sizes to as small as 0.0008 grams per 200 millimeters can be readily drawn. The finished wire is always annealed by a direct current while in an atmosphere of hydrogen.



A TYPICAL TORSION BALANCE USED FOR WEIGHING WIRE

(1) WO_3............................. 90%

H_2O and volatile matter..........7.8%

Non-volatile in HCl and air......1.2%

Insoluble in 5% $Na_2\ CO_3$..........0.7%

Insoluble in 10 parts H_2O and

4 parts NH_4 OH............1.8%

Vanadium present

(2) 27 liters of 0.9 specific gravity NH_4 OH is added to 67.5 liters of water for every sixty pounds of oxide.

(3) 260 c.c. HNO_3 of 1.42 specific gravity, 430 c.c. H_2O, and 800 c.c. HCl of 1.18 specific gravity.

(4) 36 liters of H_2O to 18 liters of NH_4 OH having a specific gravity of 0.9. The resulting solution should have a 1.2 specific gravity. If not, add 4.5 liters for each 0.01 degree specific gravity above 1.2 plus one-half the additional water in the ammonia.

(5) Made by stirring two #20 (1 quart) jars of Aquadag, 3600 c.c. of H_2O, 400 c.c. NH_4 OH, and 60 c.c. glycerine.

(6) Made by mixing one #20 (1 quart) jar of Aquadag with one gallon distilled water,

one pint of soap solution, and one-half pint of ammonia. The soap solution is made by dissolving one cake of soap to a gallon of water.

CHAPTER III

Filament Data Computation

Basic transient phenomena establishes the fact that in an electrical circuit the useful energy passes about the conductor; whereas, the energy in the conductor is lost in heat. This fact is in direct comparison to an incandescent lamp. In the lamp, the filament is the conductor and the useful energy is the light flux. The more important losses of energy which occur in lamps are due to causes which may be classified as follows:

1. Conduction of heat from filament due to the relatively cool lead-in wires and filament supports.

2. Cooling of filament by convection currents in the gas.

3. Radiation from filament of energy of wave lengths outside of the visible spectrum.

4. Absorption of light by bulb and coatings or deposits on its inner or outer surfaces.
Naturally, the magnitude of these losses signify the rating of the lamp, as 40 watts, 60 watts, 75 watts, etc.

These losses may be seen to be a function of the operating temperature, and hence, the current. For a given type of lamp construction, the losses will therefore be directly a function of the operating efficiency, lumens per watt. From this, we conclude, there must be some relationship among the losses of a given type of lamp operating at different efficiencies. This fundamental reasoning shows a way to filament data computation by knowing complete experimentally obtained information for a given construction at some particular operating efficiency. This efficiency is taken to be 16 L.P.W. (lumens per watt).

If in a given lamp, all the losses except that by radiation be considered constant, then for the same efficiency, the temperature is constant and the ratio of watts to surface area must be constant.

It is now left to determine these various constants. The following nomenclature will be used in the derivation of these constants for large lamps, both vacuum and gas filled:

K,X,Y.........Constants

E.............Volts

I.............Amperes

R.............Ohms

o.............Subscript, meaning reduced to basic efficiency

LFL or L.......Lighted filament length exclusive of ends used up in supports, clamping, and spacing between sections.

Wt.............Filament weight in mgs./200 mm.

D_f.............Filament diameter

π 3.416

For round wire:

(1) $$\frac{\text{Watts}}{\text{Surface Area}} = K_o = \frac{E\ I}{L\ \pi\ D_f}$$

As the resistance of a wire is directly proportional to the length and inversely proportional to the cross-sectional area, then

(2) $$R = K_1 \frac{L}{\frac{\pi D_f^2}{4}}$$

Substituting this value of R in Ohm's Law

(3) $$E = I\ R = K_1 \frac{L\ I}{.7854\ D_f^2}$$

Substituting (3) in (1)

(4) $$K_o = K_1 \frac{L\ I}{.7854\ D_f^2} \times \frac{I}{L\ \pi\ D_f}$$

$$K_o = K_1 \frac{I^2}{\pi^2 \frac{D_f^3}{4}}$$

Clearing constants

(5) $$K_2 = \frac{I^2}{D_f^3}$$ $D_f = (Wt/1.93)^{\frac{1}{2}}$ when the density of tungsten is 19.06.

Substituting this value of Wt for D_f in (5)

(6) $$K_3 = \frac{I^2}{Wt^{3/2}}$$

Extracting the square root

(7) $$K_4 = \frac{I}{Wt^{3/4}}$$

Therefore

(8) $$I = K_4 \times Wt^{3/4}$$

Considering K_4 as "X", the wire constant; then, at the basic efficiency

$$I_o = X \times Wt^{3/4}$$

To determine the filament length required, use Ohm's Law as in the above:

(9) $$E = I\ R$$

$$R = K_5 \frac{L}{Wt}$$ (see Equation 2)

Substituting this value of R in Ohm's Law

(10) $$E = K_5 \frac{I\ L}{Wt}$$

Transposing and considering the value of the reciprocal of K_5 as the length constant, "Y", then, at the basic efficiency

(11) $$L = Y \frac{E_o\ Wt}{I_o}$$

To illustrate the usefulness of these formulas, suppose that the lamp engineer is given the problem of designing an odd lamp, a 150 watt lamp to operate at 155 volts. This lamp is to be of the same construction as a 100 watt, 120 volt lamp for which he has complete design information and which he knows operates to give the commercial lumen output. The wire weight for the 100 watt lamp is 12.4 mg/200 mm.

$$I_{150} = \frac{150}{155} = 0.968 \text{ amperes}$$

$$I_{100} = \frac{100}{120} = .833 \text{ amperes}$$

$$Wt_{150}^{3/4} = 12.4^{3/4} \frac{.968}{.833} = 6.62 \frac{.968}{.833} = 7.69$$

$$Wt_{150} = 15.05 \text{ mg/200 mm.}$$

$$L = Y \frac{E_o\ \ Wt}{I_o} = 551 = Y \frac{120 \times 12.4}{.883}$$

$$Y_{150 \text{ or } 100} = \frac{551 \times .883}{120 \times 12.4}$$

$$L = \frac{551 \times .883}{120 \times 12.4} \times 155 \times \frac{15.05}{.968} = 788 \text{ mm/filament.}$$

If a mandrel of 0.012" is used and the filament wound with 265 turns per inch, then the cut length of the filament would be

$$C.L. = \frac{788}{3.1416 \times .01487 \times 265} + 2 \text{ (clamping allowance)} = 66 \text{ mm.}$$

Therefore, the complete specifications for a 150 watt, 155 volt lamp are:

Mandrel diameter is 0.012"

Filament cut length including clamping allowance is 66 mm.

Filament wire to use is 15.05 mg/200 mm.

Turns per inch of filament coil is 265

To illustrate the use of these formulas again, suppose the lamp engineer had to design a 1500 watt, 110 volt lamp knowing the design information of a 100 watt, 120 volt lamp:

$$I_{1500} = \frac{1500}{110} = 13.62 \text{ amperes}$$

$$Wt^{3/4} = 12.4^{3/4} \frac{13.62}{.833} = 6.62 \times 16.39 = 108.3$$

$$Wt = 516.2 \text{ mg/200 mm}$$

$$L = Y \frac{E_0 \; Wt}{I_0} = 551 = Y \frac{120 \times 12.4}{.883}$$

$$Y = \frac{551 \times .883}{120 \times 12.4} = \frac{487}{1489} = .327$$

$$L_{1500} = \frac{.327 \times 110 \times 516.2}{13.62} = 1365 \text{ mm of wire}$$

$$D_f = (516.2/1.92)^{\frac{1}{2}} = 16.4 \text{ mils}$$

$$T.P.I. = \frac{1}{1.45 \times .0164} = 42,$$ where 1.45 is a safe winding pitch depending on the machine used.

$$\text{mm/turn} = .0254 \times \left\{ (3.1416\ (50 + 16.4)\ )^2 + \left(\frac{1000}{42}\right)^2 \right\}^{\frac{1}{2}} = 5.345 \text{ mm.}$$ where the mandrel diameter is 50 mils.

$$C.L. = \frac{1365 \times 25.4}{5.345 \times 42} = 154.2 \text{ mm.}$$

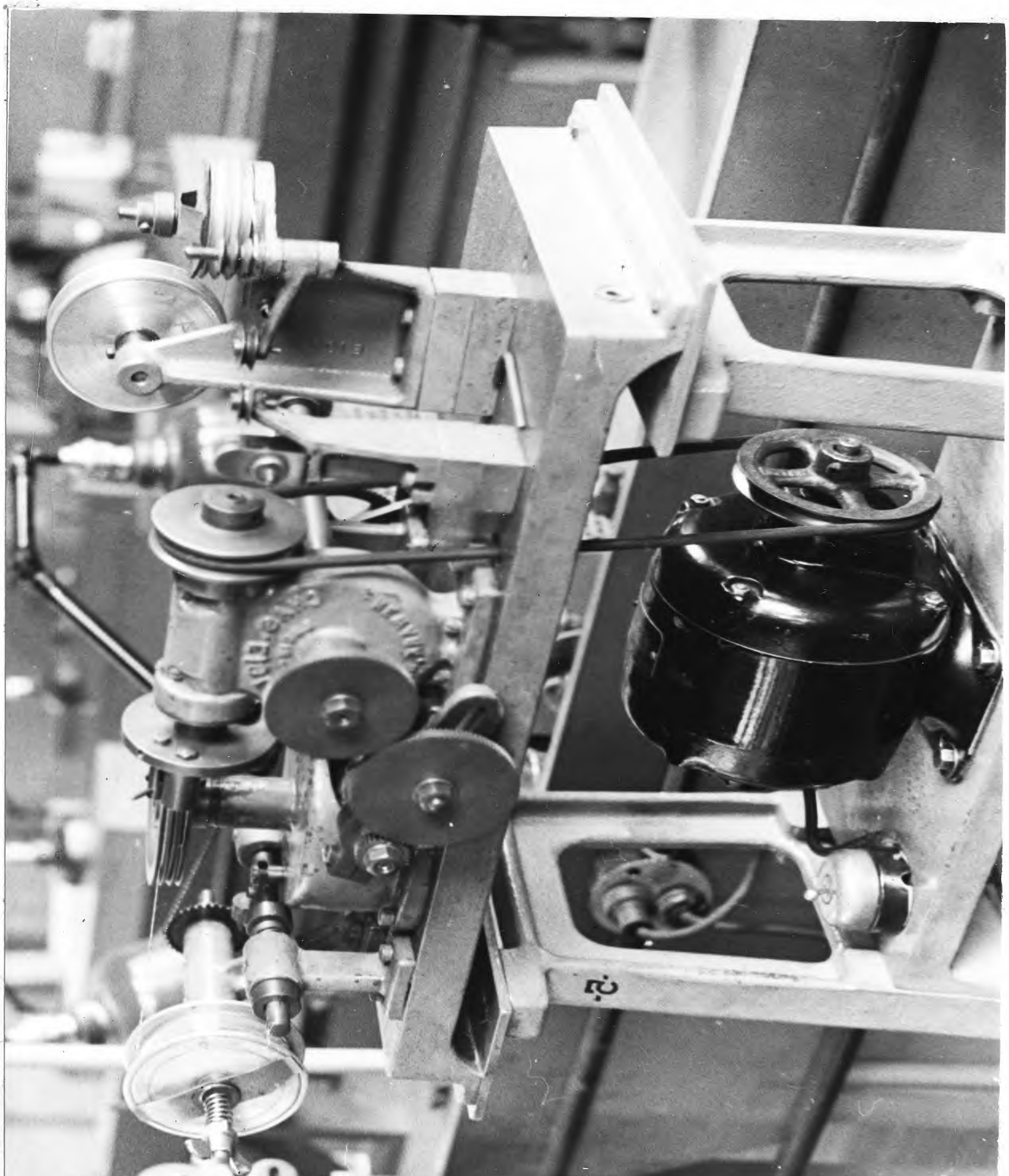
Clamping allowance = 10 mm.

