THE INSTITUTION OF MECHANICAL ENGINEERS

MANIPULATIVE AND MECHANICAL HANDLING MACHINERY GROUP

MACHINES FOR ELECTRIC LAMP MANUFACTURE

By H. W. B. GARDINER, B.Sc. (Eng.) (*Member*), E. A. HEYWOOD (*Graduate*), and W. J. WORSDELL (*Associate Member*)

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LAMP MANUFACTURING PROCESSES

BEFORE the manufacturing steps in lamp production are described, it must be realized that there are basically two types of lamp. First the filament lamp, where the useful light output is obtained directly from the thermal condition of the tungsten filament, and second the discharge lamp, where light output can be obtained by two methods: either by the passage of electrical discharge through an arc tube, into which has been inserted a metal such as sodium or mercury, which becomes vaporized and pressurizes the arc tube and transfers the electrical discharge directly into visible light, or by a fluorescent coating, where the electrical discharge creates frequencies in the ultra-violet region of the spectrum with very little useful light output and an internal coating of the tube then changes the frequency to that of visible light.

For the domestic tungsten filament lamp, generally referred to in the industry as the general lighting service (g.l.s.) lamp, the production processes as opposed to component production fall into six basic groups shown in Fig. 1.

Fig. 1*a* shows a typical pinch assembly. It consists of a glass-to-metal seal of two wires passing through, the upper ends of the wires being used in filament connection, the lower ends for cap connection. The hollow exhaust stem is for the evacuation of the lamp and the solid glass rod is for the mounting of the filament support wires. In Fig. 1*b* is shown the method of supporting and mounting the filament, the support wires being inserted into the glass rod and their outer ends then curled around the filament.

The lamp then passes to sealing-in, as illustrated in Fig. 1*c*. The glass bulb and the mount assembly are held concentrically and rotated within gas flames. This operation forms the outer bulb and welds it to the mount assembly flange, the excess glass being cut away and allowed to fall. In Fig. 1*d* is seen the exhaust process, during which the lamp in some cases passes through an oven and at the same time undergoes evacuation. Gas flushing and further evacuation is done at this stage, and a final gas filling, should it be required, is made before the stem tube is sealed off close to the lamp end.

Fig. 1*e* shows the final stage. Here the cap containing the bonding cement is fed over the lead wires and baked to secure the glass. The lead wires are then trimmed to length and the contacts soldered before the lamp is passed through several testing stations prior to semi-automatic packing and dispatch.

If the fluorescent type of discharge lamp is now considered, it is seen that the basic components and principles are very similar to those of the tungsten lamp in that a pinch and a mount are made (Fig. 2*a* illustrates the pinch). These mount assemblies are duplicated, that is, there is one at each end of the tube. A solid rod is not required in this instance, but a third wire is sometimes inserted for the supporting of a shielding strip.

Fig. 2*b* shows the mounted cathode, which is in the form of a coiled coil filament, around which a shield, secured to the third wire, is sometimes placed.

A pair of completed mounts are then put together with the coated tube for the sealing-in operation. Fig. 2*c* shows the technique employed: the tube and mount are rotated, allowing gas flames to form a weld. The lamp then passes to the exhausting process illustrated in Fig. 2*d*. During this process the lamp is exhausted and at the same time

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* *Chief Mechanical Engineer, Osram (G.E.C.) Ltd, Wembley, Middlesex.*
† *Senior Mechanical Development Engineer, Osram (G.E.C.) Ltd, Shaw, Lancashire.*
‡ *Senior Mechanical Development Engineer, Osram (G.E.C.) Ltd, Wembley, Middlesex.*

undergoes heating to drive out any gases or vapours, while various exhausting and flushing processes take place. Certain rare gases and a small amount of mercury are added to promote discharge. The lamp is then sealed off and caps are fed on to the ends, which are then baked to bond the caps (Fig. 2*e*). Other finishing processes are then completed before testing and dispatch.

EVOLUTION OF TYPICAL MACHINES

Each individual step or operation of the complete process necessary to make a lamp was first established as a separate manual operation. As techniques were developed, so were mechanical aids such as jigs, fixtures, or simple machines comprising a rotating head with or without fixed burners, developed for the more difficult or exacting

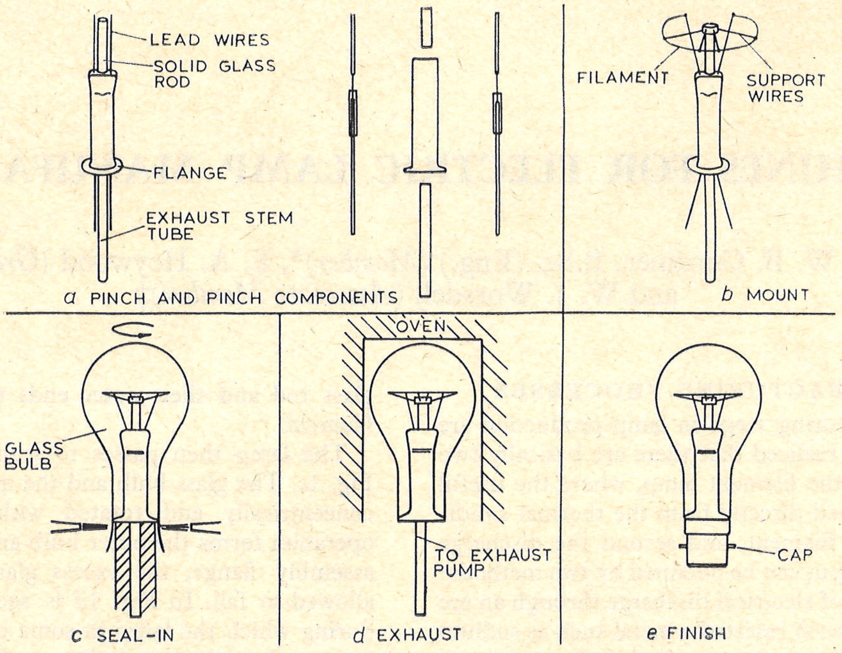


Fig. 1. Stages of manufacture of tungsten filament lamp

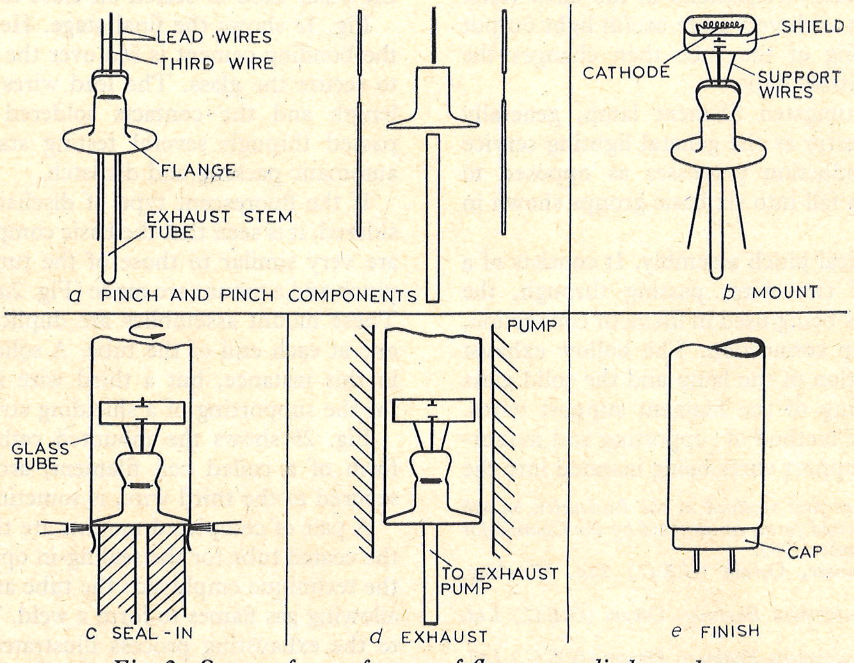


Fig. 2. Stages of manufacture of fluorescent discharge lamp

of these operations. The establishment of each separate operation in this way is still in fact the procedure when a new type of lamp is developed; the main difference nowadays lies in the greater dependence on these mechanical aids for fulfilling the more exacting requirements. The initial stages of the sequence of operations are often carried out in turn by operators stationed along a bench, who process batches of components or assemblies which are passed along successively from one operator or station to another.

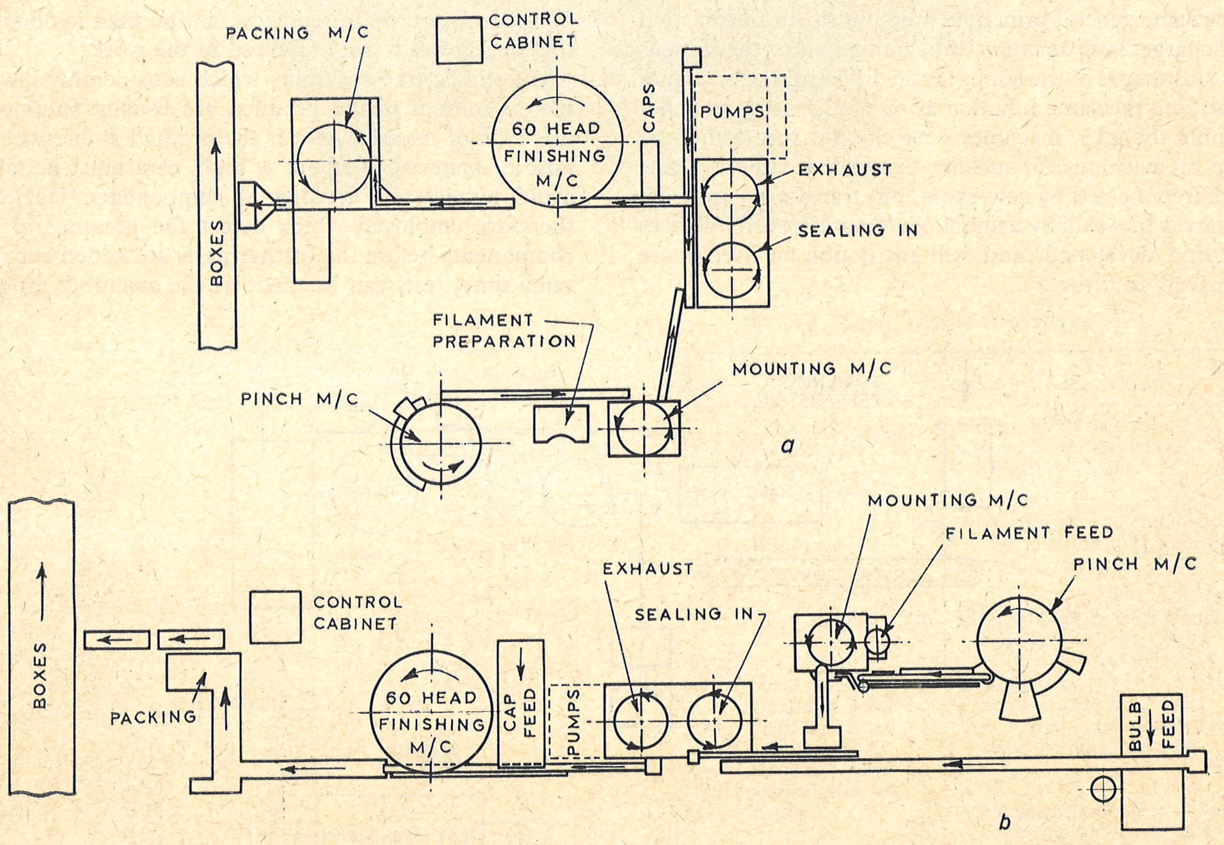
As techniques become established, it is possible for one operator to handle a much greater flow of parts by arranging a simple multi-station machine having, for example, 10 heads on an indexing turret, at two stations of which the operator inserts and removes the work, the remaining eight stations being available for the physical or manipulative operation. It is now necessary to have burners or tools at each end of these stations, and if they are operated mechanically from the same mechanism that carries out the indexing motion, the operator has little more to do than the feeding and take-out manipulations, and can handle many times the output of the single-station set-up. Furthermore, the individual steps of the process are timed and operated more precisely, and the need for special skill from the operator is reduced or eliminated.

A simple extension of this principle is, by increasing the number of indexing stations on the turret, to combine on one turret or machine the processes previously carried out by three or four operators. By the grouping together in this way of all operations at a particular phase of manufacture, machines with indexing turrets with up to 60 or 70 stations have been developed and are in regular use.

If machines for successive operations or processes can be designed to have approximately the same rate of throughput of work, they can be arranged to work together as a group. Batches of work are passed from one machine to another, there being a small 'buffer' stock of work between each to give some flexibility in working.

If conveyors are arranged between the machines to convey the work from one operator to another, flow production is achieved, with all its advantages over batch production. Fig. 3*a* shows a group of such machines for making the g.l.s. type of lamp, as in use since 1950.

