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Electrical
Manufacturing

Progress in Electron Tube Reliability

CRAIG WALSH, Associate Editor
ELECTRICAL MANUFACTURING

Progress in Electron Tube

RECENT PROGRESS in receiving tube design has been concerned mainly with improved reliability in severe environmental conditions, especially those encountered in military applications. This progress may be divided into two broad categories. The first is concerned with the improvement of currently available types of tubes. The other has a somewhat longer range viewpoint and has to do with the development of radically new principles. Examples of both are given in this article.

Reliability of an electron tube may be defined as the probability that the tube will give satisfactory performance for a given period of time when used in the manner and for the purpose intended.*(1)* * This definition is not only reducible to mathematical terms for analysis, but it also contains the caution that its use be limited to tubes designed and manufactured for the specific application at hand and used under circuit and environmental conditions for which it was designed. In practical terms it means that tubes must be designed to suit the needs of the application in which they are to be used before reliability can be fairly evaluated.

Through the years receiving tube manufacturers produced tubes primarily for the home entertainment field. The problem here was to achieve an economic balance between the cost of manufacture and degree of reliability satisfactory to the buying public. A measure of success in this might be the number of times a tube had to be replaced in a pre-war home receiver. This, on the average, was very seldom and in a great many cases extended over a period of years.

Reliability became a problem when tubes were used in applications where they were not particularly suited for the conditions. During the war years the only tubes available for the many critical uses were those designed for home entertainment use. In short, we and all other nations were caught unprepared insofar as tubes suitable for military use were concerned.

Commercial airlines became sufficiently concerned with reliability of tubes in their particular applications that they initiated a long range project to investigate the causes and possible cures of tube failures. Through Aeronautical Radio, Inc. (ARINC), owned jointly by several airlines, they conducted an investigation to determine the rate of tube failure in equipment installed in commercial aircraft and the causes of failure.

The removal rates for the first 1000 hr of operation were found to be between 0.5 per cent and 8 per cent for various tube types and manufacturers. ARINC engineers believe that tubes having a considerably higher level of reliability than the tubes investigated (made in 1952) are now being made. They believe that a removal rate of 0.1 per cent for the first 1000 hr should be attainable under optimum practical conditions of operations. *(2)*

The Defense Department and the three armed services also became greatly concerned with tube reliability in military applications. As a result, an extensive program to improve receiving tube reliability in military applications was set up and coordinated with the already existing program for tube development research. The three services have tube reliability problems which are peculiar to themselves as well as those that are common to one or both of the other services. Their work, both in their own laboratories and contracts with tube manufacturers, is coordinated by the Advisory Group on Electron Tubes (AGET). This advisory group is an agency of the Office of the Assistant Secretary of Defense (Research and Development), and its membership, as well as its working groups, includes engineers prominently identified with electron tube research and development in private organizations and in the three services. The broad function of AGET is to coordinate the activities of all groups participating in electron tube (including devices having similar properties) research and development, of which reliability is a part. The secretariat of AGET is provided under a joint service contract with New York University.

A fundamental phase of the reliability program was to survey tubes removed from service in military applications so that the cause for removal might be determined. To do this, two joint-service projects were set up to collect and analyze tubes removed from military equipment, both in

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* Italic numerals in parentheses apply to Cited References at end of article.