CHAPTER IV

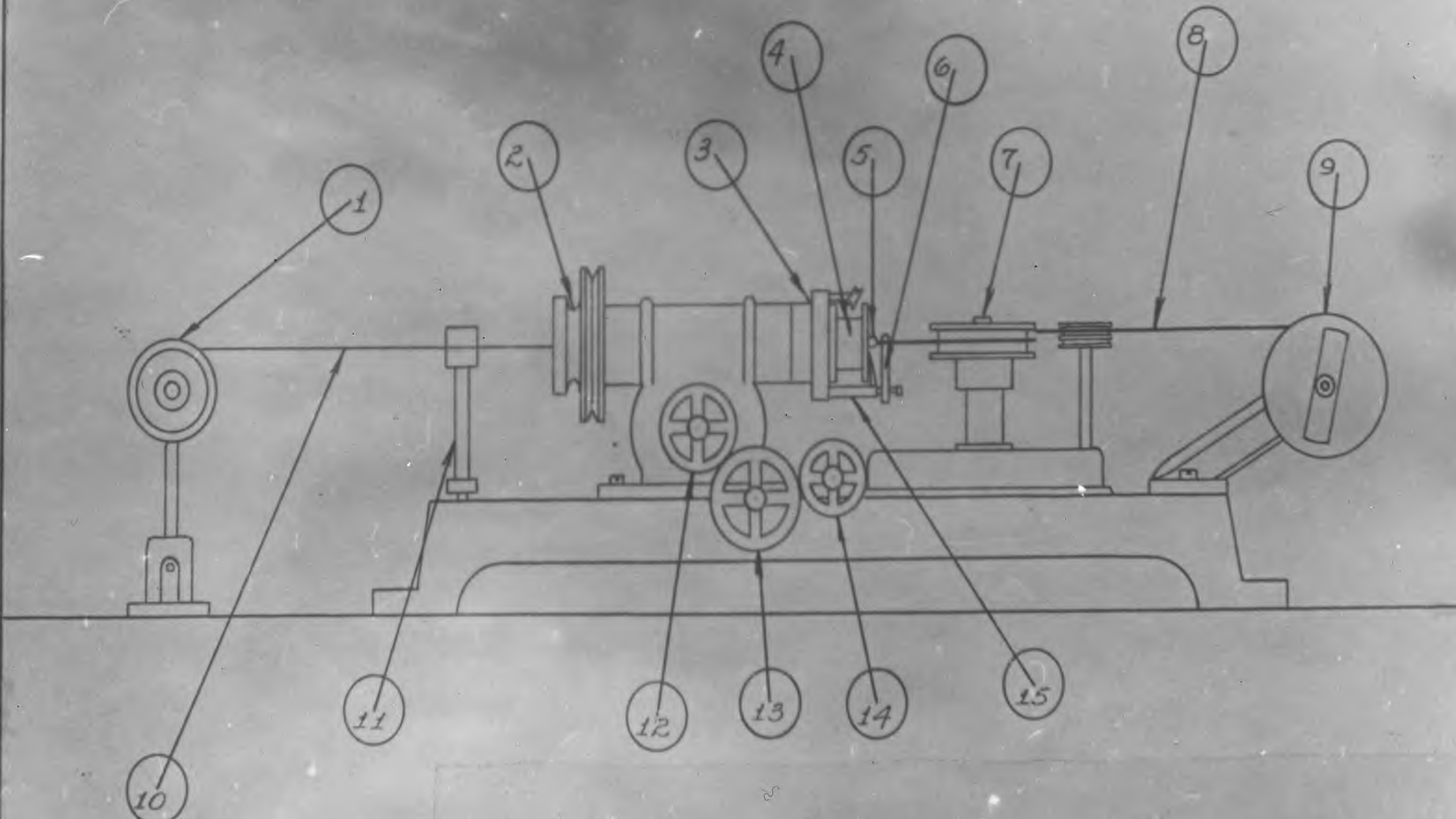
The Manufacture of Incandescent Lamps

The engineer, having determined the winding data for a particular lamp, sends this information to the coil winding department where the filament is wound in the first step of lamp production. A machine, typical of all winding machines is illustrated on the next page. It is adaptable for winding continuous filaments for lamp wattages between 5 and 200. The filaments may be set directly on the machine by passing the filament through a small electrical furnace.

Basically, a coil winding machine is a flexible gear apparatus to turn a bobbin of wire at a given speed to wind the filament wire about a definite mandrel as the latter advances. The relationship between the turns of wire about the mandrel and the advancement of the mandrel itself is known as the "turns per inch" of the filament. The turns per inch, the type of wire,



A LAMP FILAMENT WINDING MACHINE



LAMP FILAMENT WINDING MACHINE

E.T.B.

the mandrel diameter, etc. all determine the electrical characteristics of the lamp.

The common parts of the winding machine illustrated are as follows:

1. Mandrel coil, holds the mandrel about which the wire is to be wound
2. Pulley, for a belt connected to a constant speed driving motor
3. Head, holds bobbin as it turns about mandrel
4. Bobbin, holds filament wire
5. Mandrel guide
6. Finger, guides the wire to advance on the mandrel perpendicular to the axis of the mandrel
7. Feed drum, controls advancement of the mandrel
8. Coiled mandrel
9. Friction take-up, takes up coiled filament mandrel
10. Mandrel
11. Snubber, directs and withholds the mandrel
12. Gear A, drive gear
13. Gear B, idling gear
14. Gear C, driven gear
15. Two point tension piece, adjusts tension in bobbin by means of a screw attachment

In coiling tungsten filament wire, there are several significant points to the proper manipulation of the winding machine which if not observed will effect the life of the lamp. In order to obtain a uniform coil with little or no shrinkage, the following points should be observed:

(a) The mandrel should be carefully selected as to the degree of softness and temper, as well as uniformity of diameter. The tension in the mandrel wire reel (1) must be carefully adjusted by means of the snubber (11) to give uniformally equal pull in order to avoid non-uniformity in the spacing of the filament wire.

(b) The mandrel guide (5) should be properly fitted into the head (3) of the coil winding machine and must extend to a point where the filament wire will wind on the mandrel without touching any point on the machine. The mandrel guide should also be selected for the mandrel being used at the time. Not too much clearance should be permitted. A clearance of about 0.002" is generally accepted. If too much clearance is permitted, difficulties may arise due to the vibrations set up in the mandrel. It has been found that a mandrel guide having a properly coned jewel bearing, such as a sapphire bearing, will give very good results.

(c) The filament wire should be spooled on a bobbin (4) by means of a cam actuated spooling device having a proper throw. This device will guide the wire so that it will be spooled evenly over the entire width of the barrel bobbin. If the wire is not spooled evenly, loose turns may develop later and entanglement is sure to follow. As a result, there may be a loss of the winder's time and filament wire.

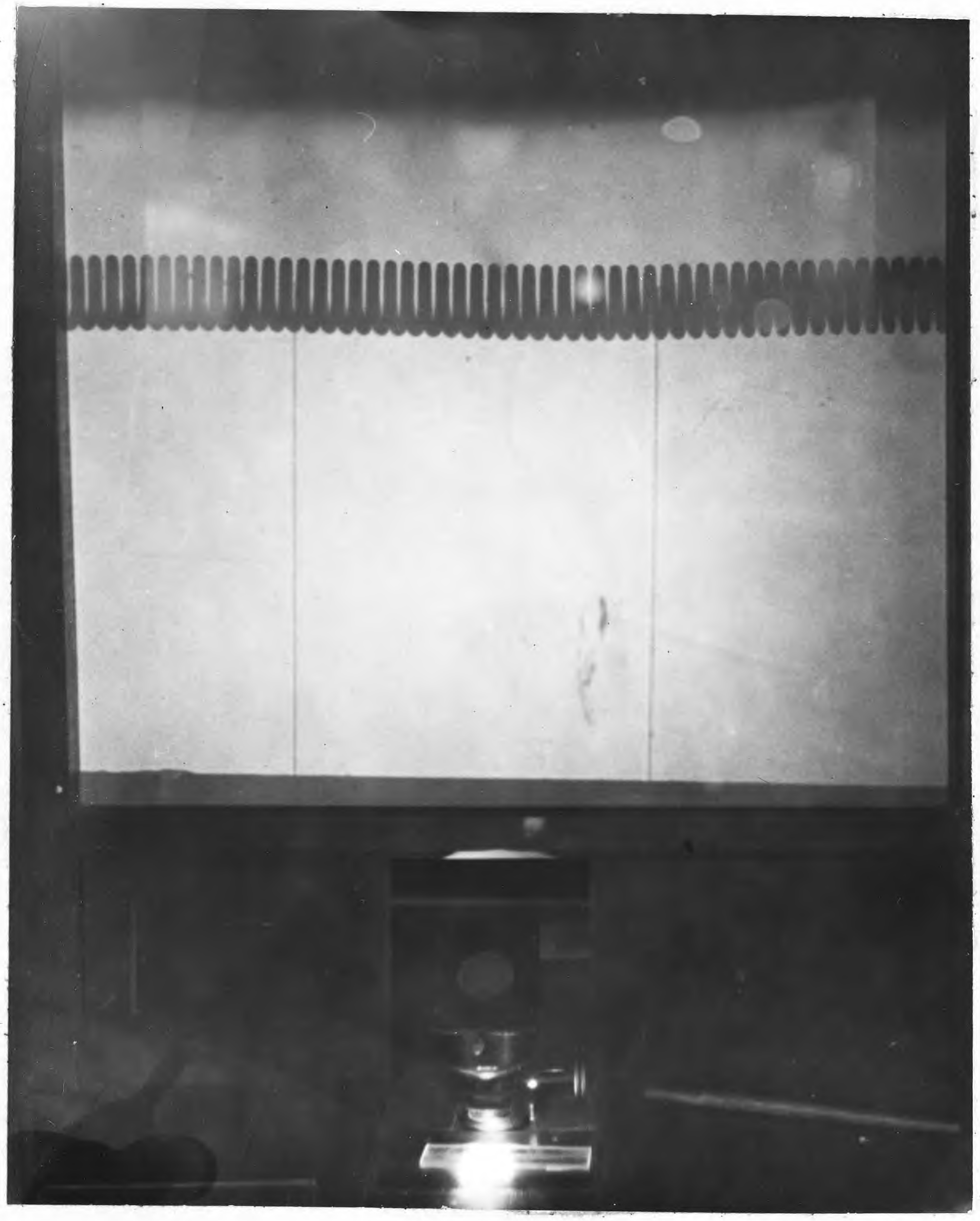
(d) The tension in the bobbin must be carefully adjusted (15) with respect to the speed of operation, as well, as the size of wire being wound. In every case, the tension should be uniform and not too great; otherwise, the non-uniformity of tension may cause the wire to break on starting the machine. It is best to determine this tension before the machine is started by pulling two or three feet of the wire by hand to see if the tension is uniform.

The machine illustrated is made by the Eisler Electric Co., Lamp Equipment Engineers and Designers. Its speed is 3500 r.p.m. and has the following operating data:

Watts	Man-drel Size	Wire Weight mg/200 mm.	Change Gears A	B	C	T.P.I.	Gear Formula
10	.004"	0.40-1.00	24	A	54	630-700	N = T.P.I.
15	.005	1.25-1.30	30	N	54	550-600	A, top gear
20	.005	1.75-1.80	24	Y	40	500-530	B, inner gear
25	.006	2.30-2.35	30		48	480-490	C, lower gear
40	.006	4.30-4.35	40	G	60	440-450	
50	.006	5.40-5.45	30	E	40	400-410	$\frac{N \times A}{307.7} = e$
60	.007	7.20-7.25	48	A	60	370-390	
75	.007	9.20-9.30	40	R	48	340-360	$\frac{307.7 \times e}{A} =$
100	.008	13.0-14.0	54		54	280-300	
150	.010	22.0-23.0	54		40	215-230	Exact T.P.I.
200	.010	31.0-32.0	48		30	175-185	

As the filament is being wound, several checks should be made to see if the machine is winding the correct number of turns per inch and if the filament is being cut to the correct length. These checks are best done by projecting the filament on a ground glass screen. On the screen the filament will appear many times larger and there will be no difficulty in checking the filament.

The cut filaments, still on the mandrel, are now sent to the chemical laboratory where the mandrel is removed by dissolving it in acids, yet, the filament is not injured. Prior to the removing of the mandrel, the filaments are cleaned to remove all foreign matter. This



A FILAMENT PROJECTION APPARATUS FOR STUDYING THE MECHANICAL CONSTRUCTION OF LAMP FILAMENTS

(Distance Between Lines Equals 0.10")

cleaning process is very necessary to prevent the inner surface of the finished lamp from becoming black while in operation. The details of the cleaning and dissolving processes are as follows:

1. Prepare a concentrated caustic solution by dissolving 300 grams of technical flake caustic in one liter of water. To save time it is advised that a gallon of this mixture be made at a time by dissolving approximately 1220 grams of flake caustic in a gallon of water.

2. Place the coils to be cleaned in a porcelain or iron casserole and cover the coils with the caustic solution. Boil for about five minutes.

3. Pour off the excess caustic solution and rinse the coils well with tap water. Be very careful while rinsing that the casserole is not too hot when the cold tap water is passed into it.

4. The filaments are now clean and the mandrel is ready to be dissolved. The mandrelled coils are placed in a porcelain dish and covered with acid. If the mandrel is advanced iron or brass, nitric acid should be used. If the mandrel is not advanced iron, either aqua regia or hydrochloric acid may be used. The aqua regia is made of three parts hydrochloric and one part

nitric acid. As the reaction progresses, the fumes are carried away by a draft.