On account of slight variations in component dimensions and in machine performance an occasional malformation or breakage of the work takes place, resulting in a loss of work at output of about 3–5 per cent of the input to the machine. In order to keep each machine fully loaded, it has been usual to run each successive machine about 4 per cent slower than the preceding one. The operator also



a Standard machine group for g.l.s. lamps (1950) *b* Latest machine group for g.l.s. lamps (1962)

Fig. 3

carries a small buffer stock to accommodate any difference between expected and actual loss rates.

The last stage of mechanization is reached by fitting automatic feeding and removal mechanisms to the machines, so that it is no longer necessary for the lamp to be handled manually. The operator thereby becomes redundant, or is free to undertake inspection and overseeing duties only. A modern group of this nature is shown in outline in Fig. 3*b*.

With these interconnected automatic feed and take-out devices and conveyors the group of machines becomes virtually integrated into one long machine, with all mechanisms automatically driven and timed to the correct sequence. One straightforward way of achieving this is to run all the component machines and connecting conveyors at a constant index speed in correct phase relationship. The first machine is then run fully loaded, any subsequent machine having some empty heads in proportion to the losses on the machine which preceded it.

Alternatively, it is possible to run machines at successively slower index rates, but then the interconnecting conveyors have to be able to accommodate an adjustable buffer storage; even so, the amount that can be accommodated is usually very limited, and it is desirable to be able to adjust automatically the speed ratio between two successive machines so as to keep the buffer stock between the limits acceptable by the conveyor.

The same general principles apply in the mechanization of discharge lamp manufacture, though since the dimensions and shapes of the lamps are so different, the machines performing the same function as on a g.l.s. lamp may not resemble the g.l.s. machines very closely. Fig. 4 shows a group of machines for making fluorescent lamps. These are interconnected by conveyors, but transfer to and from the conveyor is usually manual. Automatic transfer devices are being developed, and will no doubt be used more extensively in future.

BRIEF DESCRIPTION OF TYPICAL MACHINES

In this section some of the machines are considered in greater detail, commencing with the filament lamp group shown in Fig. 3*b*.

A standard pinch machine is illustrated in Fig. 5*a*. This machine is of an indexing-turret design with 30 identical work heads and is completely automatic in its operation, other than that a machine attendant is necessary to maintain adequate levels in all the component hoppers. Fig. 5*b* and Table 1 explain the function of the various stations.

A typical mount machine is illustrated in Fig. 6*a*. Since this machine has many features which are common to other lamp-making machines, it will be described in greater detail. Fig. 6*b* shows the main constructional points. Here can be seen the principle of a crossover-cam index mechanism where the index wheel shaft carries other cams. As shown, further cam shafts can be fitted at right angles to the master shaft, if desired. The drive to the master shaft is usually by worm and wormwheel integral with the index motion. Plate cams and lever movements are employed for controlling the tooling heads. Generally speaking, these cams are of a split construction to facilitate modification or renewal. The indexing turret carries heads which are capable of being moved in the vertical plane down to the various tooling heads. This method gives a more rigid tool design than is obtained if the tooling heads are presented to the work.

Automatic transfer units, which considerably lower the labour content of the product, are usually employed on this type of machine, but if the product is one where the ratio of material to labour is high, care must be taken to avoid unnecessary feeding of components. Devices are therefore employed which detect the presence of initial components before the further parts are added and, at the same time, tests can be made as the assembly progresses

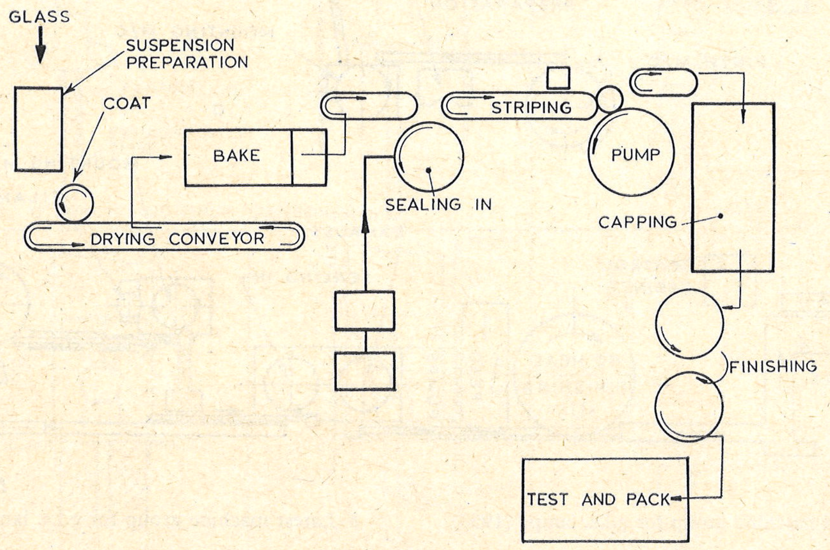
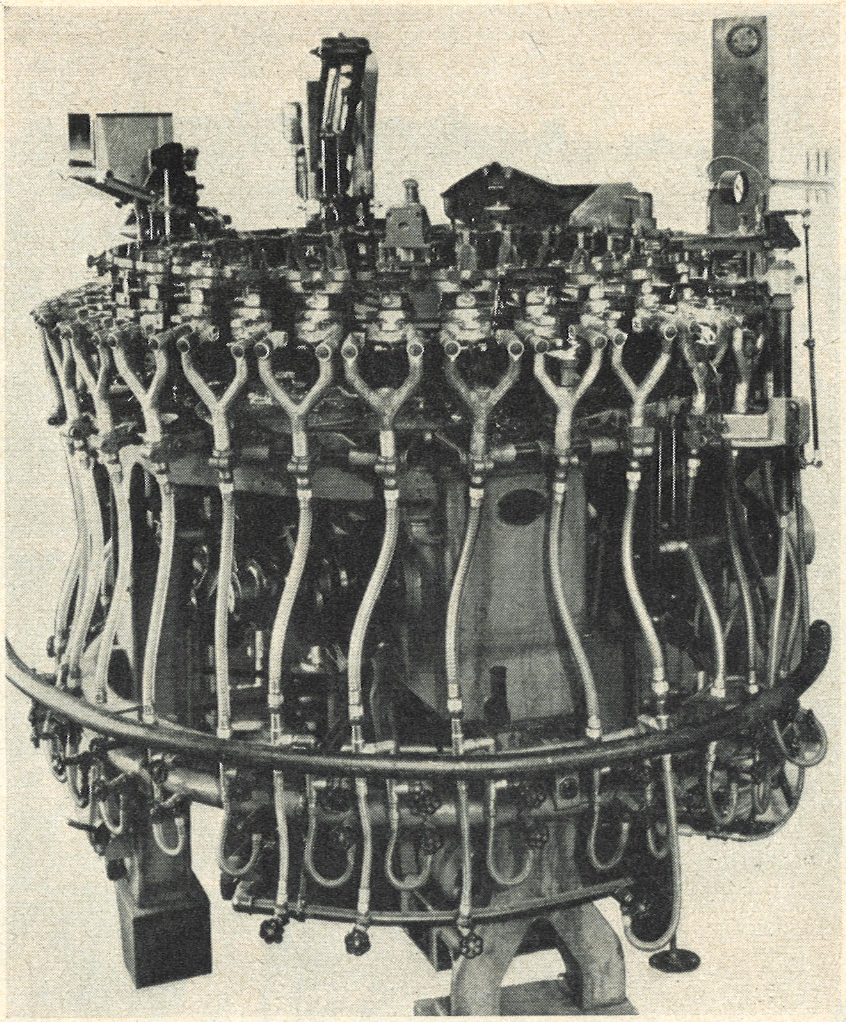


Fig. 4. Machine group for fluorescent lamps

a



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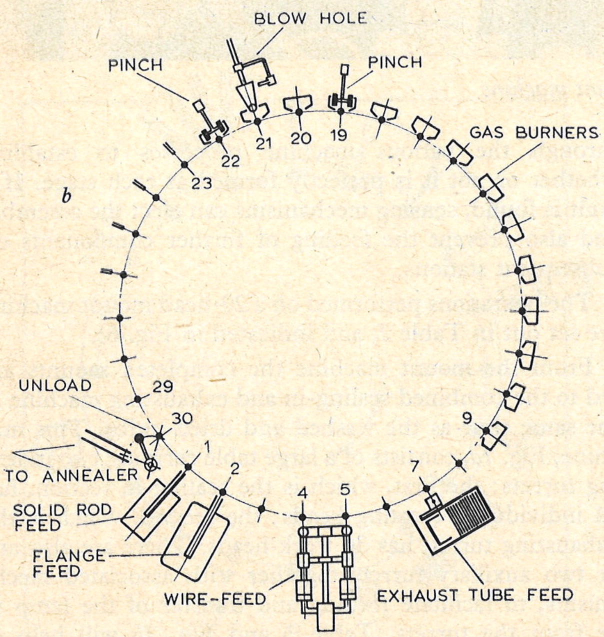


Fig. 5. Pinchmaking machine

Table 1. Pinch machine

Station	Operation	Mechanism
1	Load solid rod	Centre board hopper
2	Load flange	Centre board hopper or vibratory feeder
3	—	—
4 } 5 }	Wire feed	Mechanical or pneumatic pickup dropped through guiding quill into die blocks
6	—	—
7	Load exhaust tube	Gravity hopper with transfer fingers
8	—	—
9–18	Heat	Gas burners
19	Heat and pinch	Pinch hammer mechanism
20–21	Heat and blow hole	Gas burners and air jet through stem for lamp exhaust
22	Heat and pinch	
23–29	Anneal and cool	
30	Unload	Mechanical unload to annealing conveyor for stress relief