Reliability

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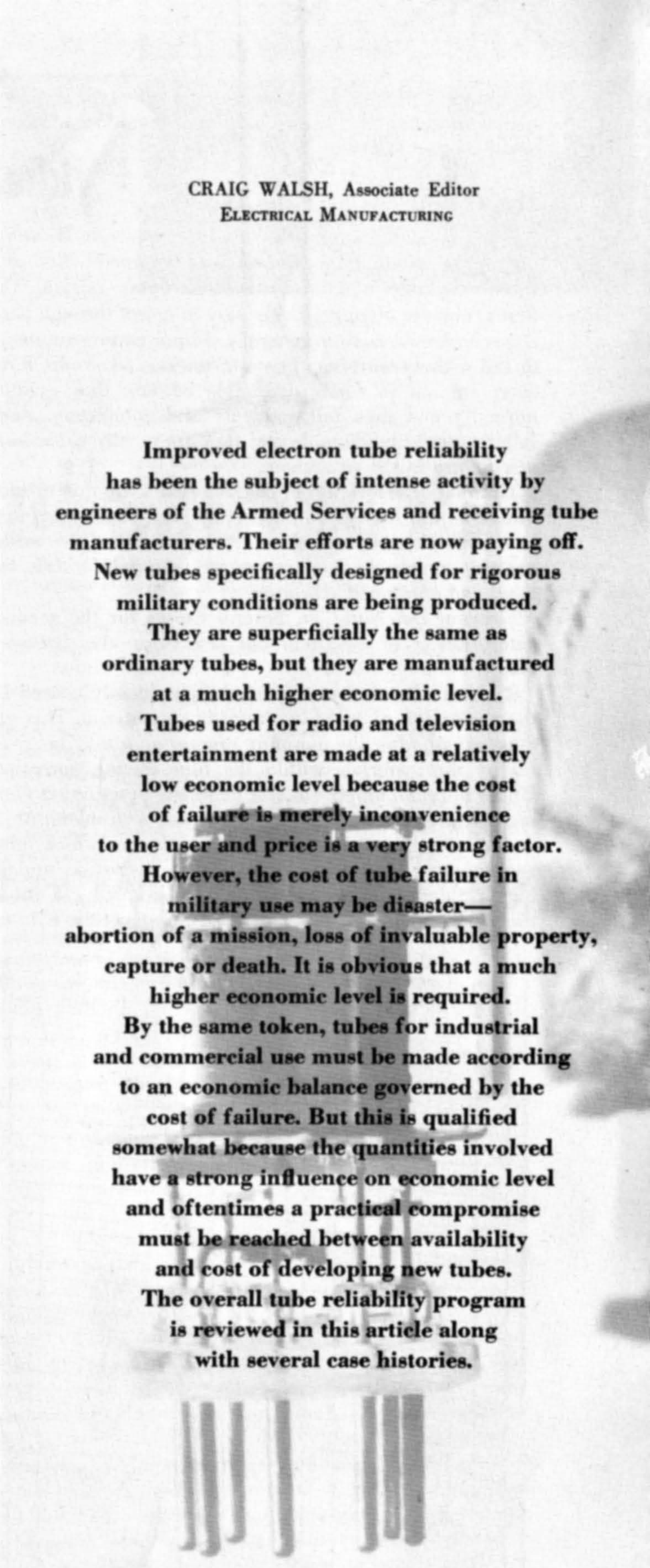
Improved electron tube reliability has been the subject of intense activity by engineers of the Armed Services and receiving tube manufacturers. Their efforts are now paying off. New tubes specifically designed for rigorous military conditions are being produced. They are superficially the same as ordinary tubes, but they are manufactured at a much higher economic level. Tubes used for radio and television entertainment are made at a relatively low economic level because the cost of failure is merely inconvenience to the user and price is a very strong factor. However, the cost of tube failure in military use may be disaster—abortion of a mission, loss of invaluable property, capture or death. It is obvious that a much higher economic level is required. By the same token, tubes for industrial and commercial use must be made according to an economic balance governed by the cost of failure. But this is qualified somewhat because the quantities involved have a strong influence on economic level and oftentimes a practical compromise must be reached between availability and cost of developing new tubes. The overall tube reliability program is reviewed in this article along with several case histories.



the field and in the equipment manufacturer's plant. A field surveillance project, administered by the Bureau of Ships of the Navy, was assigned to ARINC. The second project, administered by the Army Signal Corps and assigned to Cornell University, was to subject rejected tubes, both from the field via ARINC and from equipment manufacturers, to laboratory analysis. The two projects function in close cooperation with each other through AGET.

ARINC maintains eight collection stations for rejected tubes at military establishments in the United States and Germany. Tubes removed by regular maintenance technicians are collected by ARINC engineers from a wide variety of equipment such as communications transmitters and receivers, radar systems, amplifiers, computers, altimeters, autopilots, magnetic detectors, sonobuoys, recorders, etc. The equipment is land based, airborne, shipborne, vehicle mounted, and man packed. More than 200,000 tubes have been collected and analyzed.

From this collection and analysis program has come specific data of the shortcomings of tubes for the specific military purposes, as well as recommendations for improvements in design. Of a group of 32,909 tubes from seven of the eight collection centers, nearly one-third were found on analysis to comply with the specification under which they were procured, nearly 29 per cent had electrical defects, 21 per cent had mechanical defects, and 18.5 per cent had miscellaneous defects.