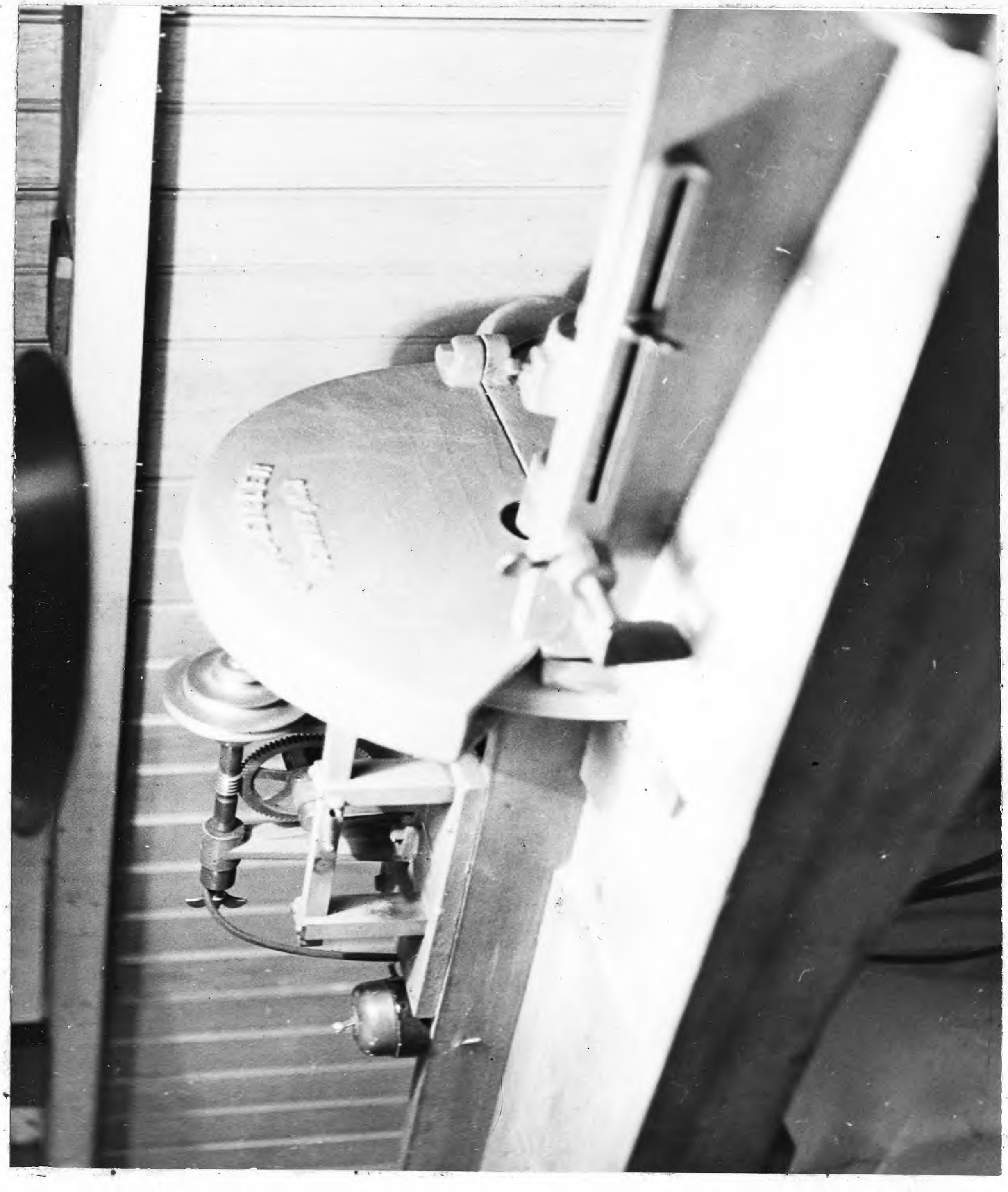
5. When the mandrel is dissolved, the acid is poured off, and the coils thoroughly rinsed with tap water. The coils are now boiled in tap water for about five minutes.

6. Pour the boiling tap water off and again boil the filaments in a water solution containing 15% caustic soda and 5% sodium carbonate. Pour off the caustic solution and rinse with a bath of weak hydrochloric acid. Rinse the coils again with water and dry with electric produced heat.

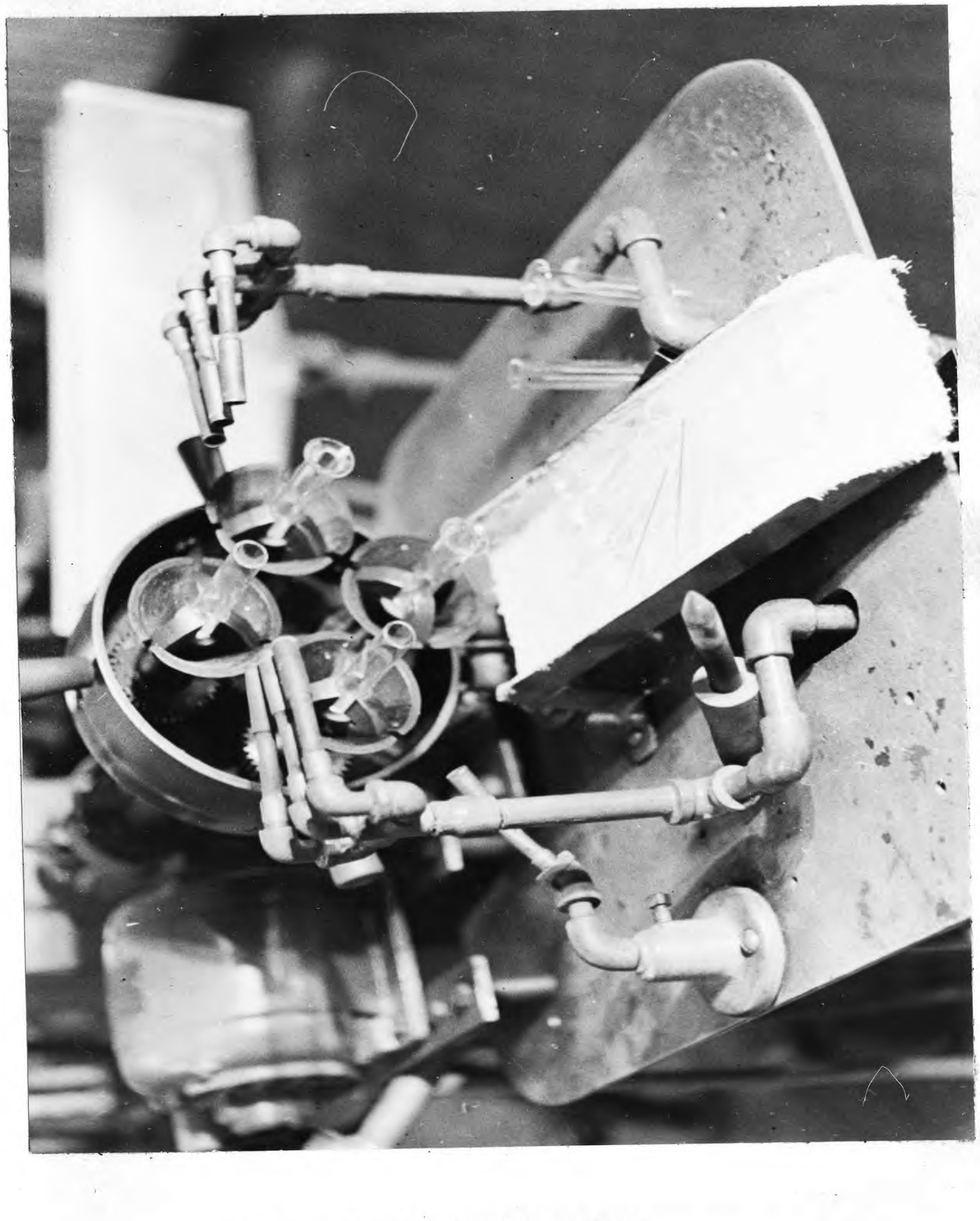
The clean filament is now ready to be assembled into a lamp. The first step in assembling the filament is to "getter" it. The word "getter" is the agent applied to the filament to improve the vacuum of the lamp or the quality of the lamp. It removes the last traces of gas and moisture left after the lamp has been exhausted of air. In this way the life of the lamp is increased and black deposits within the lamp are prevented. Various kinds of getter are used, all of which contain red phosphorus, a nitrocellulose binder, and cryolite. The amount of getter applied to a filament is predetermined and is expressed as a percentage by weight of the total weight of the cleaned filament. The percentage of getter specified for different lamps is as follows: 25 watt, 2.5% to 5.5%; 40 watt, 2% to 7%; 50 watt, 1.5% to 5.5%; and 60 watt, 1.5% to 5.5%. After gettering the filaments, sample lamps are made of the gettered filaments and a life test is made of the lamps. If the life test is satisfactory, then the remaining filaments from which the sample was taken is put into production.

The accompanying drawings show the various steps necessary to make a lamp. The flare is made by heating the end of a suitable piece of glass tubing and with the aid of a flaring tool, form a flare or "skirt" on the end of the heated tube. The circular tubing is cut into the various lengths needed for different lamps by nicking the surface of the glass with the edge of a revolving grindstone. The operator next breaks the tubing at the nick and sends it to the flaring operator. Tubing can be cut at the rate of about 3000 per hour.

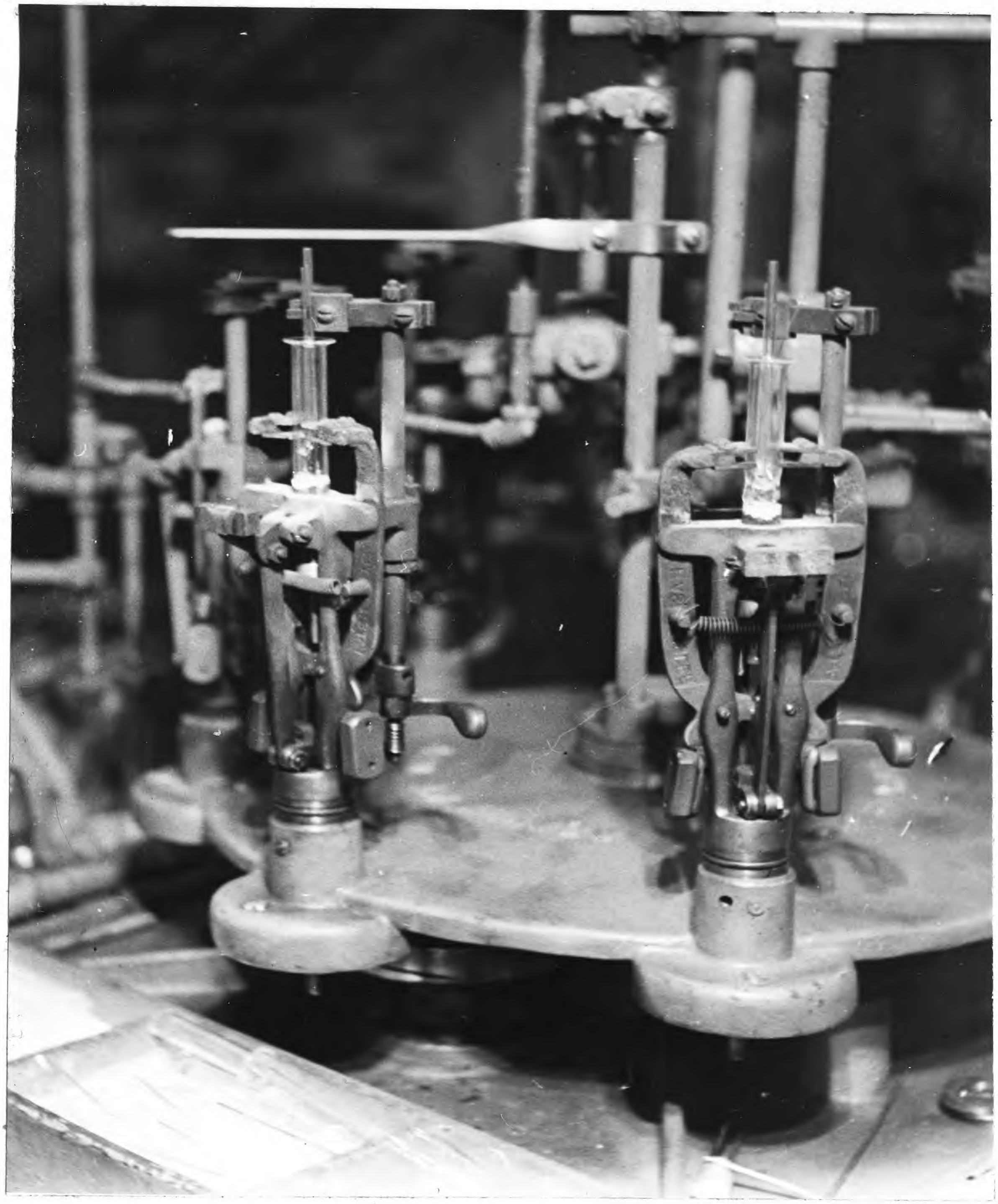
At the flaring machine, the operator inserts the tubing in a number of revolving holders. As the flare is revolved it is heated by a flame applied to one end of the tubing. When the glass is sufficiently