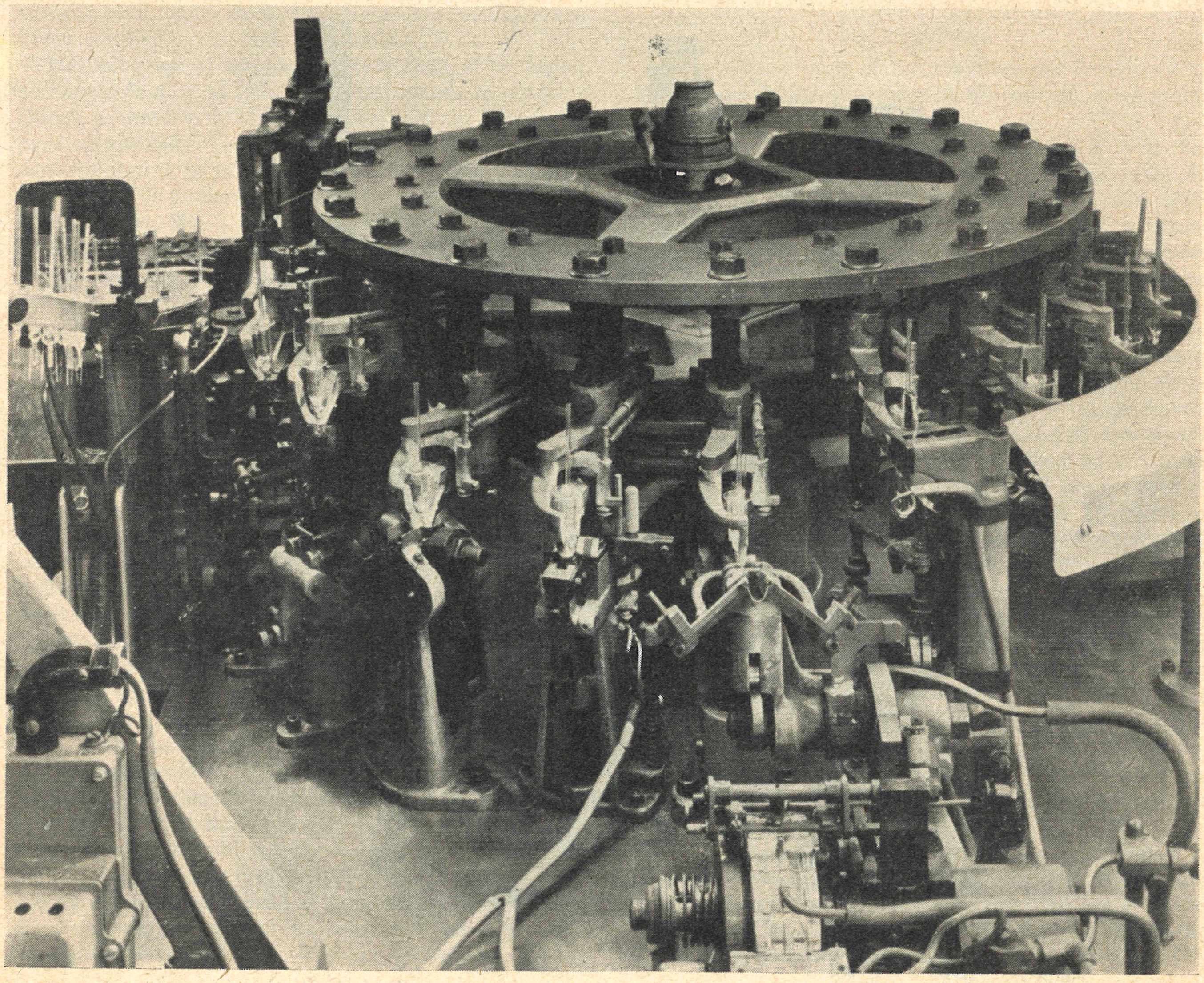


Fig. 6a. Typical mount machine

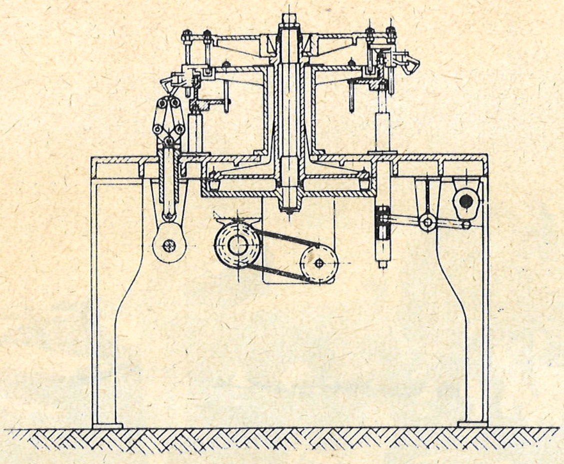
Table 2. Mount machine

Station	Operation	Mechanism
1	Load pinch	Auto load
2–4	Pre-form lead wires	Former dies
5	Hook lead wires	
6	—	—
7	Feed and clamp filament	Auto transfer from filament storage drum or plate
8–11	Heat solid rod for wire insertion	Gas burners
12	Insert and crop support wires	Wire fed from storage reels and cropped to length after insertion
14	Curl support wires around filament	
16	—	—
17	'Getter'	Dip filament in coating medium designed to improve atmosphere of lamp and improve characteristics
18–19	—	—
20	Unload	Auto unload mechanism

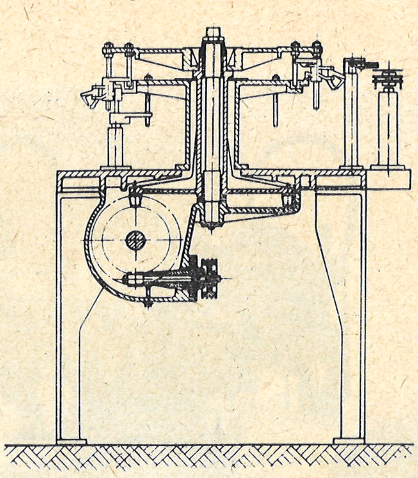
through the various machine processes to establish whether or not it is perfectly formed at each stage. If a fault is found, sensing mechanisms can eject the assembly and also prevent the feeding of further components on subsequent stations.

The operations performed on a 20-head mount machine are set out in Table 2, and indicated in Fig. 6*c*.

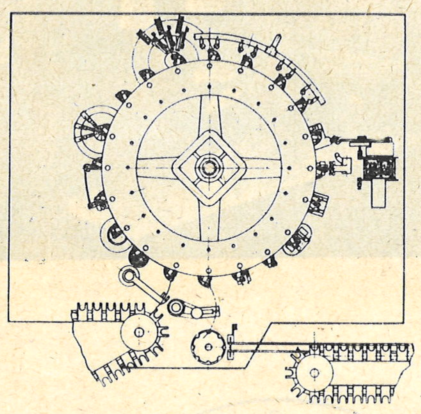
From the mount machine the completed mounts are fed to the combined sealing-in and exhausting machine at the same time as the washed and dried bulbs. This machine, Fig. 7*a*, consists of a large table carrying two indexing turrets: the first, which is the sealing-in section, has 24 individually rotating heads; the second, which is the exhausting turret, has 36 work heads. There are also one or two auxiliary turrets together with associated mechanisms, to facilitate feeding and transfer of the lamp to or from the turrets. Table 3 and Fig. 7*b* will help to illustrate the various functions.



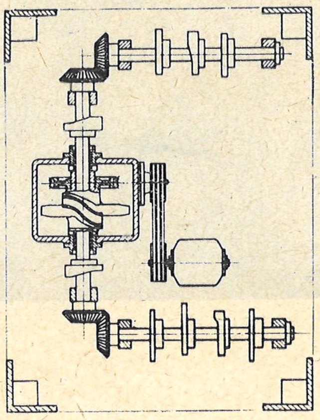
SECTIONAL ELEVATION SHOWING DRIVE AND AUXILIARY MECHANISMS



SECTIONAL ELEVATION SHOWING TURRET INDEXING MECHANISM



PLAN VIEW OF TURRET AND TABLE



SECTION SHOWING DRIVE AND CAM SHAFTS

Fig. 6b. Constructional features of mount machine

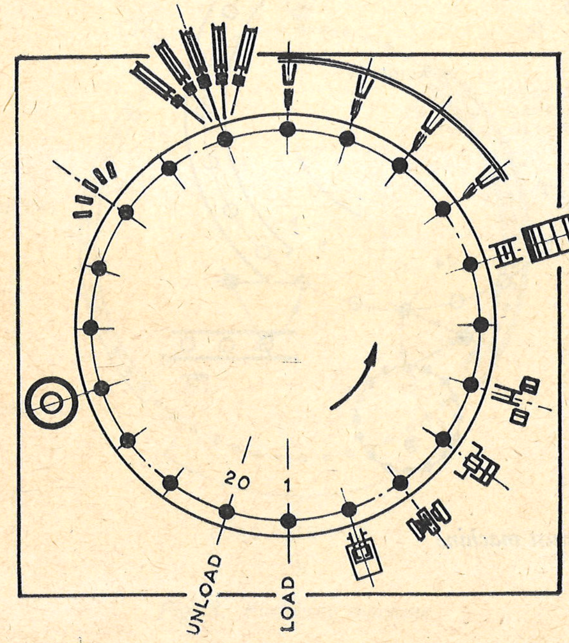
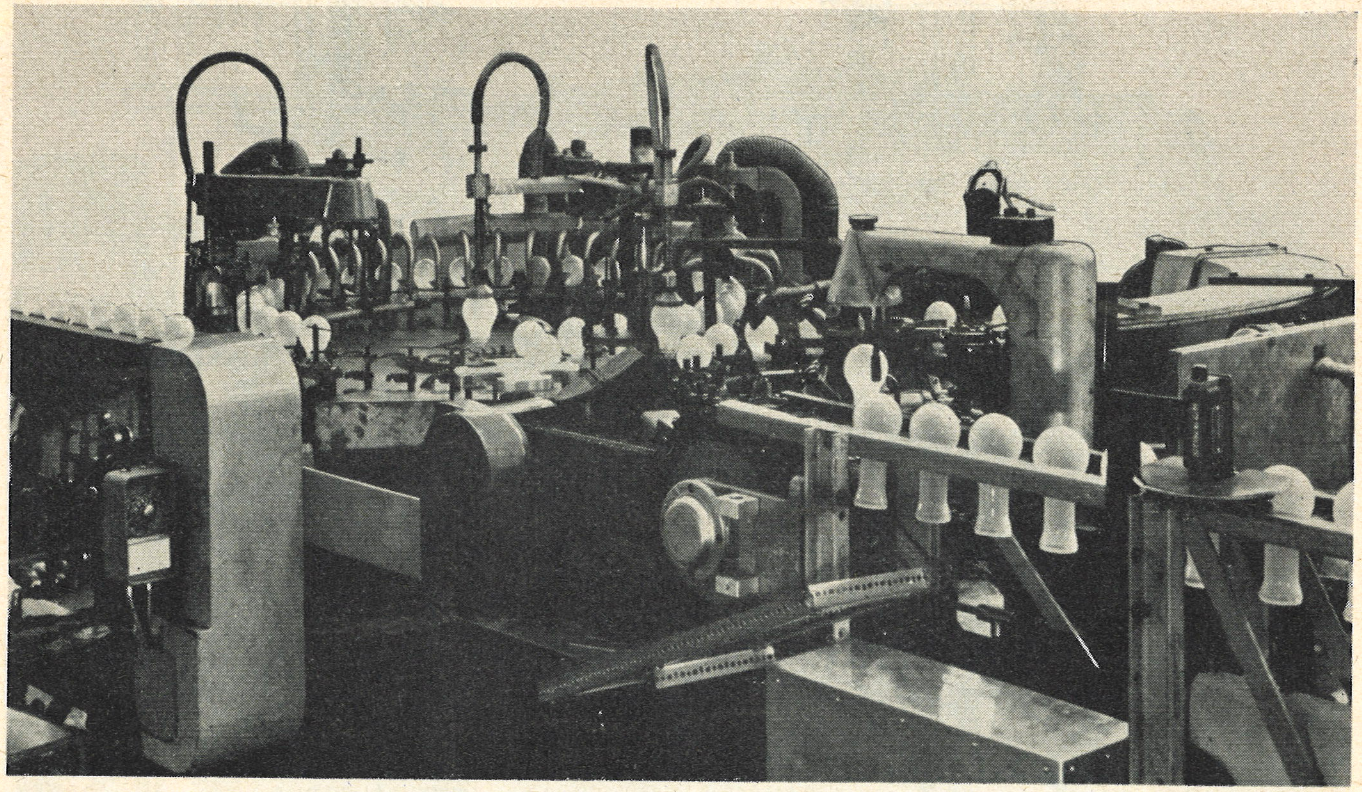


Fig. 6c Operation Diagram of mount machine

Table 3. Sealing-in and exhaust machine

Station	Operation	Mechanism
	Seal	
1	Load mount	Semi auto load
2	—	—
3	Load washed bulbs	Auto load
4–16	Heat and rotate	Gas burners
17	Stop and mould	Seal finally formed by dies
18–20	Anneal	
21	Unload to pump turret	
22–24	—	—
	Exhaust	
1	Feed sealed lamp	
2–11	Pump and flush	Often under heat
12–30	Pump and cool	Gas fill if required
31	Seal exhaust stem tube	Gas burner
32	Unload	Auto unload
33–36	—	—



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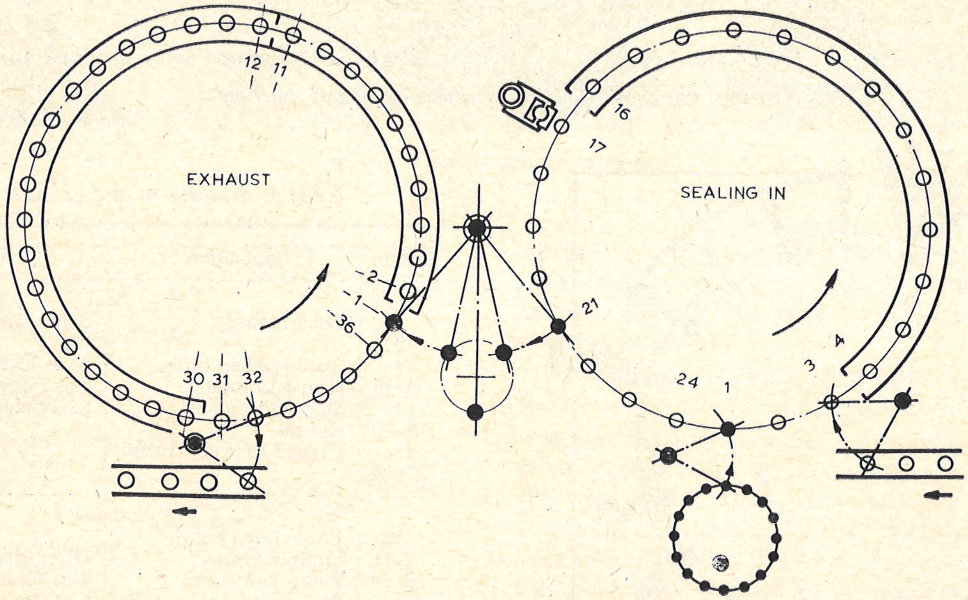
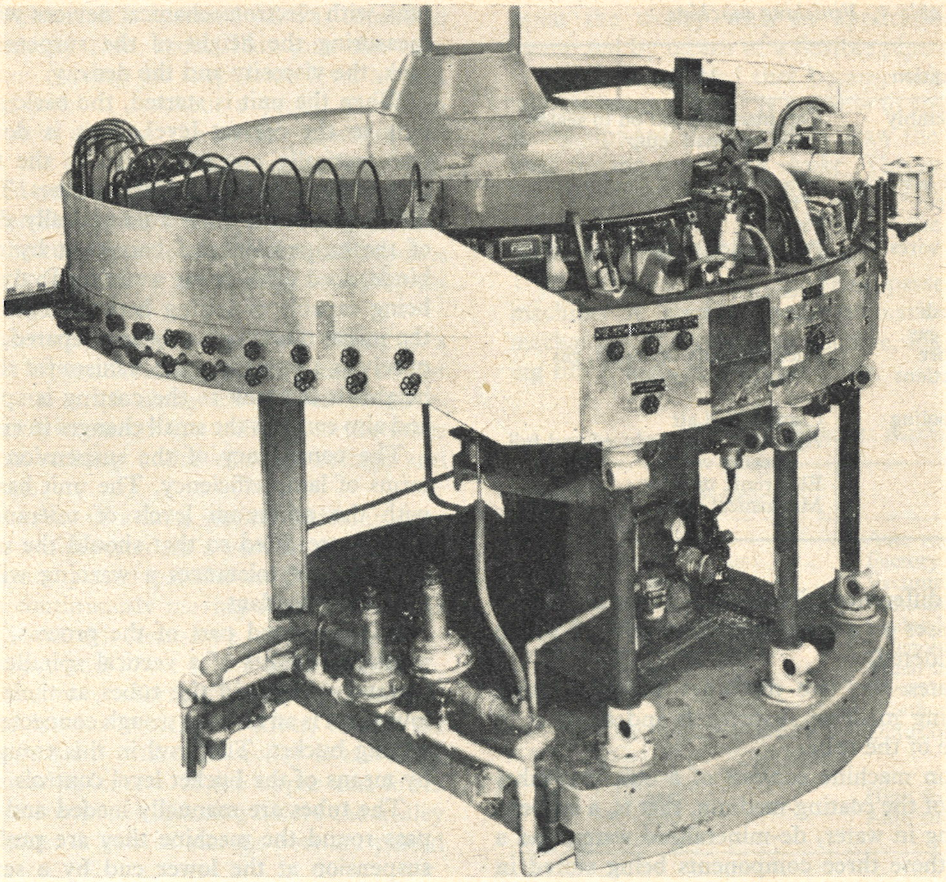