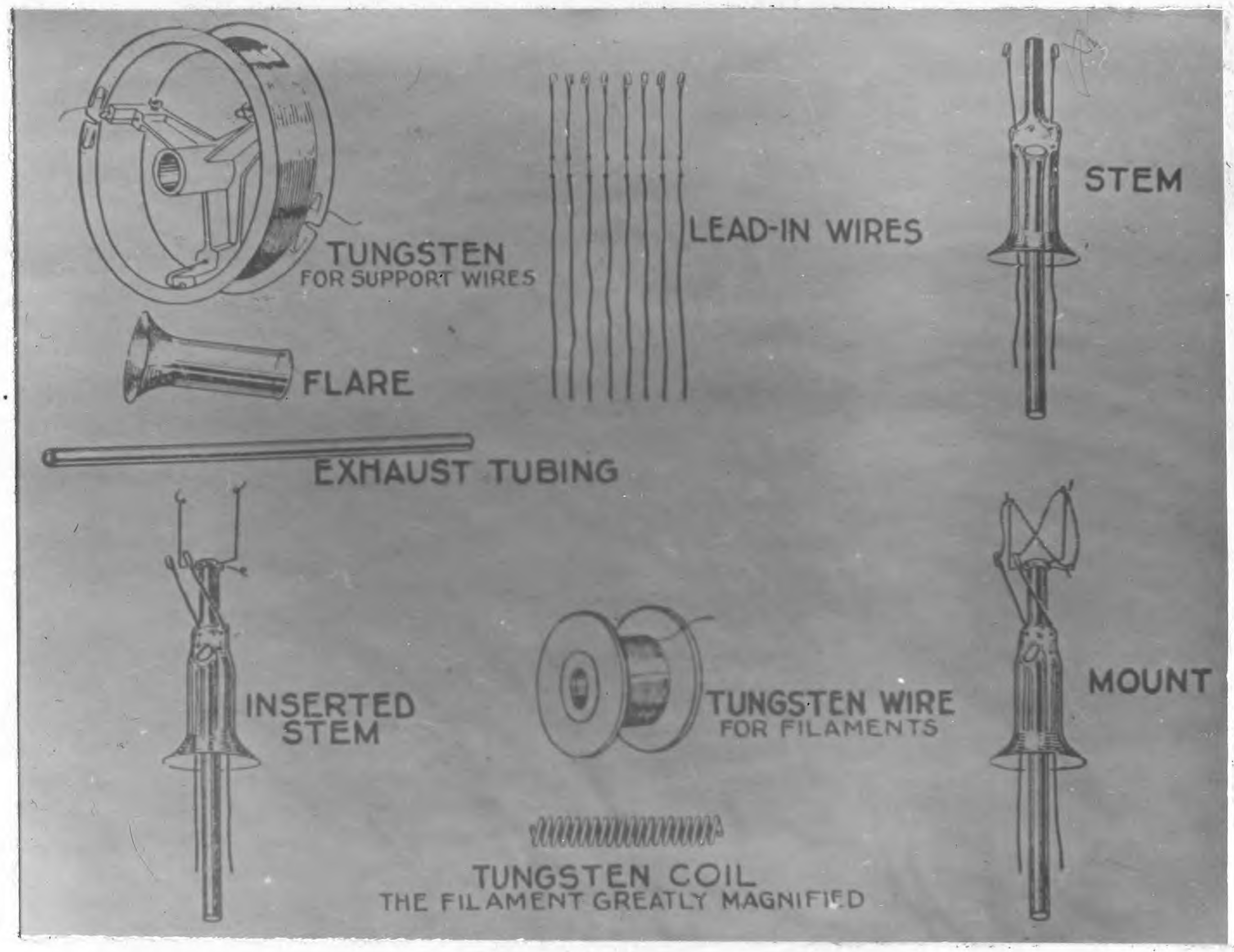
GLASS TUBE CUTTING MACHINE



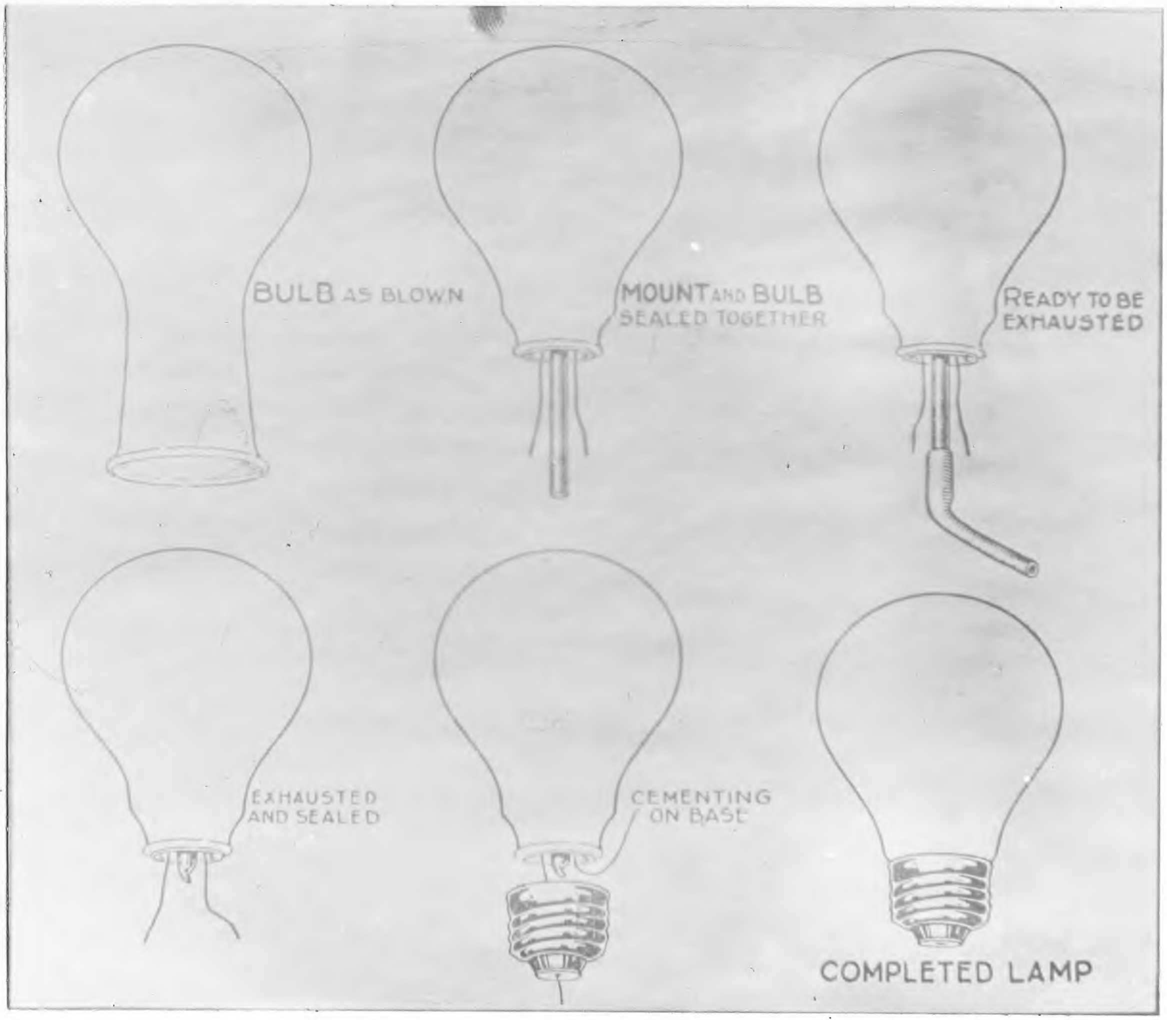
A FLARE MAKING MACHINE



A STEM MAKING MACHINE



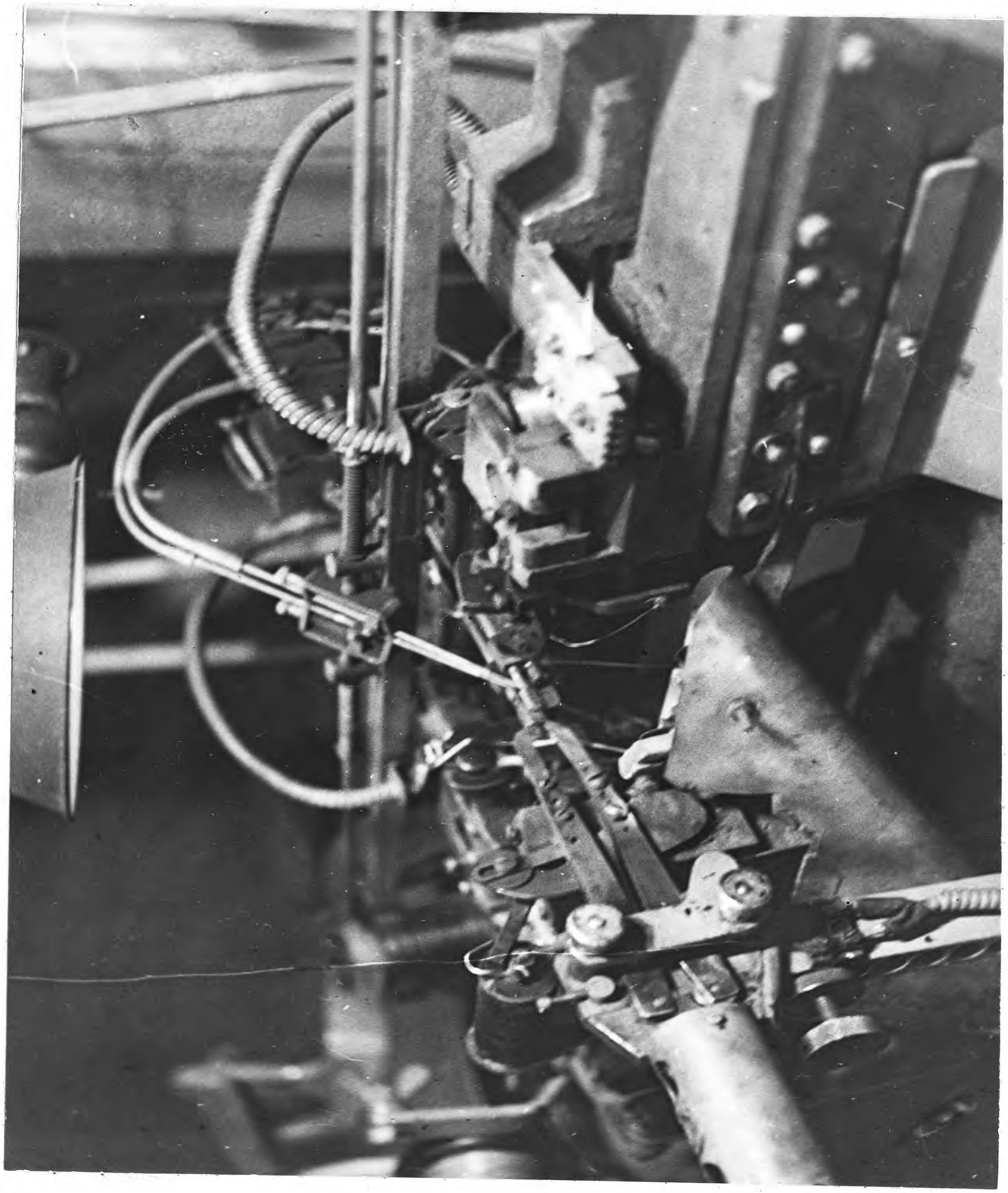
LAMP COMPONENT PARTS AND THEIR ASSEMBLY



THE FINAL STAGES OF LAMP MANUFACTURE

warm, the operator inserts a round pointed tool within the tubing and works a "skirt" at the end which is about twice the diameter of the tubing. The old flaring machines can make about 420 flares per hour, whereas, the newer machines, which also cut the tubing, can make 960 per hour. All flares are then inspected removing broken, cracked, undersized, over-sized, and uneven flares.

The next part of the lamp to be considered are the welds which connect the filament through the lamp to the source of power. These welds are made of one, two or three pieces of metal. The metal may be copper, nickel, dumet, tungsten, molybdenum wire or some combination of these wires. The three piece weld common to the larger lamps is made of copper, dumet and nickel wire. Nickel wire is used within the lamp from the press to the filament, dumet is used through the press, and copper wire joins the dumet wire with the base of the lamp. The dumet wire is an iron-nickel core which has a copper film about it over which a brass sheath is placed. This in turn is placed in a copper tube. When drawn and treated the resulting wire, dumet, has the special property of having a coefficient of expansion similar to glass. This wire makes an excellent hermetical seal with glass and because of this, it is used



A LEAD-IN-WIRE WELD MACHINE

to "lead" the wire into the lamp to complete the electrical circuit. The welding machine which makes these three piece welds cuts, welds, and counts the welds as they are made. The welding may be done with a gas flame or by an electrical arc. In the operation of this welding machine, care must be taken that the dumet wire is fed to the machine over smooth wheels. If the coating of the wire is injured it is very likely that the lamp using the imperfect wire may develop a leak and burn out very shortly. Dumet wire welds should also be kept dry. This can be done by wrapping in wax paper and storing in a dry place until used.

The flare, two welds and an exhaust tube are now ready to be assembled together. The tube is placed in the center of a revolving holder about which is placed the two welds definitely spaced from the tube and in a line with it. The flare is placed over these with its skirt downward. By directing a flame at the top of the flare, the glass becomes soft and is pressed together. In pressing, the flare adheres to the exhaust tube with the two welds sealed in their joint.