b

Fig. 7. Sealing-in and exhaust machine



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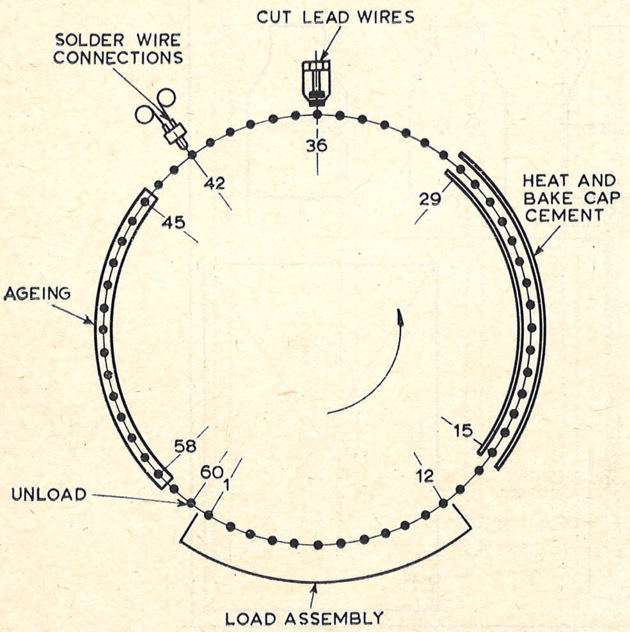


b

Fig. 8. Finishing machine

At this point perhaps a brief mention could be made of the exhaust machine principles. Generally speaking, exhaust machines carry at their rotational centre a pair of port plates, one plate being carried by the turret and allowed to float kinematically, whilst the stationary member is connected through its various drilled holes to a vacuum pump, flushing systems, or gas filling systems, whatever the requirements may be at one station. These port plates are lapped to a flatness of around three light bands and are approximately one foot in diameter.

Should there be no lamp assembly present in a head, or should a lamp crack upon being heated, an automatic device will switch off the vacuum connection at that individual head, thus preventing the overloading of the vacuum system. This mechanism is a common feature of all types of rotary exhausting machine.

From here the sealed lamps pass to the finishing machine, shown in Fig. 8*a*; Table 4 and Fig. 8*b* give the sequence of operations performed at this stage. From the finishing machine, the completed and tested lamps are passed by conveyor to the automatic packing machine.

The pinch and mount assemblies of a fluorescent lamp, as seen previously, are very similar to those of a tungsten lamp and are therefore made on similar machinery with

Table 4. Finishing machine

Station	Operation	Mechanism
1–12	Load assembly	Cap manually fed on to sealed and pumped lamp
13–14	Idle	
15–29	Heat and bake cap cement	Direct heating of cap by gas burners
30–35	Cooling	Free air
36	Cut lead wires	Pneumatically operated cutters
37–39	Cooling	Free air
40	Wire brush	Electric motor
41	Forming gas	
42	Solder wire connections	Pneumatically operated, gas heated solder unit
43–44	Solder cooling	Compressed air
45–58	Ageing	Age and test at reduced and full working voltage
59	Test	Electronic unit
60	Unload	Mechanical device

small individual differences. There are, however, several interesting processes on a fluorescent line, three of which will now be considered.

Fig. 9 illustrates the two machines which together prepare the coating medium suspension and apply it to the inside surface of the tube.

The preparation machine consists of a unit that takes the raw material of the coating medium, that is, a suspension of the coating in water, de-mineralized water, and a suitable binder, these three components being stored in vessels as shown. There is, at a lower level, a common tank with electromechanical devices which are capable of measuring the height of the suspension in the mixing tank, the viscosity and the density.

When the unit is started, the basic suspension fills the tank to the correct level. This is done by means of a pneumatically operated valve in the feed line which is controlled by electronic level probes. The viscometer and the densitometer then automatically determine the state of the suspension and correct it by opening either the binder feed valve or the water feed valve, the control units being capable of setting between two given limits. After the initial quantity has been prepared, the unit functions purely as a correcting mechanism for the small changes in height in the tank as the coating is applied to the tubes, and also controls the small changes in viscosity and density.

The consistency of the suspension is very critical in terms of lamp efficiency. The unit has, therefore, to run with the minimum levels of tolerance, and automatic devices are fitted so that should the units fail to correct within these tolerances a warning will be given to the machine attendant.

In the second part of the process, it is seen that the machine consists of a vertical spindle carrying a pair of turrets which hold the tubes at their periphery. At the lower end is an annular trough connected to the suspension mixing bucket. The level in this trough is kept constant by means of the bucket level controls.

The tubes are manually loaded and unloaded. As they pass round the machine they are pushed down into the suspension at the lower end by a series of heads with rubber fittings, into which the upper end of the tube has

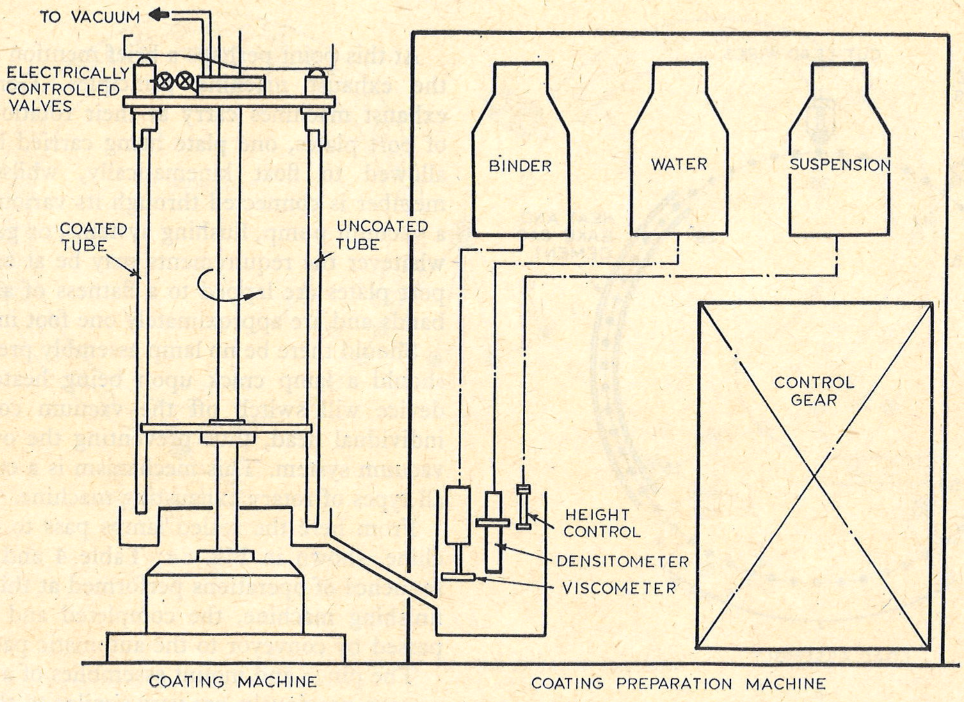


Fig. 9. Coating machine

been inserted. An electrically operated valve is caused to open and is electrically held open. This puts the tube under vacuum, thus causing the suspension level to rise. When the desired level is reached, a probe allows an electrical path to flow through the coating medium and electrically closes the valve. The suspension now falls at a predetermined rate controlled by an air bleed. By this means a uniformly coated tube is left. After a short draining period, the tube is unloaded and placed upon a drying conveyor so that heated air may be blown down the tube to dry off the coating.

Fig. 10 illustrates the striping machine, which is a device that applies externally a silver compound in the form of a continuous stripe along the axis of the tube. This stripe ultimately connects one end cap to the other and thus facilitates striking under extreme voltage and humidity conditions.

The machine consists of a long vertical indexing conveyor. A trolley is reciprocated in a vertical plane along guide rods which are placed parallel to the tube axes. This is done by a continuously moving chain and sliding crosshead; thus a smooth transition of movement is obtained at the upper and lower limits of its excursion. This mechanism also gives a form of intermittent motion from a continuous motion which, in effect, allows the conveyor to move forward whilst the trolley is travelling along the last part of its course at the upper and lower ends. The conveyor completes indexing before the trolley reaches the tube zone. A pair of storage pots are placed upon the trolley with an application roller assembly connected by means of a flexible pipe to the storage.

It will be realized that because this machine has two application systems it is possible to stripe a pair of lamps in the upward stroke and to draw the application rollers back for the downward stroke. This was found necessary for consistent quality. After striping, the lamp passes through a drying zone, which dries the stripe to a state in which it can be easily handled.

The striped lamps are then passed to the exhaust machine by means of an automatic indexing transfer mechanism. This exhaust machine, Fig. 11, has an indexing turret with 36 head positions.

Table 5. Exhaust machine

Station	Operation	Mechanism
1	Load	Auto transfer mechanism
2	Rough vacuum	Factory vacuum system
3	Detect leaks	Vacuum supply closing mechanism
4–16	Exhaust/flush/exhaust	Under heat
23	Inject mercury	Solenoid operated head
17–27	Heat cathodes	Brush tracks supplying varying current to cathodes
27–32	Fine vacuum exhaust	Diffusion pumps
33	Gas fill	
34	Tip off	
35	Inspect	High frequency discharge
36	Unload	Auto transfer mechanism