On the end of the exhaust tube, supports or hooks are to be placed through which will be suspended the tungsten filament. To support the hooks, the end of the tube is flattened and wire hooks inserted in the glass. This is done by placing the part now made of the flare, welds, and exhaust tube in an inserting machine. While in the holder of this machine, a gas flame is directed at the top of the tube. When the glass is soft enough, a plunger flattens the top to form a "button". While the glass is still hot, the ends of the wire hooks are inserted in the button. When the glass has cooled, these hooks are held firmly and are now ready to serve their purpose of supporting the filament.

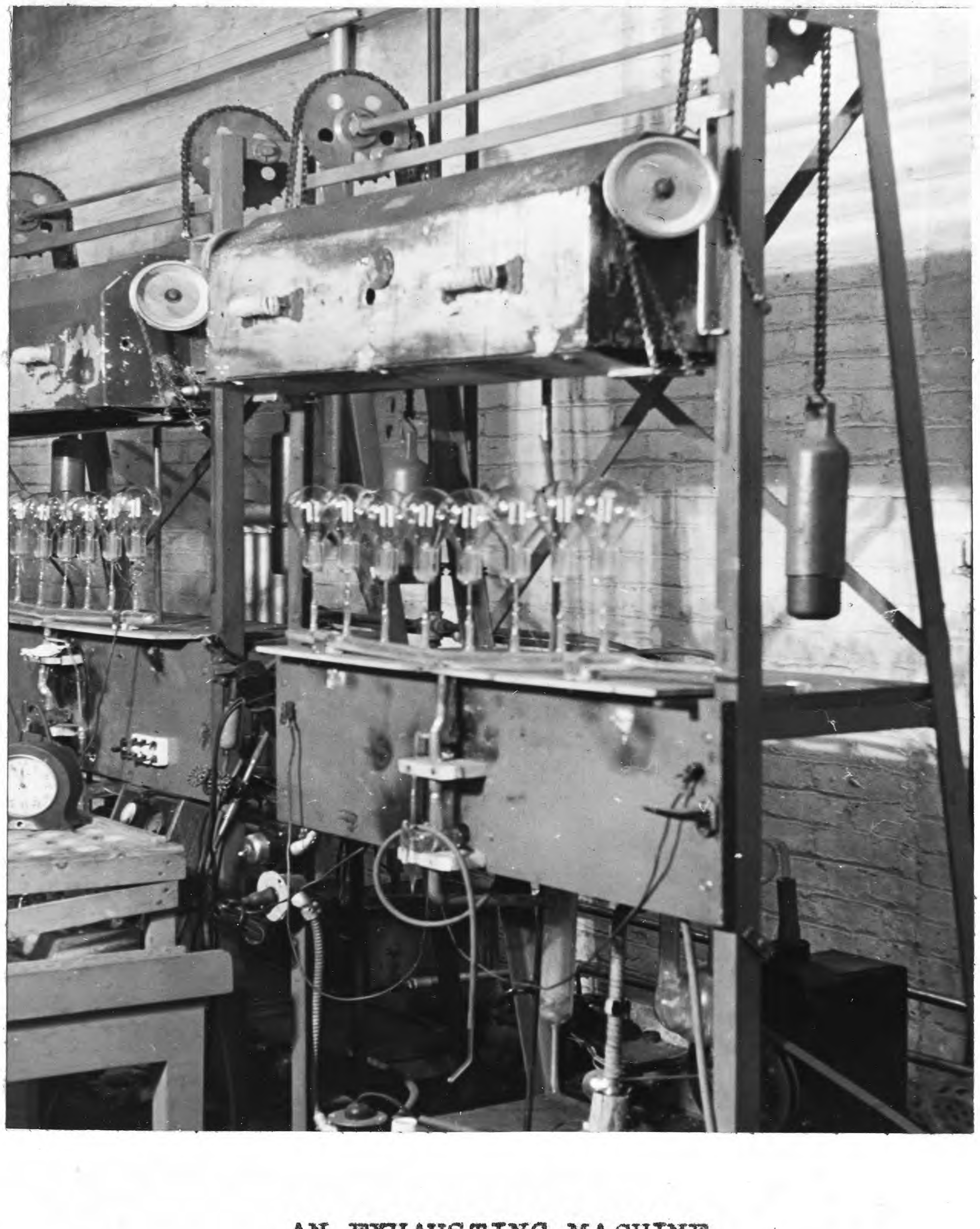
The filament is now put through the hooks and clamped to the nickel end of the weld. The weld has been suitably formed for clamping at the time of manufacture by flattening the end and bending it into a hook. It will be remembered that two extra millimeters were added to the lighted length of the filament to account for the loss in filament length due to this clamping. This final assembly is known in the lamp industry as the mount.

Properly named, the mount is ready to be "mounted" within a bulb. However, before the bulbs as received from the supplier can be used, they must be inspected and cleaned. After the broken, cracked, strained, and other defective bulbs are removed, the remaining bulbs are washed in a tank of water. Here the dirty bulbs are sprayed with a jet of water and cleaned. The jet washing is preferable as it is faster, the water remains cleaner, and it is more pleasant to the operator. The water in the tank where the washing is done is changed once a day. In that time, approximately 30,000 lamps are cleaned.

The bulb is now ready to be sealed to the mount. About eight mounts are placed in revolving holders on a turn-table. Over each mount is placed a bulb. Each bulb must pass through three different flames before the seal is complete. All three flames are directed at a point on the neck of the bulb just below the skirt of the flare. The first flame is broad and not very hot. It heats a large portion of the bulb neck. The second flame is very hot and more direct. In this flame, the glass is melted and the weight of the glass which is below the seal to be formed draws the bulb down and about the flare. The third flame is accurately directed and is of a higher pressure than the other two flames. In this flame, the unnecessary portion of bulb below the seal is made to fall off. The bulb is then removed and the exhaust tube aligned before it is too cool to adjust. The bulb is now ready to be exhausted or filled with an inert gas.

In the exhausting machine, the bulbs are connected within an oven to a vacuum pump. As the lamp is

A SEALING-IN MACHINE



AN EXHAUSTING MACHINE

being exhausted, it is being heated to a temperature between 350 and 460 degrees Centigrade. The reason for this heating is to drive off the gases held within the pores of the glass in the inside of the bulb. In this way, a higher vacuum, and, therefore, a longer life will result. The exhausting continues until a colorless or very slight purple color appears by passing a high tension electrical spark through the lamp. A deep purple color, as a result of this test, indicates a poor vacuum and the exhausting process must be continued. Of course, it is quite possible that a good vacuum can not be obtained due to a leak in the seals of the lamp. A leak can readily be detected by the slowing of the pump motor due to the extra load placed on it or by a rush of oil in the oil trap between the high pressure side of the pump and the low vacuum exhaust line. Castor oil should be used in exhausting, as it not only lubricates but seals all possible leaks in the exhaust system. This oil is also recommended to be used where the rubber tubing about the exhaust tube of the lamp connects it to the pump. Castor oil does not injure rubber as most oils do, and, hence, less trouble with possible leaks will be experienced. The exhausting of the lamp is concluded by cutting off the exhaust tube of the lamp with a flame which at the same time seals the vacuum.

REMOVING LAMP FROM EXHAUST MACHINE BY SEALING EXHAUST TUBING

The base of the lamp is now ready to be fitted to the exhausted or filled lamp. On the basing machine, the lamp is capped with a brass base having a lining of plastic cement. One lead wire makes contact with the shell and the other is threaded through the contact to the end. As the lamps pass through a heated oven the cement hardens and mechanical fingers solder the lead wires or welds to the base and the excess length is cut off. The basing cement used is a mixture of rosin, shellac, bakelite, and marble ground finely together. Alcohol is added to this mixture and a paste formed. When this cement is heated, the alcohol evaporates and passes off. In this way, the cement hardens and adheres to the glass bulb. Care should be taken not to heat the bases too much as they will discolor.

The last step in the manufacture of lamps is to identify them as to their ratings. This can be done by stamping them using a special monogram ink. This ink is made of approximately 70% of silver oxide and 30% lead borate mixed with a small amount of glycerine to make a paste. On being heated, this ink turns to a silver white color. Too much heat will make the stamping yellowish.

The lamps are now ready to be used.

REVOLVING BASE BAKING OVEN

CHAPTER V

Lamp Testing

With the fitting of the brass base to the mounted bulb, the lamp is ready for service. However, as a means of quality control and to furnish sales data, the lamps are tested. All lamps are given a visual mechanical inspection. A few lamps, representative of a "run" of a particular lamp, are tested more severely. Some of the tests made are destructive tests, as they completely destroy the lamp.

Lamp tests may be divided into two classes: mechanical and electrical. The mechanical tests check the following:

1. light center length
2. shape of the bulb above the base; so that it will fit easily into any standard socket
3. overall length of lamp
4. adhesion of base to bulb

5. alignment of base on bulb
6. lamp breaking strength
7. filament vibration strength

The electrical tests given to a lamp are a spot test to determine filament wire defects, a photometric test to determine the light output and the efficiency of the lamp, and a forced life test to determine if the lamp will meet the requirement of 1000 hours set by the Bureau of Standards.

In the spot test, the lamp is enclosed in a dark box to be viewed from above through a colored glass. The rated voltage of the lamp is permitted to pass through it for a period of one-half to one second. The filament is observed and any spots on the filament which appear brighter than the rest of the filament are noted. A bright spot indicates a higher resistance at that point in the wire. This condition may be caused by a decrease in cross-sectional area of the wire as a result of the drawing process or may be due to the shifting of the crystals of tungsten within the wire. In a Mazda C lamp, a mottled condition of alternate groups of bright and dark turns indicates a poor crystal structure or a dirty filament. The so-called "star" spot in Mazda B lamps indicate an offset of crystal structure which will later cause the lamp to "burn out" before its normal life. "Band" spots appearing symmetrically on the filament of a Mazda B lamp indicates the presence of moisture or oxygen within the bulb. If these band spots are not symmetrical but scattered at random along the length of the filament, they are caused by a split filament, lumpy getter, or moisture from the operator's fingers. In studying a lamp during the spot test, care must be taken not to burn the lamp for more than a second or make one test after another without permitting the filament to cool. This precaution is necessary to prevent the filament from getting too hot so the spots can be recognized.

Lamps are photometered to determine the light or lumen output and the lumen efficiency of a shipment of lamps. Since a poor emitting lamp is quite recognizable, the lamp manufacturer must produce lamps which meet the regulations set up by the Bureau of Standards. Inferior lamps will sooner or later mean the loss of sales and a decreased profit to the manufacturer of such lamps. Hence, it is desirable for a manufacturer to determine the quality of his lamps; so that he might withhold such lamps that do not meet the requirements.

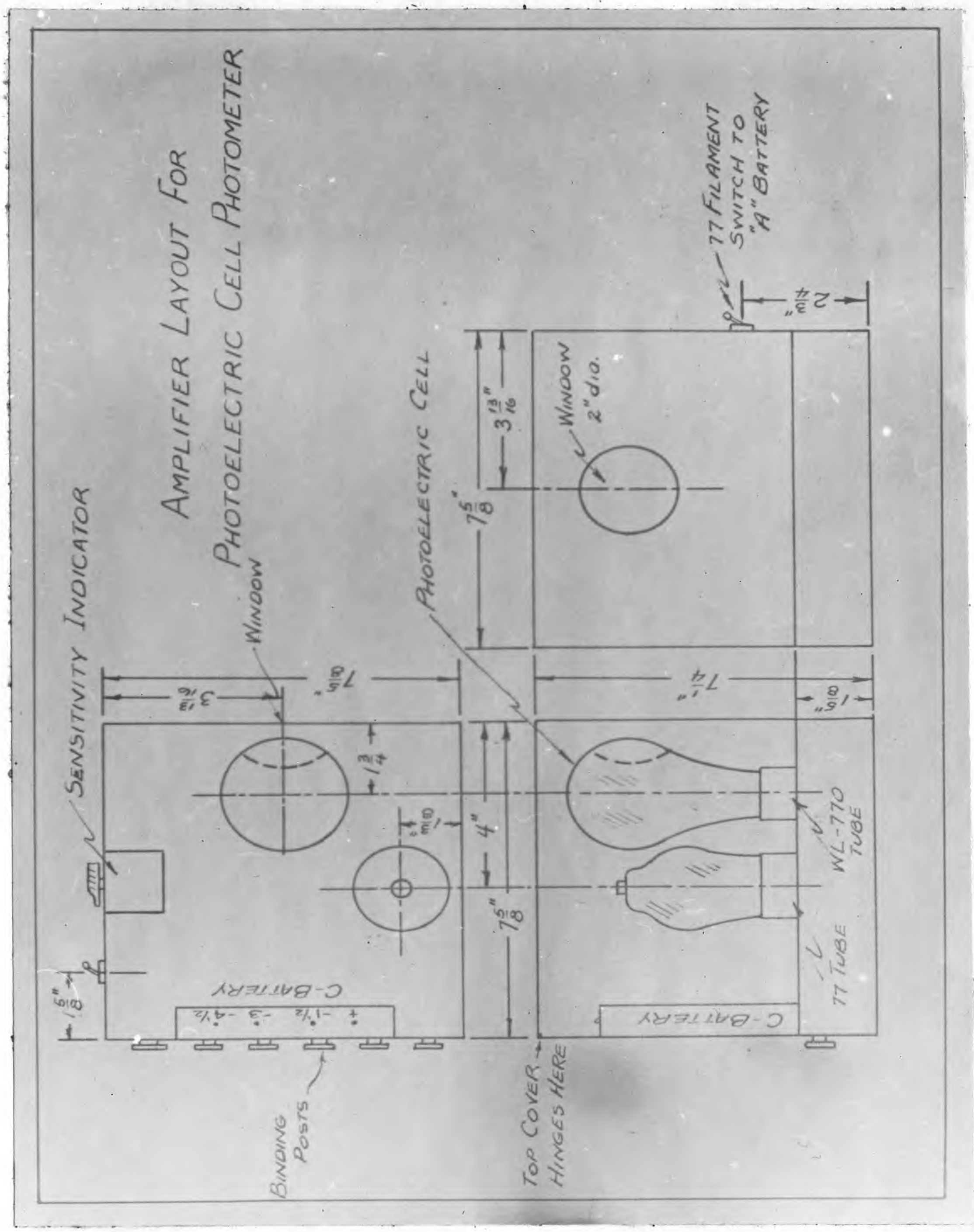
The photometer may be considered to be made of two parts: an integrating sphere and a measuring circuit. The sphere is an orb about four feet in diameter. The inside of the sphere is painted white with a special paint preparation. It has two openings. One opening has a door on it to permit the operator to insert a lamp in the center of the sphere. The other opening permits the light given off by the lamp under test to fall on the photoelectric cell in the measuring circuit. The greater the amount of light which falls on the photoelectric cell, the greater will be the current to flow through the measuring circuit to be recorded in micro or milliamperes. A new and very accurate photometer is shown in the accompanying pages.

Two sources of error are possible in any photometer no matter how accurately the measuring circuit is designed. One source of error is caused by the glare within the sphere due to the light incident on the white walls. This glare reacts on the photoelectric cell to indicate a higher lumen output than really exists. This source of error may be corrected by placing a baffle within the sphere between the lamp being tested and the opening which permits the light to fall on the photoelectric cell. The other source of error is the sensitivity of the photoelectric cell to wave lengths of light not in the visual spectrum.

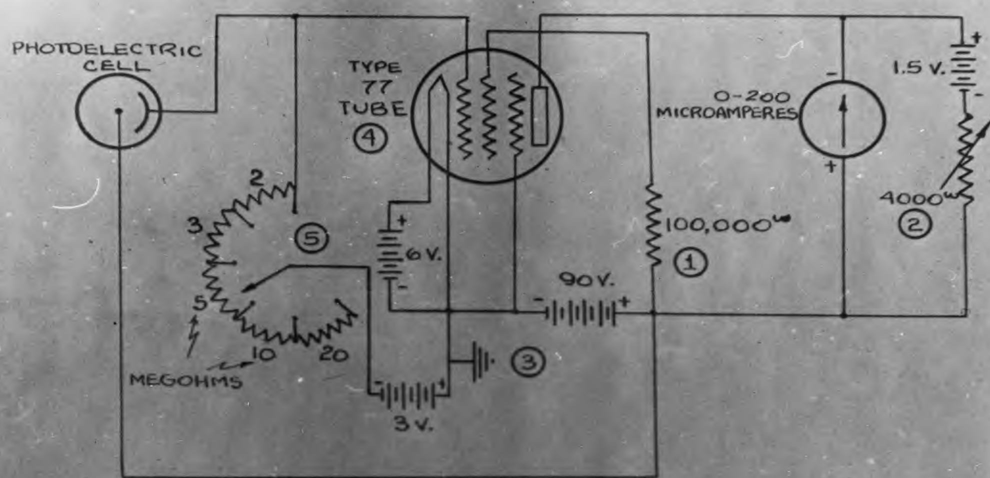
A PHOTOMETER SPHERE

(Note Baffle Behind Lamp And Position Of Amplifier

At The Right Of Sphere)



A PHOTOELECTRIC CELL PHOTOMETER



SCHEMATIC DRAWING OF A PHOTOMETER PHOTOELECTRIC CELL AMPLIFIER.

NOTES

1. Value given is approximate and should be modified as necessary to obtain a plate current of 0.5 to 0.6 mils(with photoelectric cell dark).

2. To secure fine adjustment of zero setting on meter, this may consist of a series combination of a 2000 ohm fixed resistor, a 2000 ohm variable resistor, and a 50 ohm variable resistor.

3. Connect to metal box containing photoelectric cell and tube, and to frame of sphere. Actual earth connector is not necessary.

4. Tube must be selected for low grid current.

5. Switch contacts should be supported on hard rubber posts.

E.T.B.

This last error may be corrected by passing the light through a special filter before it falls on the electric cell. The filter used with this photometer, which proved very satisfactory by comparison with the Electrical Testing Laboratories of New York, was the Wrattan filter made by the Eastman Kodak Co. of Rochester, N. Y.

The procedure in operating the photometer shown in the following pages is as follows:

Starting: With the microammeter disconnected, the 77 tube filament switch off and the positive lead to the B batteries disconnected,

1. make sure that the sphere switch is off and the photometer door closed
2. turn on the 77 tube filament switch
3. after a few seconds, which is necessary to heat the cathode of the 77 tube, connect the positive lead to the B batteries.

After a lapse of about fifteen minutes, the tube elements have reached an even temperature and the test may be started. It is necessary that the elements reach an even operating temperature before measurements are made; otherwise, inaccuracies will result due to the "creeping" of the needle on the milliammeter during readings.

4. set the microammeter to read on the maximum scale as a safety precaution in preventing the needle from going off scale should the lumen output be too great

5. touch the disconnected lead to the microammeter binding post

6. if the meter reading is only a slight deflection, permanently connect the lead to the binding post

7. adjust the potentiometers until the microammeter needle reads zero

8. change the scale reading of the microammeter to its most sensitive setting, 0.2 microamperes full scale

9. again adjust the microammeter to read zero

The photometer is now ready to be used. It is necessary to have the sensitivity setting at the correct point for the lumen output of the lamps to be read. The most sensitive setting is with the microammeter needle reading as far clockwise as possible. With the microammeter in operation and of maximum sensitivity, place the secondary comparison standard in the socket within the integrating sphere. Secondary standards are lamps calibrated against a certain primary standard of internationally agreed lumen output. The primary standard is kept at the Bureau of Standards in Washington, D.C., where the secondary lamps are calibrated against it. This calibration will show the lumen output of the lamp at various voltages and the current flowing in the filament. When adjusted in the sphere to the rated calibrated voltage, the microammeter will give a reading proportional to the lumen output of the standard. Knowing the microammeter deflection and the lumen output of the lamp at rated voltage, it is a simple matter to determine the lumen output of the lamps under test. Next, remove the secondary standard lamp from the socket, and place the lamp to be tested in place of it. Adjust the lamp to its rated voltage, noting the current reading and the microammeter deflection. The lumen output of the lamp under test is:

$$\text{Lumen output(standard)} \times \frac{\text{Microammeter deflection(std.)}}{\text{Microammeter deflection(test lamp)}}$$

When the microammeter deflection of the standard is less than the deflection caused by the lamp under test, the lumen output of the test lamp will be greater than the output of the standard lamp. Knowing the voltage and the current in the filament, the energy drain in watts can be calculated by multiplying them together. The efficiency of the lamp is the lumen output divided by the power taken by the lamp expressed in lumens per watt. The variation of this efficiency from the efficiency of the standard lamp will tell the manufacturer how good his lamps are. Naturally, the more tests photometered, the more accurate will be his conclusions.

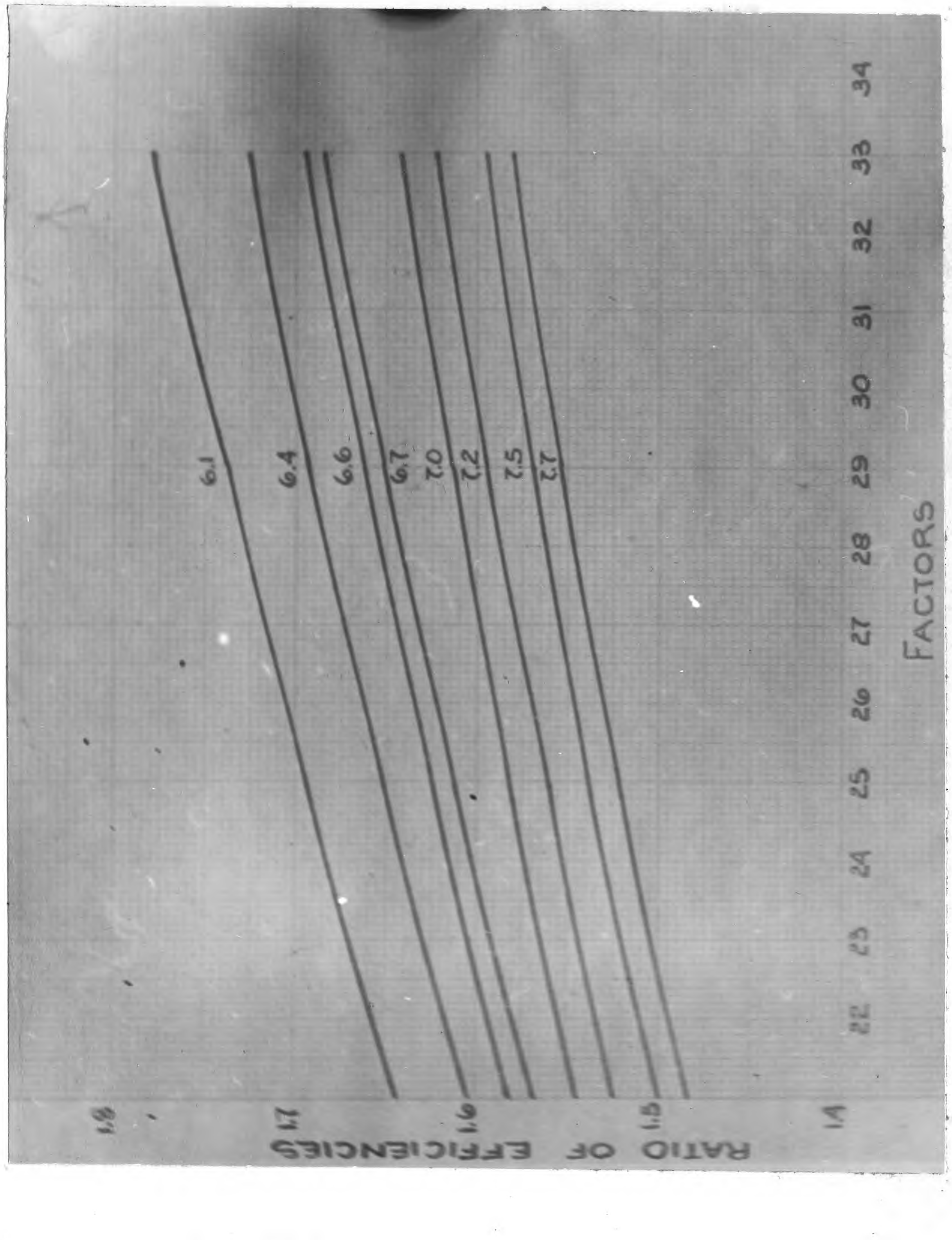
Even with the lamp giving off the required amount of light, the manufacturer still has the life of his lamps to consider. The rated average life of most of the general lighting service lamps is 1000 hours. It is impossible to make lamps so accurately that the actual life of each individual lamp will just equal its rated life. Some lamps have less than the rated life, others have a correspondingly longer life. However, the average life of a number of lamps will be close to the rated life provided they are burned correctly; i.e., at their rated voltage, on a well regulated circuit, and without excessive vibration or handling. To illustrate this, the table on the next page will show a test made on 100-60 watt Mazda C lamps.