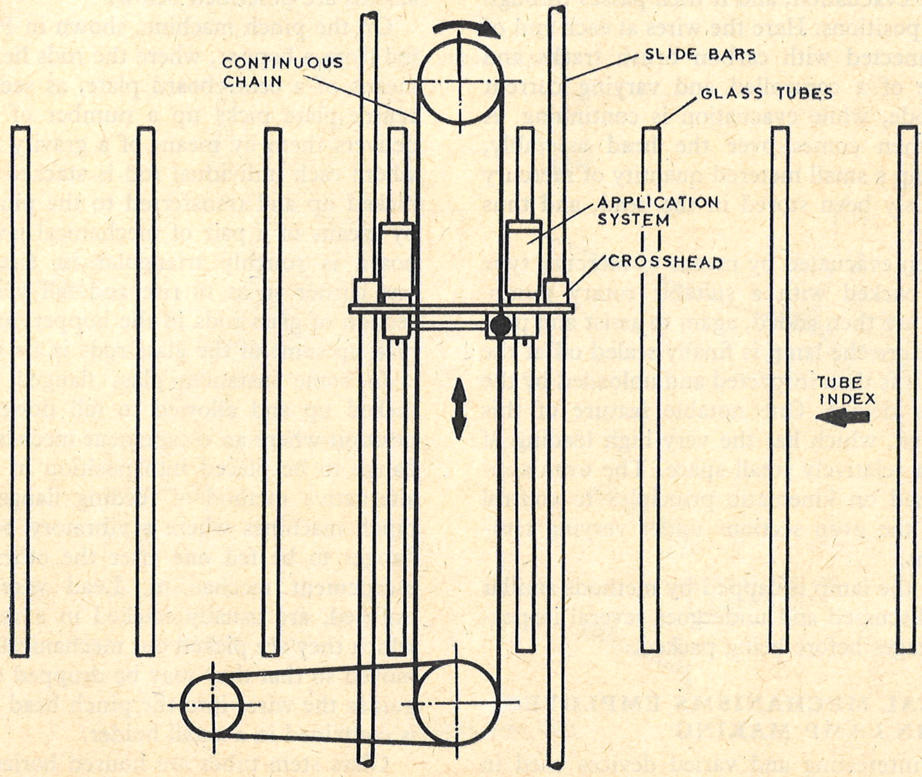


Fig. 10. Striping machine

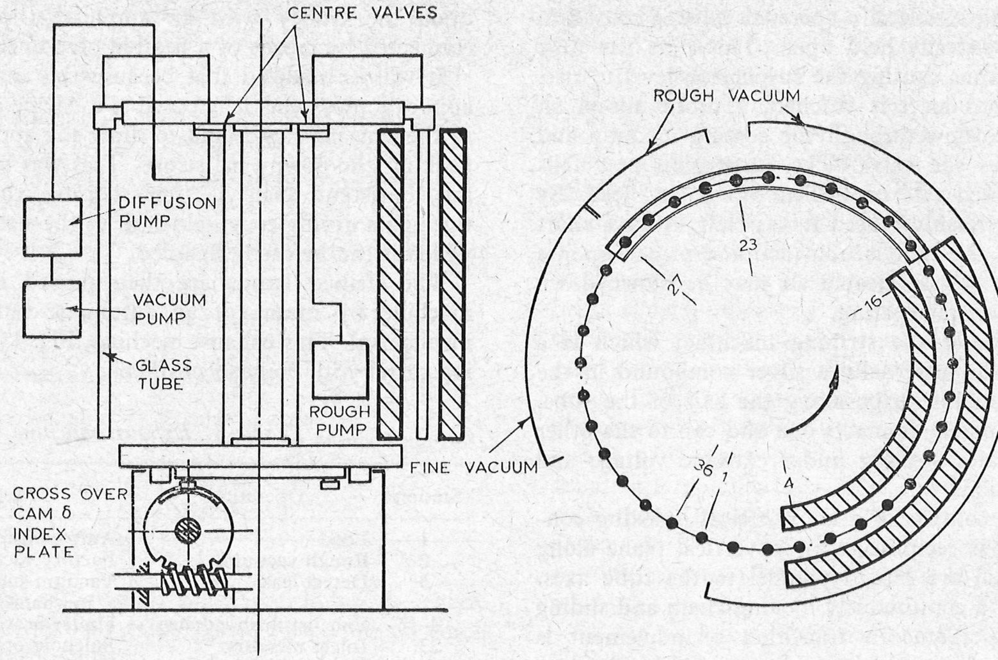


Fig. 11. Exhausting machine

As for the tungsten lamp, the vacuum supply is connected to each individual head by means of a pair of port plates. The stationary member is again connected to various types of pump or gas filling systems. The lamp then indexes through an oven, which dries off vapours and gases whilst under evacuation, and it then passes through ten lighting track positions. Here the wires at each end of the lamp are connected with carbon brush tracks and allow the passage of a controlled and varying current through the cathode, while evacuation is continuing. A solenoid device then comes over the head assembly, injects into the lamp a small metered quantity of mercury which has previously been stored in the head, and thus promotes discharge.

The lamp is then evacuated by means of mercury type diffusion pumps backed with a suitable rotary pump. Certain rare gases are then added, again to assist and promote discharge before the lamp is finally sealed off at the following station. It is then inspected and unloaded by the automatic transfer device. One notable feature of this machine is the oven, which has the very high loading of some 150 kW in a relatively small space. The oven supports were designed on kinematic principles to control the movement of the oven sections under varying temperature conditions.

After pumping, the lamp is capped by methods similar to those already discussed and undergoes several inspection and testing stages before being packed.

SOME TYPICAL MECHANISMS EMPLOYED IN LAMP MAKING

There are many interesting and varied devices used in lamp making machinery, both for feeding components and for manipulating parts that are used to form a lamp. As has been seen previously, these components are made of glass, metal, or a combination of both, and the forms that they take vary quite widely, depending on the use to which they are put. Some of the more interesting mechanisms are described below.

On the pinch machine, shown in Fig. 5, glass rods are fed from a hopper, where the rods lie quite randomly, by means of a centreboard plate, as seen in Fig. 12. The centre plate picks up a number of the glass rods and delivers them by means of a gravity feed to the position where each individual rod is stacked in line, and can be picked up and transferred to the pinch machine in turn by means of a pair of mechanical jaw grips. The centre board is roughly triangular in shape, pivoting about one corner so as to rise and fall vertically through the section of glass rods in the hopper, and by this means to pick up some of the glass rods in its vertical movement.

In some instances glass flanged tubes are similarly picked up and allowed to fall down guide rails into a position where an escapement mechanism allows a single flange to be placed into position in the pinch head. An alternative method of feeding flanges is used on some pinch machines where a vibratory bowl feed causes the flanges to be fed one after the other down rails to the escapement mechanism. Lead wires, either fused or unfused, are usually stacked in a vertical hopper, from which they are picked out mechanically by jaws, and then moved so that they may be dropped down a chute which guides the wires into the pinch head where the lead wire is contained in a small holder.

Glass stem tubes are housed horizontally in a hopper, and allowed to roll into a position where they may be

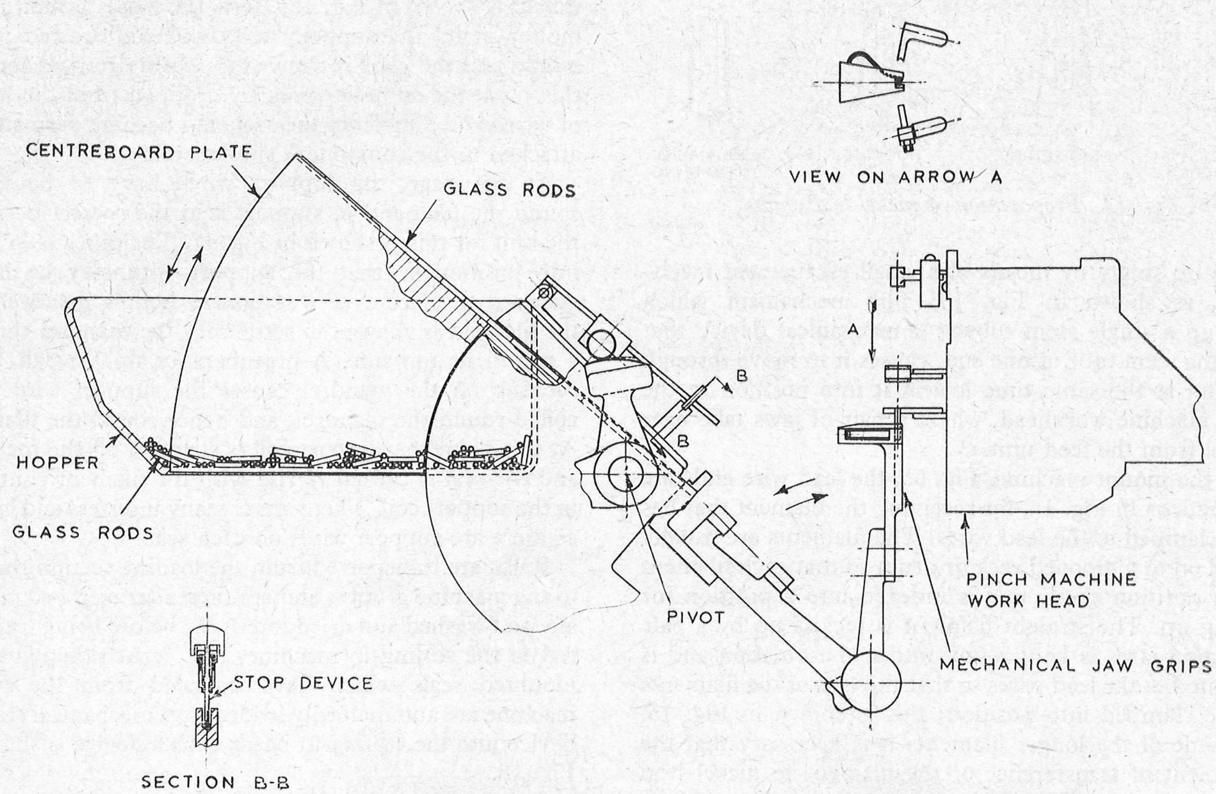


Fig. 12. Solid rod feed

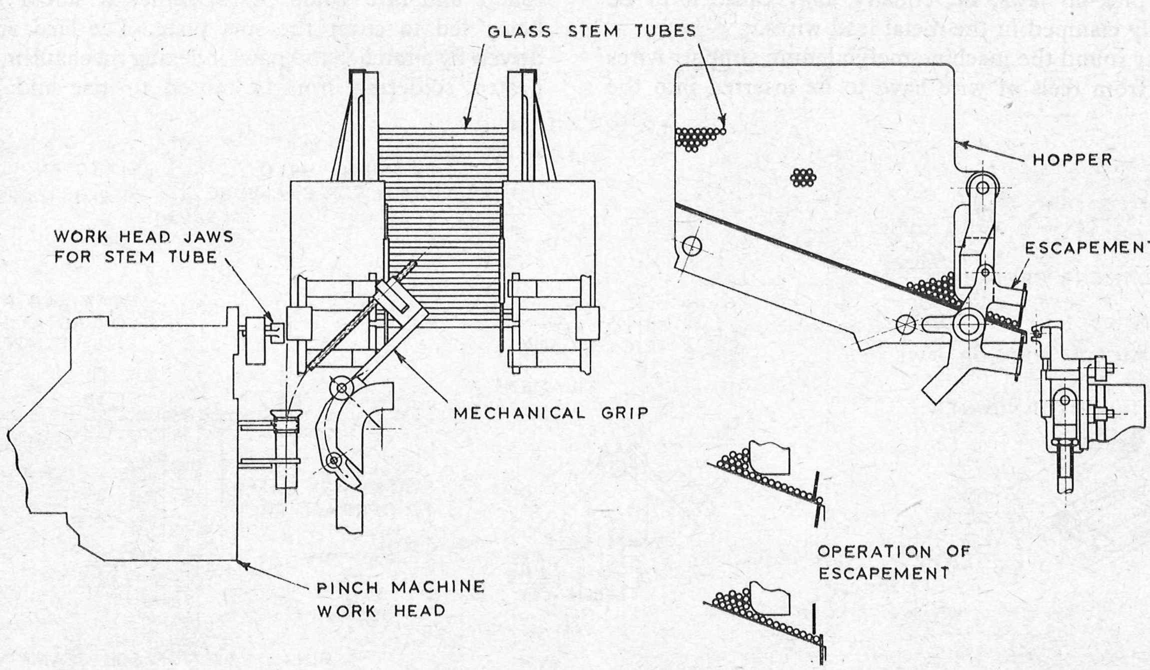


Fig. 13. Stem tube feed

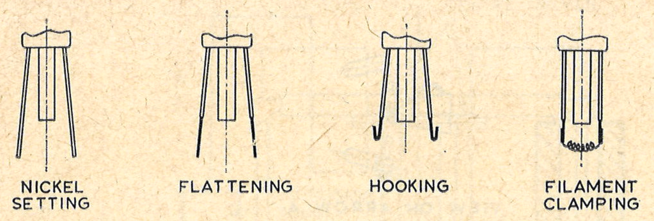


Fig. 14. Preparation of nickel lead wires

picked up singly by means of a small escapement mechanism, as shown in Fig. 13. The mechanism which picks up a single stem tube is a mechanical device that grips the stem tube at one end, causes it to move through 90°, and at the same time lowers it into position in the pinch machine workhead, where a pair of jaws take over control from the feed unit.

On the mount machine, Fig. 6*b*, the lead wire ends are prepared, as in Fig. 14, for receiving the filament that has to be clamped to the lead wires. The filaments are usually loaded on to a grooved rack or drum so that each filament lies in position singly and is indexed into a position for picking up. The straight filament is picked up by a pair of suction jaws, is bent round into a **U**-formation and is presented to the lead wires so that the tails of the filaments can be clamped into position; this is shown in Fig. 15. For some of the longer filaments it is necessary that the movement of transference of the filament to nickel lead wires be as smooth and slow as possible, since violent vibration may take place in the filament itself and may sometimes cause the filament to be thrown out from the vacuum pick-up jaws, or, equally, may cause it to be incorrectly clamped in the metal lead wires.

Further round the machine molybdenum support wires cropped from reels of wire have to be inserted into the glass rod. A typical inserting mechanism, as this unit is called, is shown in Fig. 16. Here, the rod is heated into a molten state, the support wires and rod are fed into a mould and the glass is allowed to solidify round them. At this point the support wires are cropped from the length of wire extending from the reel, and become permanently attached to the component sub-assembly.

At this stage, the support wires have to be curled round the filament, to support it in the correct position; the unit for this is shown in Fig. 17. The pinch is lowered into position so that the support wire may be lightly clamped in place over a stationary hollow mandrel, and the filament is allowed to settle into the mandrel through a gap in its top side. A protuberance on a small wheel rotating on the mandrel causes the support wire to be coiled round the mandrel, and hence round the filament. At this point the support coil is stripped off the mandrel, and the seal is caused to rise with the filament contained in the support coil. There are as many inserters and curlers as there are support wires on each seal.

Bulbs are transported from the loading section through to the machine groups, and are thereafter stamped externally and washed and dried internally before being transferred to the sealing-in machine, Fig. 7. At this point also, mounted seals which have travelled from the mount machine are automatically loaded by a mechanical transfer device into the sealing-in head; such a device is shown in Fig. 18.

A typical soldering device for soldering the copper lead wires into the brass sole plates of the cap is shown in Fig. 19. Solder is fed from two spools through two feed rollers and into guide tubes, sufficient solder normally being fed to cover the sole plate. The feed rollers are driven by a ratchet and pawl indexing mechanism, and the heated soldering iron is caused to rise and fall at a

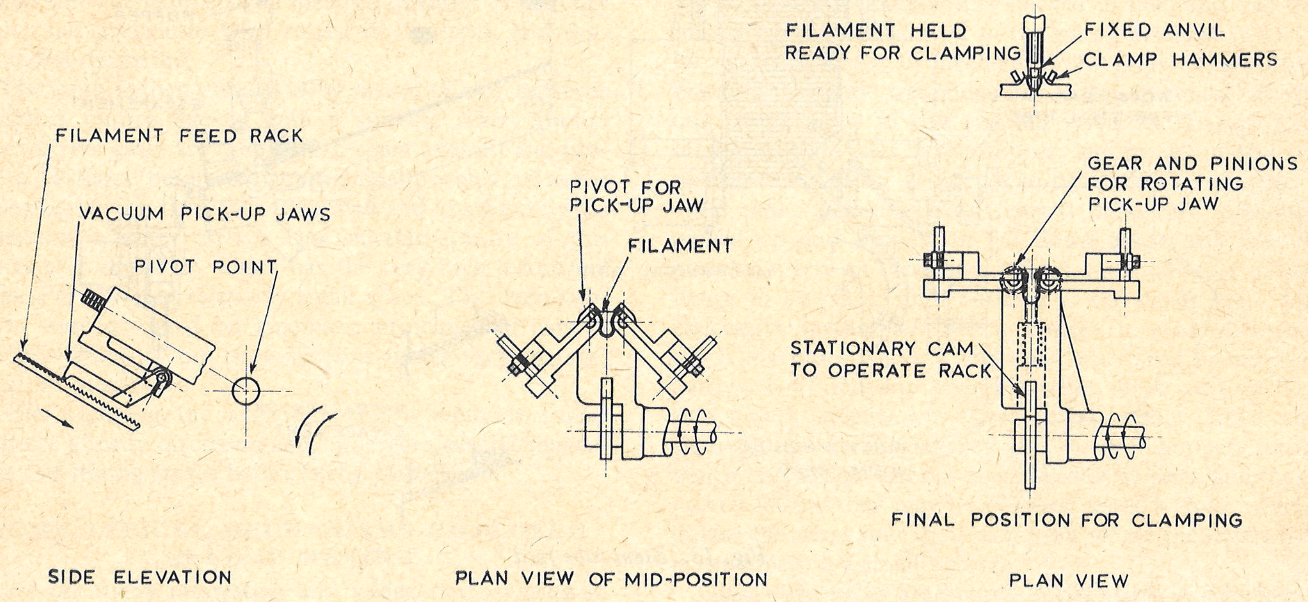


Fig. 15. Filament feed

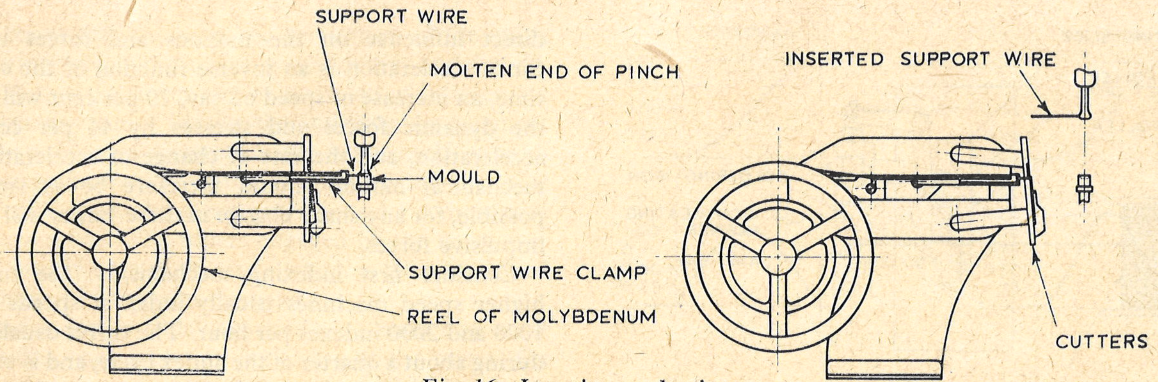


Fig. 16. Inserting mechanism

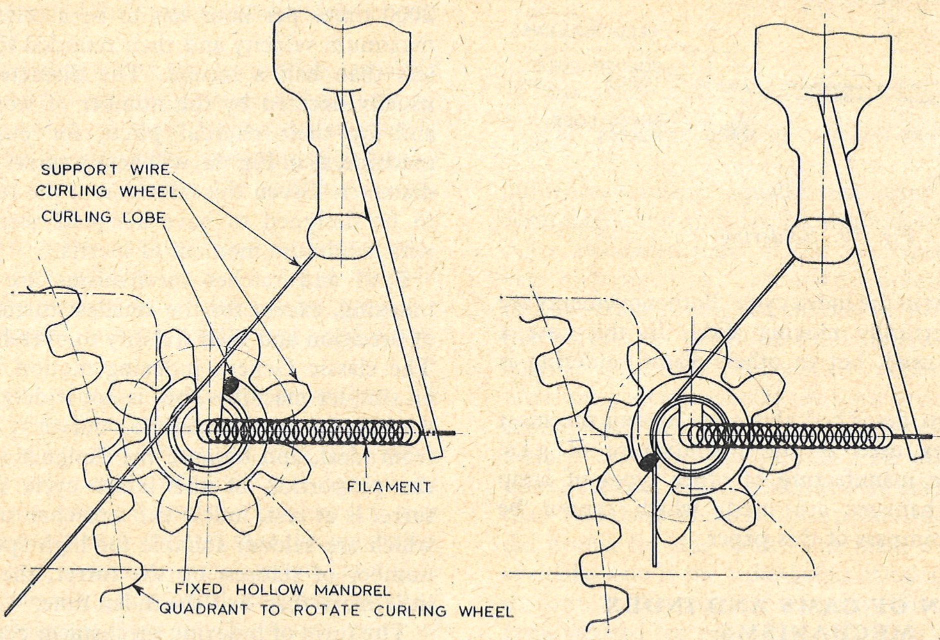


Fig. 17. Curling

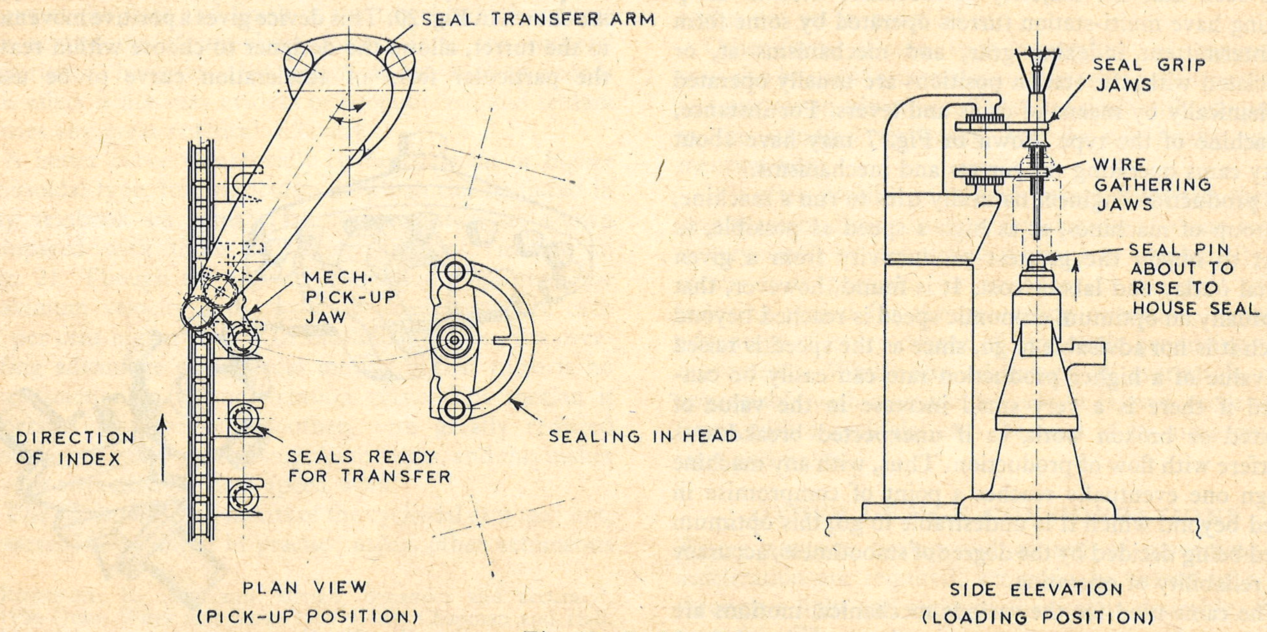


Fig. 18. Seal loading

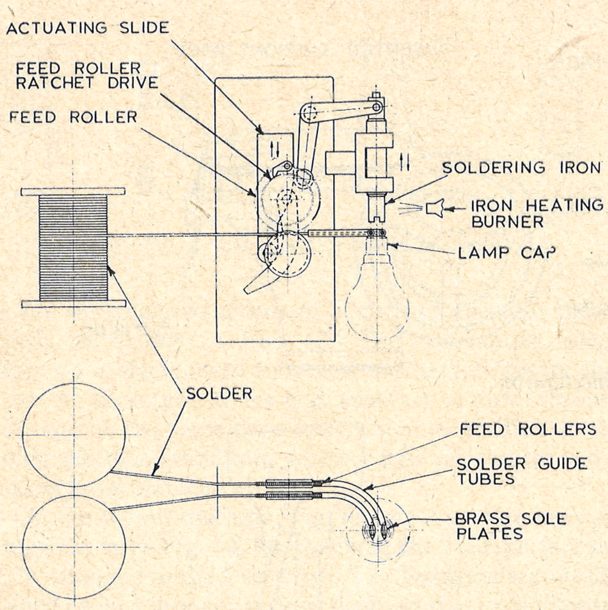


Fig. 19. Soldering

prescribed moment in the index cycle. Both movements are actuated by a vertically moving slide. In this case a soldering iron is used, but in others flame soldering is sometimes used.

The mechanisms described above are among the most interesting devices used in the manufacture of g.l.s. lamps, but in the manufacture of other types of lamp many other mechanisms are used, which cannot be described in the compass of this paper.

DESIGN OF CAMS AND INDEX MECHANISMS

It is seen that the majority of machines used in lamp making have multi-station turrets operated by some form of intermittent indexing gear, and mechanisms at, or associated with, the station positions are usually operated mechanically by means of cams and levers. For instance, a machine of the type shown in Fig. 7 may have about thirty cams operating the turrets and mechanisms.

A production engineer naturally tries to run a machine, or group of machines, at as high a speed as possible, in order to obtain the greatest productivity from a given capital outlay and labour cost. It is found, however, that eventually an optimum economic speed is reached beyond which it is not advisable to go, since as the speed is raised the value of a higher production rate can easily be cancelled if there is a very small increase in the value of rejected or broken work, or if unexpected breakdowns interfere with flow of production. Thus, with any machine design one eventually reaches a point of compromise in speed beyond which it is undesirable to go, this optimum speed being decided by the degree of smoothness, accuracy and reliability of operation.