Number of Lamps Remaining	Hours Burned
100	0
99	200
97	400
91	600
75	800
50	1000
25	1200
9	1400
3	1600
1	1800
0	2000

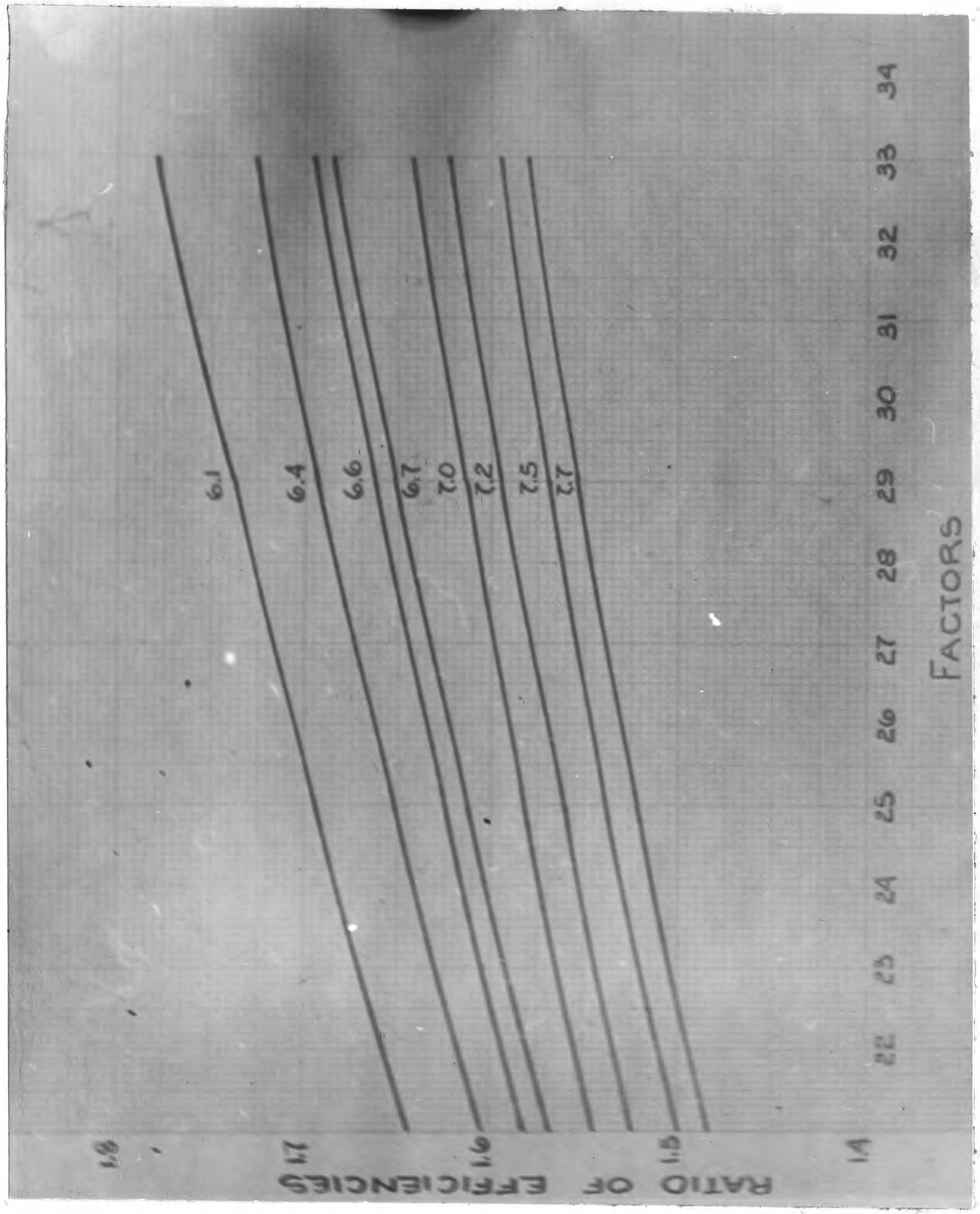
The average life of this group was close to 1000 hours. This data clearly shows the fallacy of judging lamp quality on the basis of tests of only a few lamps.

To get some idea of the life of a group of lamps, the manufacturer burns these lamps at a voltage greatly in excess of the rated voltage of the lamps. Knowing the efficiency of the lamp at rated voltage and at "forced" voltage and the life of the lamp at the excessive voltage or "forced" voltage, the life of the lamp at normal voltage can be calculated by an exponential relationship.

The following is an actual life test:



LIFE CORRECTION FACTOR CURVES



LIFE CORRECTION FACTOR CURVES

Photometer and Life Test Report

on

100W.-120V. Lamps with Filaments of Various Types of Wire

Group 1	Lamp No. 2	Watts at Normal V 3	LPW Normal V 4	LPW 150v. 5	Volts Test 6	LPW Test V 7	Life Test 8	Life Normal V 9
A	2 B-2	100.9	12.78	19.93	151.5	20.00	104	2155
	-3	100.0	12.90	20.05	151.4	20.12	71	1428
	-4	100.1	12.84	20.11	151.4	20.18	71	1490
	-5	99.6	12.70	20.06	151.4	20.14	71	1581
	-6	99.5	13.17	20.71	151.3	20.78	60	1301
B	-7	99.6	13.00	20.19	151.4	20.26	71	1428
	-8	99.8	13.23	20.54	151.4	20.62	66	1325
	-9	99.7	13.04	20.38	151.2	20.44	73	1531
	-10	99.8	13.48	20.75	151.4	20.83	67	1291
	-12	99.6	13.30	20.78	151.4	20.85	63	1266
C	-13	98.2	13.29	20.65	151.4	20.73	66	1332
	-14	98.4	13.62	21.19	151.4	20.27	62	887
	-15	98.5	13.76	21.23	151.2	21.30	36	685
	-16	97.6	13.47	20.93	151.2	21.00	47	945
	-18	98.0	13.78	21.10	151.1	21.16	48	875
D	-21	98.8	12.35	19.35	151.2	19.41	118	2500
	-22	98.2	12.32	19.43	151.2	19.51	123	2741
	-23	98.8	12.96	20.20	151.1	20.25	71½	1450
	-24	98.8	12.35	19.46	151.2	19.54	94	2067
E	-25	101.5	13.45	20.74	151.1	20.80	70	1560
	-26	101.0	13.27	20.56	151.3	20.62	74	1465
	-27	100.2	13.97	21.28	151.5	21.37	58	1015
F	-29	100.2	13.22	20.39	151.5	20.47	81	1570
	-30	100.6	12.72	19.87	151.4	19.95	86	1795
	-31	100.2	13.17	20.28	151.1	20.34	70	1316
	-32	100.2	13.17	20.14	151.5	20.22	81	1490
	-33	99.7	13.29	20.09	151.4	20.15	86	1445
H	-41	101.4	13.26	20.21	151.3	20.28	75	1320
	-42	101.4	13.41	20.35	151.5	20.42	81	1381
	-43	100.7	13.01	19.95	150.2	19.96	107½	1912
	-45	100.8	13.59	20.59	150.5	20.62	83½	1419
	-46	99.7	13.39	20.55	150.8	20.59	69½	1280

Group 1	Lamp No. 2	Watts at Normal V 3	LPW Normal V 4	LPW 150v. 5	Volts Test 6	LPW Test V 7	Life Test 8	Life Normal V 9
K	2 B-47	99.4	13.73	20.74	150.5	20.77	77½	1248
	-48	97.8	13.65	20.65	150.8	20.89	51½	855
	-49	97.6	12.70	19.77	150.2	19.79	121½	2440
	-50	98.0	13.93	20.84	151.1	20.89	46½	707
	-51	99.7	13.99	21.34	150.8	21.38	54	935
L	-52	99.2	12.85	19.81	150.2	19.84	118½	2228
	-53	99.2	13.51	20.59	149.4	20.57	74½	1265
	-54	98.9	12.74	19.47	149.8	19.46	108½	1900
	-57	99.5	13.17	20.13	149.7	20.12	101½	1775

Group 1	Lamp No. 2	Hours Life at 13.8 LPW 10	Average Life at 13.8 LPW 11
A	2 B-2	1249	
	-3	880	
	-4	875	
	-5	880	
	-6	925	966
B	-7	930	
	-8	970	
	-9	1010	
	-10	1071	
	-12	1020	1000
C	-13	1010	
	-14	819	
	-15	475	
	-16	800	
	-18	850	791
D	-21	1168	
	-22	1256	
	-23	938	
	-24	959	1080
E	-25	1111	
	-26	1088	
	-27	1107	1102

Group 1	Lamp No. 2	Hours Life at 13.8 LPW 10	Average Life at 13.8 LPW 11
F	2 B-29	1126	
	-30	1021	
	-31	925	
	-32	1051	
	-33	1084	1042
H	-41	990	
	-42	1118	
	-43	1280	
	-45	1235	
	-46	1000	1125
K	-47	1194	
	-48	783	
	-49	1350	
	-50	753	
	-51	1036	1023
L	-52	1350	
	-53	1072	
	-54	1085	
	-57	1280	1197

The groups of lamps shown as letters in the preceding table represents lamps of the exact same construction but of different filament wire. The results, therefrom, indicate what wire has the best life characteristics. Of course, any conclusions from this test is not conclusive in view of the fact that so few lamps were tested in the various groups. The wire tested is as follows:

A..........Thoriated Non-sag

B..........Westinghouse Lamp Co.

C.........Callite Products Regular Wire

D.........General Electric Co.

E.........White Binder

F.........Washed Metal

H.........Caramel Solution doped on oxide

K.........Serian Co.

L.........Serian Co.

The table on the preceding pages was determined in the following way:

Columns 3,4,5 were determined by a photometric test

Column 6 is the average test voltage during the forced life test

Column 7 is determined by multiplying the difference between the efficiencies at 120v., and 150v., by the ratio of the test voltage to 150v. and adding this figure to the efficiency at 120v.

Column 8 is the actual life of the lamp at the forced voltage

Column 9 is the life of the lamp at 120v. as determined by the accompanying curve sheets where

"L" is the life at test voltage, Column 8 "l" is the life at 120v.

"E" is the efficiency at the test voltage

"e" is the efficiency at the rated voltage, 120v.

"b" is 6.7 for this type of lamp

Column 10 is the life of the lamps reduced to the same efficiency (13.8 LPW) to enable a better interpretation of the results of the test. This information was again determined with the aid of the forced life test formula, where

"l" is the life at 13.8 LPW

"L" is the life at 120v.

"E" is the efficiency at 120v.

"e" is 13.8 LPW

"b" is 6.7

From the test, we learn that the lamps made with the Serian Co. wire, Type L, are the best for life. We also are shown that the manufacturer of Type C filament needs to improve his wire.

The results of these three tests gives the manufacturer a very good idea of the quality of his wire.

Naturally, if his lamps do not have the life or light output characteristics, he will soon find himself losing business. A correct interpretation of these tests will be the starting point for improving his wire. Some of the things affecting lamp quality have been discussed; whereas, others will be explained in a following chapter.

CHAPTER VI

General Lamp Information

Incandescence and Visibility

As previously stated, a material gives light by incandescence when it is heated above a certain temperature. The higher this temperature is the greater will be the amount of light given off and the whiter will be the light. In the lamp, light is given off by heating the filament by an electric current to a temperature from about 2430° K to 3000° K for lamps rated at 115 volts.

The radiant heat and light given off by a lamp are considered forms of wave motion. These waves are extremely short in length, varying from about 40 to 76 hundred thousandths of a millimeter in length or from about 0.40 to 0.76 microns. A micron is an adopted unit of wave length equal to one-one thousandth of a millimeter. Light having wave lengths between the range mentioned, also known as the visible spectrum, has various colors depending on its wave length. These colors and wave lengths are shown below:

Color	Wave length Range
Violet	0.40u to 0.45u
Blue	0.45u to 0.49u
Green	0.49u to 0.55u
Yellow	0.55u to 0.59u
Orange	0.59u to 0.63u
Red	0.63u to 0.76u

where "u" is the symbol for microns. Wave lengths longer than 0.76 microns are in the infra-red region and those below 0.40 microns are in the ultra-violet and x-ray region.

The amount of energy having wave lengths which fall within the visible spectrum is not a measure of the lumen output of a lamp. Different wave lengths of light within this range affects the eye with different intensities. The yellow-green color having a wave length of 0.556 microns affects the eye more intensily than a blue-green or orange color having a wave length of 0.510 and 0.610 microns, respectively.

Pure white light, in accurate terminology, is designated as the color of a black body raised to a temperature. The magnitude of this temperature is still in disagreement as some scientists claim this temperature to be 5000° K and by others 7000° K. A black body is a theoretical object which is assumed to absorb completely all radiations falling on it, and, when raised in temperature, to radiate more energy throughout the entire spectrum than any other incandescent solid. Lamps have a greater amount of radiant energy when operated at a temperature to produce wave lengths that are at the red end of the visible spectrum or of wave lengths between 0.59 microns and 0.76 microns than between 0.40 microns and 0.59 microns. In comparing Mazda B and a Mazda C lamp, the former will give off a great deal more effective light when the lamps are operated at the same temperature because it gives off wave lengths of light on the red side of the visible spectrum.

The Use of Gas

All lamps are either vacuum, Mazda B, or gas-filled, Mazda C. If the oxygen in a lamp is not removed, the lamp would immediately burn out in a cloud of white smoke, tungsten trioxide. For this reason lamps are either exhausted or filled with an inert gas. The absence of a gas eliminates the loss of heat by convection and conduction, which would otherwise occur if a gas was present.

The disadvantage of operating a vacuum lamp is the limitation of the temperature at which the filament can be operated. For this reason, the larger lamps are filled with a gas composition of 86% nitrogen and 14% argon. Nitrogen is a good gas for this purpose because of its inertness. A certain amount of argon is added to the nitrogen to increase the dielectric strength of the gas mixture. Nitrogen, besides being inert, has also the property of being a poor heat conductor. This property reduces the amount of filament heat that might be carried away. The addition of a gas in the bulb, whereas, it reduces the evaporation of the filament and permits the lamp filament to operate at a higher temperature with a corresponding increase in lumen output; nevertheless, offers an opportunity for the filament heat to be taken away by conduction and convection. Convection in the lamp takes place as the hot gas carrying heat from the filament passes to the top of the bulb where the cool atmosphere, about the outside of the bulb, cools the hot gas. Once cooled the gas falls to the filament again to cool it and carry away more of its heat. This cooling effect, which is lost energy, is about 19% of the total energy drain of the lamp.