The cams used for the various mechanical motions are therefore of paramount importance, because they have a direct influence on the motions and forces involved. Since acceleration is an inverse function of the square of time, an increase of speed of, say, 20 per cent will increase the dynamic forces and stresses by 44 per cent. The acceleration, and the rate of change of acceleration, of a mechanical motion should therefore be as smooth as possible, for any sharp change in these values will produce impulsive forces.

Consider first indexing mechanisms: the turrets of higher speed machines usually index at speeds between 1000 and 2000 indexes per hour. The turret usually moves during about a quarter of the index cycle, and is stationary for three-quarters of the cycle. Thus a turret which indexes 2000 times per hour has to be accelerated from rest to maximum velocity and then retarded to a stop position in less than half a second. The diameter of the turret is usually decided by the number of work heads it carries and by their chordal pitch, for example, a 60-head machine, as in Fig. 8*a*, will have a turret of $5\frac{1}{2}$ ft pitch circle diameter. Given this dimension, the turret assembly has to be designed to have adequate strength and rigidity with minimum moment of inertia.

Pawl and ratchet mechanisms are seldom used for indexing, except for the smallest turrets, because of lack of precision and their liability to overshoot if speeded up. The classic Geneva indexing motion is sometimes used on simpler machines, but is not widely favoured, because the velocity and acceleration curves it gives are often far from ideal, and because the designer is left no choice of the proportion of the index cycle during which the turret is at rest, unless extra mechanisms are introduced, which are seldom suitable for high speeds. With a large number of stations on the turret, the rest time is very little more than half the index time.

The form of indexing mechanism generally favoured in the present day is the cross-over cam, of which two types are shown in Fig. 20. This device gives a positive movement to the turret, allows the designer to choose within reason the particular form of acceleration curve to be used,

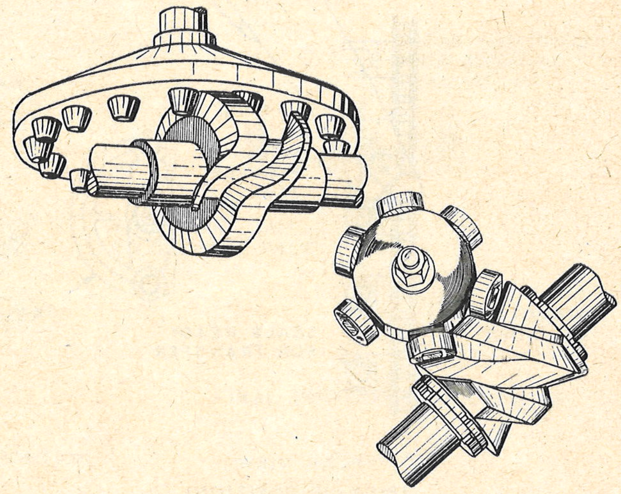


Fig. 20. Cross-over cam

permits reasonable choice of the proportion of the index cycle during which the turret is stationary, and is self-locking, so that the turret cannot move out of its intended position at any time. Ideally the indexing arrangement should be as large in diameter as the turret itself, so as to reduce magnification of errors in locating the turret at each index. Usually this is not possible and a compromise has to be reached. The rollers engaged by the cross-over cam are usually on a pitch circle which is from one third to two thirds of the turret diameter.

The index cam is usually carried on a main cam shaft which makes one revolution per index of the turret. On this cam shaft are also placed the cams which, by means of suitable levers, actuate the various mechanisms on the station position, etc.

The time displacement curve of the motion imparted by a cam, whether it be for indexing a turret or for operating a mechanism around it, is most important, in that it decides the velocities, accelerations, and rates of change of acceleration, and so decides whether the resulting motion will be smooth or jerky.

Whilst some slow speed machines have been run quite successfully with cam profiles giving a curve of radii suitably blended by straight lines, these cams are quite unsuited to high speeds, and are hardly ever used nowadays.

The form of cam most favoured by the authors for general use is one that gives simple harmonic motion at its active periods. It has the advantages that the profile can be very simply calculated, that it may, if desired, be easily generated by a simple geometric mechanism, that the motion is reasonably smooth, and that the maximum values of velocity and acceleration for a given amplitude and cycle time are not as great as with some other types of cam. Its one disadvantage from the theoretical point of view is that there is a step function in the acceleration curve at the start and finish of the travel, which induces the setting up of impulsive forces. It is the authors' experience, however, that except at the highest speeds this effect is not very evident or pronounced, and seldom causes any great practical difficulty.

A better curve theoretically is the cycloidal or higher sinusoidal type, full particulars of which can be found in any textbook on cams*. Its characteristics are shown compared with those of simple harmonic motion in Fig. 21. Though for a given stroke and cycle time the maximum velocity and maximum acceleration are each 27 per cent higher than with sinusoidal motion, the overriding advantage of cycloidal motion is that there is no step function in the acceleration curve. The motion it generates is therefore smoother, with greatly reduced tendency to cause jerks or impulsive forces, and this makes it very attractive for high-speed work.

The advantages and merits of the cycloidal cam may not, however, be achieved in practice unless other extraneous

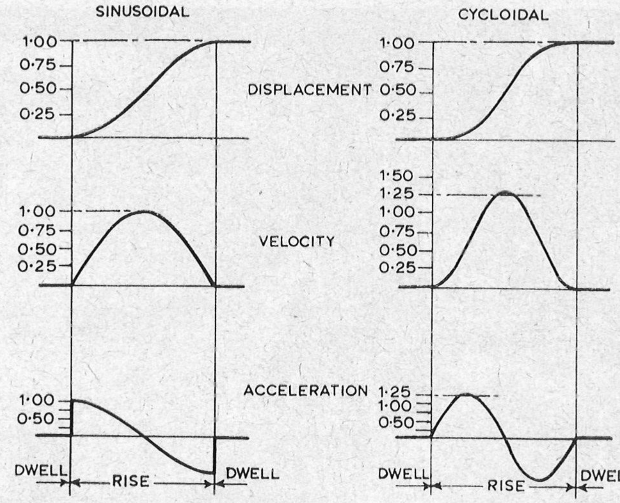


Fig. 21. Comparison of cycloidal and sinusoidal cams

influences causing equally significant perturbations are eliminated, and this can be attained only if the cam and other associated parts of the mechanism are made with very high precision. Take for example a cam giving a rise of 2 in. from an angular motion of 90°; it can be shown that an error of profile of 0·001 in. rise and fall over a 4° angular increment of camshaft motion will produce an interfering acceleration of the same order as the maximum acceleration due to the smooth motion of a perfectly formed cam through the full 2 in. displacement. Thus, unless the cam and mechanism were made to finer accuracy than this, there would be little point in adopting the cycloidal profile for this work. The main disadvantage of the cycloidal cam is the tediousness of calculating and cutting its form to the required accuracy. Though a method has been devised for generating this form of cam, the mechanism is more elaborate than that for a harmonic cam, and is not yet in practical use.

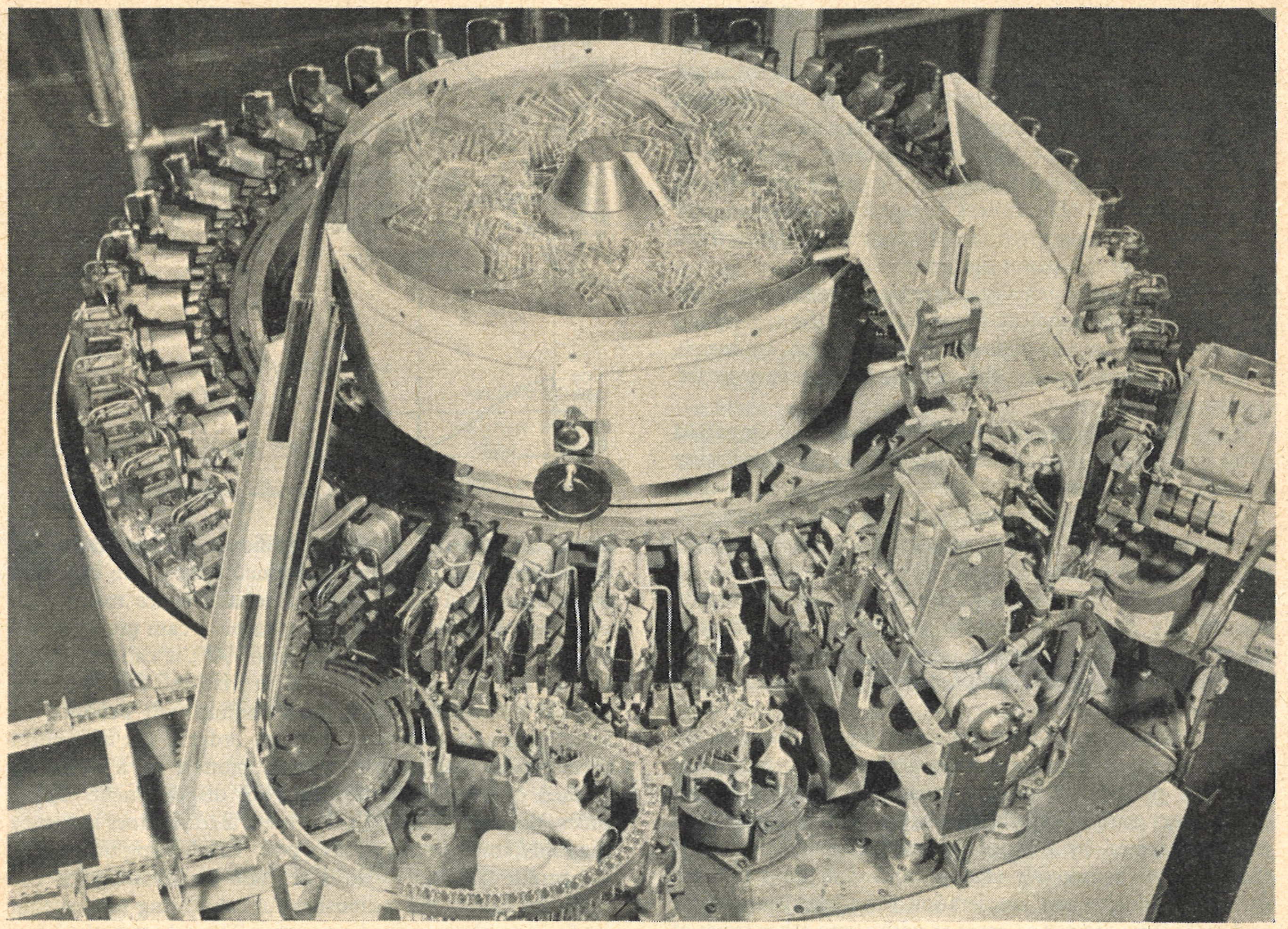
Other forms of cam, such as parabolic or trapezoidal, may also be used in special instances where their particular features are an advantage. These are dealt with adequately in the standard textbooks, and do not justify special mention here.

It is often possible to take advantage of the fact that the displacement during the first few degrees of a cam motion is very small by permitting motions to overlap. By this means it is possible, for instance, to use part of the indexing period for the processing operation, so taking advantage of every degree of cam angle producing these movements. Whilst the advantage of overlap is quite appreciable with a sinusoidal cam, it is even more significant with a cycloidal cam, because of its more gradual start and finish.

OTHER DESIGN CONSIDERATIONS

Where accurate timing and control of movement and acceleration are required, actuation by means of a cam through a light and rigid mechanism is desirable, if not essential. There are, however, many instances where

* Rothbart, H. A. 'Cams: design, dynamics and accuracy', 1956 (John Wiley and Sons, New York; Chapman and Hall, London).



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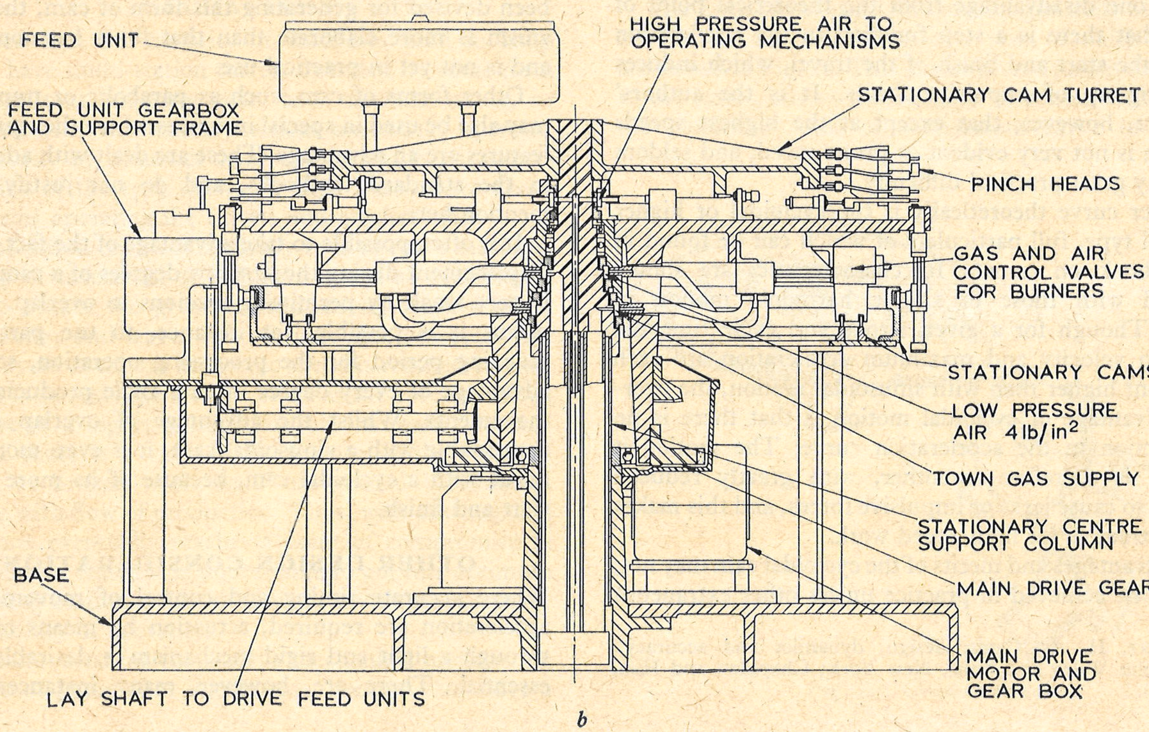

b

Fig. 22. Uniform-flow pinch machine

such precise control is not essential, and pneumatic operation may be used with advantage, particularly when the mechanism is at a distance from the timing device. In addition, by a suitable selection of cylinder, considerable force may be made available at a point of a machine where power from a mechanical or electrical source would be very difficult to obtain.

Very fast speeds of operation can be obtained by the use of air equipment, and quite frequently this is an advantage, particularly where such a movement with cam operated arrangement would give an unduly large lift and high pressure-angle to the cam. It is also possible to obtain quite slow movements from pneumatic devices such as restriction of exhaust air flow, but the motion cannot be as accurately controlled as with mechanically operated devices.

It has been seen that quite large amounts of heat are supplied to lamp machinery, usually intense at some particular point, and because of the lack of uniformity in the heating processes distortion is quite common. For this reason normal engineering tolerances cannot be maintained except on purely mechanical motions not subject to heat, such as indexing mechanisms.

It is usual to increase running clearances in bearings and slideways where there is a danger of heat distortion, to a point where satisfactory running is obtained. The necessary clearances can be found only by development, and in fact may not be exactly the same in similar machines.

The use of oils in excess is not permitted on mechanisms where the lamp components are likely to be fouled, and in such instances recent developments such as graphite-loaded materials, molybdenum disulphide lubricants, polytetrafluorethylene and nylon have, to some extent, alleviated the difficulties.

FUTURE POSSIBILITIES

With increasing markets requiring higher production rates, one may ask whether the ultimate limit in speed is being approached. It is the authors' view that it is quite possible technically to construct machines for higher speeds; deciding how fast one should go is often influenced more by non-technical considerations.

Higher index speeds of turrets or conveyors are still possible, if mechanisms of improved dynamic performance and lighter moving parts are used, but the limit of these speeds is now being approached. It is thought unlikely that machines of conventional design could operate satisfactorily at index speeds much over 2500/h.

Another way of increasing the throughput is to have two or more work stations at each indexing position; this, however, also doubles the mechanisms to be provided at

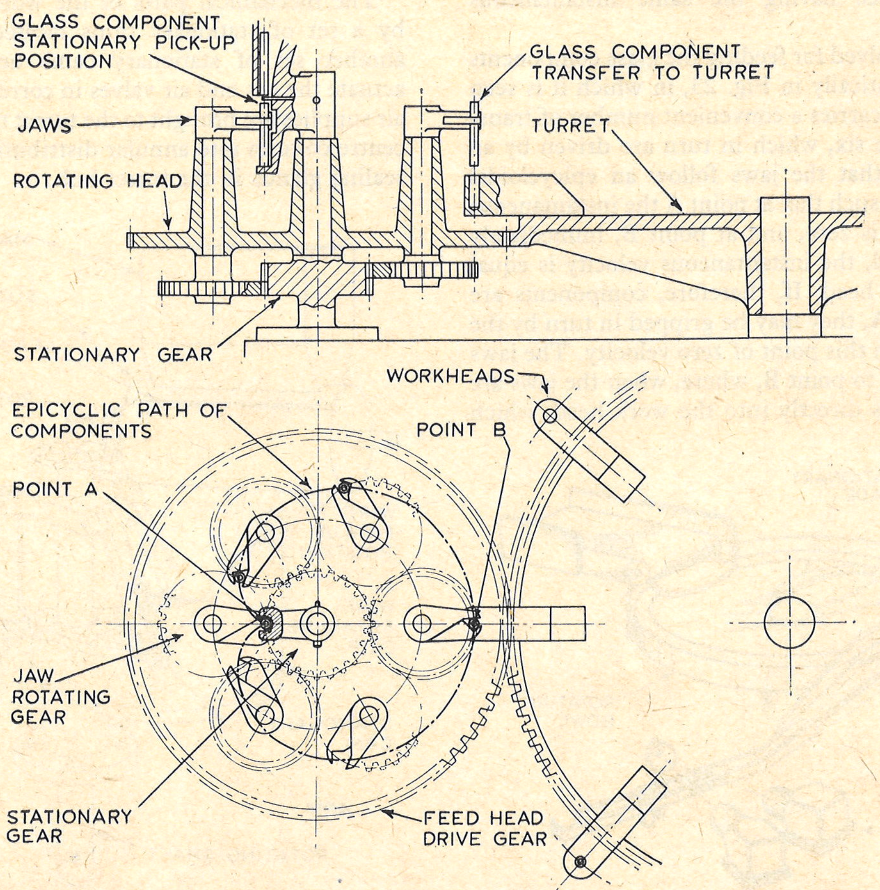

Fig. 23. Epicyclic feed head

each index position, and creates a need for rather large turrets and long conveyors.

Another method is to keep the work heads moving at a uniform speed; components have then to be fed to the moving head, and each head must have its tools and burners which move with it. The resulting machine is much more complicated and expensive, but there is now no speed limitation imposed by indexing mechanisms and their problems of alternate acceleration and deceleration.

Fig. 22*a* shows a general view, and Fig. 22*b* a sectional elevation, of an experimental pinch-making machine of this type developed by the authors. It has a turret with 40 heads, each head having its own complement of holding jaws, burners, pinch hammers, etc. The machine operates at a turret speed of 1·375 rev/min, which is equivalent to 3300 indexes/h. Its top limit of speed would probably be determined not by mechanical limitations, but by how much the time during which the parts are available on the turret for processing (heating, forming and cooling) could be reduced by raising the machine speed without detriment to the quality of work produced.

Components are fed into the work heads on the turret by feed devices, which accelerate the parts to a tangential velocity equal to that of the turret heads before transfer takes place. The finished work is removed from the heads by a transfer device having the same instantaneous velocity.

The principle involved for feeding the glass components is shown diagrammatically in Fig. 23, in which it is seen that a rotating head carries a convenient number of transfer jaws, in this case six, which in turn are driven by an epicyclic chain, so that the jaws follow an epicycloidal path. This motion is such that at point A the instantaneous velocity of the jaws is zero, and at point B, immediately above the work head, the instantaneous velocity is equal to that of the work head. If, therefore, components are fed in turn to point A, they may be gripped in turn by the jaws when they reach this point of zero velocity. The jaws then accelerate them to point B, where, when the jaws are opened, the part falls directly into the work head, which is travelling at identical speed. In practice a more convenient form of epicyclic drive is used, which gives an identical motion to that described.

To feed the glass-flanged components to point A, a rotary vibratory feeder was first tried, but it was found very difficult to feed parts at the required rate, without introducing such excessive vibration that the parts would abrade each other and would be likely to chip. A form of mechanical rotary disc feeder was therefore evolved, shown in Fig. 24, which feeds these parts satisfactorily at speeds well above that required by the machine. When the photocell device detects that the storage rail is full, it operates the deflector so that surplus parts are fed back into the centre of the disc until the rail is in need of further replenishment.

The feeding of the lead wires required a different solution, and is shown in principle in Fig. 25. These wires are fed from a magazine, by means of a slotted drum, into three arms, arranged on a rotating shaft. Each arm is lifted by means of a stationary cam to the underside of the drum where it receives a wire, which is retained by a clip until the arm drops to a vertical position, when it is immediately over the work head on the turret. At this instant the arm and work head are travelling at the same velocity, and release of the clip enables the wire to fall by gravity directly into the work head.

The mechanical parts of the work heads are actuated by a set of stationary cams located behind them, and another set of stationary cams underneath the turret actuate the gas and air valves in correct sequence. Gas and air supplies are brought to the turret through the stationary centre column into annular distribution channels between sealing glands in the turret hub.

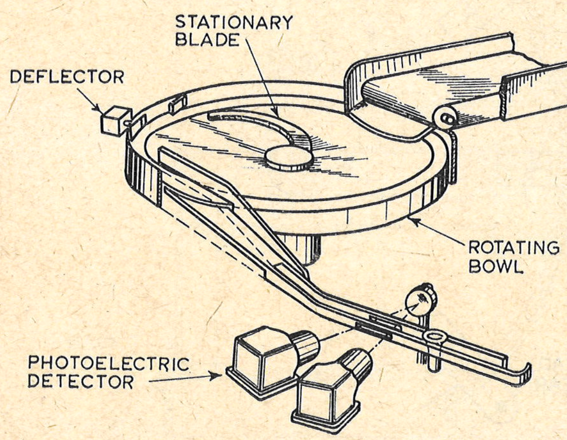

Fig. 24. Rotary disc flange feeder

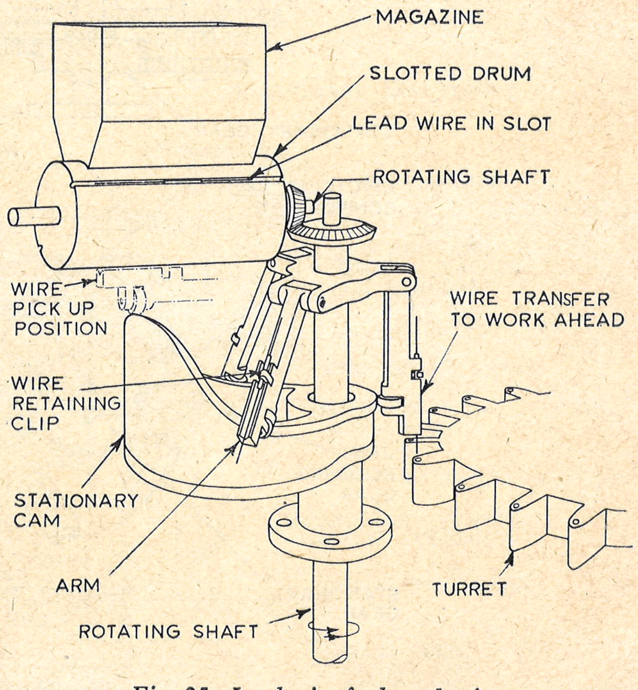

Fig. 25. Lead wire feed mechanism

Experience with this machine has shown that with such high outputs it is extremely difficult to handle the off-coming work satisfactorily unless there is a subsequent machine of equal speed to accept it at the same rate by direct mechanical transfer. To produce a complete set of machines running at that speed would, however, be a very long and expensive development project. Such elaborate machines are not easily adaptable to changes of production types, nor are they easily modified to suit changes of product design due to market trends or fashions. They are, therefore, suitable only for steady runs of long duration, preferably on a two or three shift basis in order to recover capital charges at an adequate rate.

The inflexibility of such a group, coupled with its high cost, was considered to make it unsuitable for present production requirements of this type of lamp in present market conditions, in which a rapid change from one type to another is often required, so the project is shelved at the moment. The principle could, however, be applied to this lamp or any other product, should more suitable circumstances arise in the future.

The degree of mechanization to be adopted on machines in order to make a particular product is usually dependent on the stability of its design, the size and growth of its market, and the cost of development and construction of such plant. Where the product is new and its design is still likely to change, and where the market requirement is yet small, it would be imprudent to incur a heavy cost by building elaborate plant. With an established and expanding market and a stable and well-tried product, intensive mechanization may be fully justified.

ACKNOWLEDGEMENTS

In conclusion, the authors wish to express their thanks to Osram (G.E.C.) Ltd, who have kindly permitted descriptions to be given of the machines used in their organization. Furthermore, the authors wish to emphasize that they are not alone responsible for all of the later developments mentioned in the paper, and that they have had the privilege of the co-operation of many of their colleagues in the Osram organization during the later phases of this work.

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