This convection loss is the greatest in the smaller wattage lamps. This follows because the diameter of the filament wire used in the smaller wattage lamps is also smaller. Suppose a filament wire was halved, the wire surface for a given length will also be halved. However, the rate at which the heat will be carried away will not be halved. This is because the heat conduction takes place in a film of hot gas about one-sixteenth of an inch in diameter adhering to the filament. In this film, most of the temperature drop occurs. The heat conduction of such a film increases with the filament diameter but not proportionately; so that less heat is lost from the larger filaments. The heat is then carried to the bulb at a rate depending on the outside diameter of the film. This outside film diameter has such a value to make the rate of heat transfer by conduction and convection the same.

The dividing line for gas filled and vacuum lamps is about 50 watts.

Blackening of Lamps

The possible sources which might cause a lamp to blacken are enumerable. Some of these causes are listed hereafter. In the manufacture of lamps, it is wise to pay strict attention to these factors which not only reduces the lumen output of the lamp during its life but also shortens the lamps' life.

1. Mandrel not completely removed from filament.
2. Aquadag not completely removed from the coil as the result of insufficient boiling or too weak a caustic solution.
3. Bulbs not hot enough on exhausting allowing moisture to remain.
4. Flush gas not free from hydrocarbons or moisture.
5. Filling gas not free from hydrocarbons or moisture.
6. Drying outfit used in cleaning the coils is not efficient.
7. Coil data incorrect; the lamp efficiency having been calculated too high.
8. Introduction of moisture on stem.
9. Dirty fingers of coil mounters.
10. Insufficient getter on coil.

11. Getter burned and destroyed in bulb heating.

12. Filling pressure too low.

The degree of bulb blackening is not a sure indication of the life of the lamp. Some lamps will blacken quicker than others. Inside frosted lamps appear darker than clear bulb lamps due to the light background. Blackening caused by water vapor can be readily identified by a dark shiny deposit. Normal blackening in a lamp is a brownish black color. Water vapor blackening also occurs early in the life of a lamp. Getters counteract this action if there is not too much vapor present.

Exponents of Lamp Characteristics

The resistance, amperes, watts, etc., can be mathematically calculated at other than normal values as follows:

Let v and V	represent	volts
c and C	"	lumens
i and I	"	amperes
w and W	"	watts
r and R	"	ohms
e and E	"	lumens per watt (efficiency)
l and L	"	life

where the capital letters represent normal values and the small letters, other than normal values. Then

$$1/L = (C/c)^a = (E/e)^b = (V/v)^d = (I/i)^u$$

$$c/C = (e/E)^h = (v/V)^k = (w/W)^s = (i/I)^y = (r/R)^z$$

$$E/e = (C/c)^f = (V/v)^g = (I/i)^j$$

$$i/I = (v/V)^t \quad \text{and} \quad w/W = (v/V)^N$$

where

	a	b	u	h	k	s	y
Mazda C lamps	3.86	7.1	24.1	1.84	3.38	2.19	6.25
Mazda B lamps	3.85	7.0	23.3	1.82	3.51	2.22	6.05

	z	d	t	N	f	g	j
Mazda C lamps	7.36	13.1	.541	1.54	.544	1.84	3.40
Mazda B lamps	8.36	13.5	.580	1.58	.550	1.93	3.33

These exponential values apply for small deviations from normal efficiency but will also apply, with reasonable accuracy, through short ranges of other efficiencies.

Suppose it was desired to know the lumen output of a Mazda C lamp, 100 watt size, knowing that at its rated voltage, 120 volts, the lumen output was 1320 lumens, at 110 volts. Using the formula

$$c/C = (v/V)^k = c/1320 = (110/120)^{3.38}$$

$$c = 984 \text{ lumens}$$

Lamp Life as Affected by Filament Wire Variations

For a better understanding of the effect of filament wire variations on lamp life, consider the volts, watts, and lumens per watt of a lamp and its lamp construction details to be always the same; the only variations in this hypothetical lamp being the details of the filament. These variations in filament characteristics are the roundness of cross-section, variation in cross-section, and smoothness of surface. By considering the effect of these variations in filament characteristics one at a time, and then all in the same filament; a better understanding of their effect will be had.

In any lamp of constant watts and efficiency, the life will be proportional to the cross-sectional area of the wire. Anything that can be done to increase this area will lengthen the life. This is because a larger cross-section delays the disintegration of the filament, whether this disintegration is progressing from the vapor pressure of the metal or any other reason. It is this condition that permits the higher efficiencies in the larger lamps. However, with the volts, watts, and L.P.W. constant, the increase in cross-sectional area of a wire is limited. In this hypothetical lamp, the mean filament temperature is a constant. With constant watts being dissipated at constant temperature, the filament surface must be also a constant. Since the filament surface is a constant, the greatest cross-sectional area from a perfectly round wire will be a perfectly smooth surface. Conversely, the only way a constant filament surface can be kept when the wire varied from perfect roundness would be by decreasing the cross-sectional area. To maintain a constant filament surface when the wire becomes rough or pitted would be to reduce the cross-sectional area. Obviously, any variation from perfect roundness in the wire or any variation from perfect smoothness in surface will shorten the lamp life. The farther that the wire is removed from these ideal conditions, the shorter will be the lamp life.

In our hypothetical lamp of constant watts and L.P.W., the life of this lamp is not limited by the mean temperature of the filament but by the spots of highest temperature along the filament length. Anything that can be done to reduce this variation in temperature would lengthen the lamp life. This fact is shown in the progress of lamp construction. Whereas, the first lamps had a great many filament supports with their cooling effect on the filament, the latest lamps of the coiled-coil filament has only one support at the most. For every portion of the filament which operates below the mean temperature and does not deliver its proportional share of light, some other portion must operate above the mean temperature at an overload. Any variation along the filament from roundness, or any variation in smoothness will cause hot spots and shortened lamp life.

As all these filament characteristics are determined in the wire drawing process, it can be seen the early stage in which lamp life is controlled. One of the chief causes for this variation from an ideal filament is the quantity variation in Aquadag loss. To analyze the Aquadag problem, the details of wire drawing must be studied more closely than discussed in a previous chapter.

Excessive oxidation may cause pitting and rough surface. Variable and uncontrolled oxidation may cause variation in wire diameter and an elliptical cross-section. Insufficient oxidation may cause the Aquadag to be pressed into the tungsten, making it difficult to remove and permitting carbide formation or blackening of the lamp. Insufficient oxidation will also cause excessive wearing of the drawing dies. Too thick or lumpy aquadag will cause surface imperfections. For wire with better life characteristics, it is absolutely necessary to control the oxidation of the aquadag lubricant for the dies, as well, as the dies themselves. A routine inspection of these dies should be made to compare them with a standard.

Flashing Schedules

Assuming that an ideal lamp has been made, that is, the filament is properly wound and mounted in a lamp perfectly sealed, with all traces of hydrogen and carbon removed; the life of a lamp may still be shortened. If the crystal structure of the wire is such to permit crystal growth, the life of the lamp will be greatly shortened. A means of controlling this crystal formation is by operating or "flashing" the lamp for a definite time at some part of the rated voltage of the lamp. Two flashing schedules are given below:

Gas-Filled Lamps

Schedule (1)	1st. step:	50%	of	rated	voltage	for	30	seconds
	2nd. " :	100%	"	"	"	"	15	"
Schedule (2)	1st. step:	"	"	"	"	"	5	"
	2nd. " :	120%	"	"	"	"	15	"

Vacuum Lamps

__Note__: For flashing schedules below rated voltage, a series resistance should be used to prevent the arcing of the lamp.

Schedule (1)	1st. step:	30%	of	rated	voltage	for	20	seconds
	2nd. " :	100%	"	"	"	"	10	"
Schedule (2)	1st. step:	30%	"	"	"	"	5	"
	2nd. " :	60%	"	"	"	"	5	"
	3rd. " :	100%	"	"	"	"	5	"
	4th. " :	120%	"	"	"	"	15	"

Recent Developments

Today definite advancement has taken place towards higher efficiency lamps in the development of the coiled coil filament lamp and the vapor lamp.

The coiled coil filament lamp differs from the popular incandescent lamp only in the construction of the filament and the number of filament supports required. The coiled coil filament is made by again coiling the already coiled filament. It is readily seen that by coiling the filament again, the new filament will be much shorter in length than the longer singly wound filament. Two advantages are gained by "concentrating" the filament. First, as the filament is smaller, it will operate at a higher temperature because there will be less radiation heat loss. As the coiled coil filament has less radiation heat loss, it will operate at a higher temperature with a corresponding increase in efficiency and brightness. Secondly, as this new filament is shorter in length it will require only one or no supports. As previously stated, the more supports used the greater will be the heat loss due to conduction. By using fewer supports, the coiled coil filament will operate at a still higher temperature with a corresponding still greater efficiency and whiter light. Although, at most, an increase in efficiency of 2 lumens per watt in the coiled coil lamp does make a definite step toward better lamps. Another gain resulting from the use of fewer filament supports is a longer lamp life. By using fewer supports, the mean filament temperature is more constant, with the result that the parts of the lighted filament furthest away from the supports will not be so greatly overloaded due to the cooling of the filament at the support. By operating at a more even temperature, the filament can be constructed more readily to give a rated life of 1000 hours.

Although this type of lamp has not been put into the market extensively, as yet; these lamps are already advertised for sale by our larger manufacturers. This filament will receive particular acclaim in countries using 220 volts as their "housing" voltage. This is true because at this voltage the ordinary coil filament is so much longer than the filament made for 110 volt use.

The second advancement is the vapor lamp, best known today in the popular neon, mercury and argon "show" sign and the sodium lamp used in lighting many of our highways. This type of lamp does not give off light by heating a solid to a high temperature but gives light by virtue of an arc established by "breaking down" a gas or vapor at a high voltage. This lamp employs a small porous lighting element coated with a chemical to give off light and which is inserted in a gas-filled bulb and sealed. Lamps of this type are about twice as efficient as the tungsten filament incandescent lamp. The present 400 watt vapor lamp operating at an efficiency of about 40 lumens per watt is comparable to the 750 watt incandescent lamp. One bad feature about this type of lamp is the color of the light emitted. The color of this light is determined by the vapor used; mercury being blue, argon being yellow, and neon being red. To read or do fine work under this type of light is out of the question as the eye will become quickly fatigued.

Although this type of lamp gives higher efficiencies, the lamp engineer is still very far away from the ideal lamp of an efficiency of about 600 lumens per watt. It has been shown that a great deal of the light emitted by this type of lamp is outside the wave lengths of light in the visible spectrum. A novel experiment proving this point is shown by enclosing a mercury vapor lamp in a dark violet glass "cap". The characteristic blue light of the mercury lamp will be absorbed by the violet glass cap and no light will be seen through the outer glass. Normally, we would conclude that all light had been reflected or absorbed because we no longer saw the blue original light. However, if we were to cover the already "capped" lamp with another glass "cap" whose inside walls were painted with a fluorescent paint we would again see light. This light will be the color of the fluorescent paint used and will be produced by the "invisible" light passing through the violet cap in wave lengths outside the visible spectrum and in the ultraviolet region.

Despite the colored light given off by this type of lamp the mercury vapor lamp is being introduced in industrial and commercial lighting units. A good light is obtained by operating the vapor lamp in a large fixture containing three or four large incandescent lamps. It has been shown that with a properly designed lighting fixture, whiter light can be obtained than with the totally incandescent lamp fixture. Most of these fixtures are used in places which will permit the fixture to be hung at a distance not less than eighteen feet above the work to be illuminated.

The sodium vapor lamp is commercially used in the illumination of highways. Besides being less expensive to operate, the yellowish light given off by this lamp is beneficial because of its fog penetrating properties.

The argon and neon lamps are chiefly used for sign and decorative purposes. The argon lamp, however, has two other uses; as a night lamp and in telephoto transmission. The economical operation of this lamp in the five watt sizes make it ideal for night illumination in stores and private homes. Its soft yellowish light is ideal as a night bedroom or nursery lamp. In the telephoto apparatus, this lamp has been acclaimed because of its directional light properties due to the design of a crater type arcing element.

One might conclude:that if the practical limitations of this vapor lamp are its color characteristics, why not mix gases and get a gas mixture having whiter light characterisitcs. This has been done and it was found out that the gases do not mix and the resulting light is just as poor. By mixing mercury and neon vapors, the color is still very definitely blue with a tint of red or pink.

Definitions

Candlepower: The luminous intensity of a light source in a particular direction is expressed in candlepower in that direction. These directional candlepowers are measured by comparison with the luminous intensity of a "standard" under certain specified conditions. The average of these intensities in all directions is known as the mean spherical candlepower. The mean spherical candlepower is no longer used as a measuring unit as it has been replaced by the "lumen".

Lumen: The unit of total light output is the lumen. One lumen will light an area of one square foot with the intensity of one foot candle.

<u>Efficiency</u>: The efficiency of a lamp is expressed in lumens per watt. The lower the energy drain, expressed in watts, for a definite light output, expressed in lumens, the greater is the efficiency of the lamp.

Formulae:

Watts = Volts x Amperes

Spherical candlepower = Lumens/12.57

Lumens per watt = Lumens/Watts = Lumens/(Volts x Amperes)

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