The pattern of failures varies widely according to the type of tube and the application. Maintenance procedures have been found to have a very important bearing on the removal rate for tubes. In a test designed in accordance with statistical principles, ARINC engineers have found that the number of tubes removed from military equipment can be drastically reduced, in some cases by a factor as high as 8 to 1.

Another important source of information on tubes is the production line of the equipment manufacturer. When tube rejections in such a manufacturer's plant exceed 1 or perhaps 2 per cent on a particular type, the rejected tubes may be sent to Cornell for laboratory analysis. This has been found to be an especially good means of obtaining data since it permits a comparison of a tube type in a particular socket and made by a particular manufacturer, generally during a specific period of time.

Major Sources of Tube Defects

Tube failures fall into two broad categories. Those resulting in gradual deterioration of characteristics and those resulting in sudden or catastrophic failure. The first group are often relatively easy to detect through periodic checks. Also, they generally do not cause equipment to fail without warning. Those of the second group, however, are not so easily detectable because they operate normally and then fail suddenly and completely. Such failures are unpredictable and they frequently cause sudden failure in the equipment.

Gradual deterioration of characteristics are due to such things as the loss of cathode emission properties, interface formation between the cathode sleeve and the oxide-emitting material, evaporation of materials within the tube, and continued vibration.

Gradual Deterioration. Several causes for the gradual deterioration of electrical characteristics are discussed below.

1. Loss of emission properties is frequently caused by the absorption of gases by the cathode material. This gas may remain after the pumping process or it may be given off by the materials within the tube during operation. Under normal pumping as it is generally practiced in commercial production, residual gas is not a problem. More serious are the temperature conditions under which tubes are operated in service. High power dissipation and/or high ambient temperature may drive occluded gas out of the glass envelope or metal parts of the structure. Life expectancy is seriously affected when the bulb temperature is allowed to exceed 200 C in tubes made with soft glass. The use of high-temperature glass eases this problem.(*3*)

2. Interface is the name given to the condition in which a material of high electrical resistance is formed between the nickel sleeve and the emitting material of the cathode. It acts as a high resistance in series with the cathode and in some cases effectively reduces the flow of current to a value below the minimum for circuit operation. Interface has been a serious problem in computer circuits where it caused a condition known as "sleeping sickness," and perhaps also in other circuits where it may have gone unrecognized. It is formed by the reaction of the barium oxide of the emitting material and silicon, used as an activating agent in the nickel cathode sleeve. Interface formation is accelerated if the cathode temperature is above the specified value and low or zero current flow further accelerates it. Because tubes in computer circuits frequently operate in a standby condition with all voltages applied and with a grid bias voltage sufficiently negative to prevent current flow, interface formation may be rapid.

Eliminating silicon from the nickel cathode sleeve and adjusting the processing conditions seemed to reduce the seriousness of interface formation. However, other difficulties were introduced because of its activating properties. The stabilizing period increases from the order of 30 to 60 min to about 100 to 200 hr. Various other activating agents such as tungsten (about 2 per cent) and aluminum (about 0.1 per cent) were tried with favorable results.

3. Unwanted conductive paths sometimes form between electrodes and cause a gradual deterioration in characteristics. This happens because over a long period of time the hot metal parts in the vacuum evaporate and condense on relatively cool mica and glass parts. Sufficient metal condenses in many cases to permit leakage current to flow between electrodes.

Among the methods used for minimizing the formation of leakage paths due to metallic deposits are the following: (a) Coat mica parts with a coarse insulating powder to increase the length of the potential leakage path, (b) shield the micas to reduce access of the metal vapors to critical insulator areas, (c) use metal alloys which do not evaporate readily, (d) punch "leakage slots" at critical locations in the mica between electrode supports, and (e) use non-evaporating getter materials and (f) limit the operating temperature.

4. Exposure to vibration causes a deterioration in tube characteristics by a gradual enlargement of the mica holes into which the electrode supports are inserted. If the vibration is continued long enough the holes become enlarged to the extent that the relative mechanical motion of the electrodes prevent the tube from operating properly. Also, as the mica holes are enlarged, the mica is pulverized and decrystallized to release a small amount of water of crystallization and other gases.

Catastrophic Failures. The main causes of catastrophic tube failure are opens and shorts, and heavy currents due to gas discharge. These are discussed below.

1. The heater, made of fine tungsten, or alloy wire and operated at elevated temperatures, is perhaps the most critical electrode for opens and shorts. The most important factor in heater operation seems to be temperature. The surveillance work of ARINC shows a close correlation

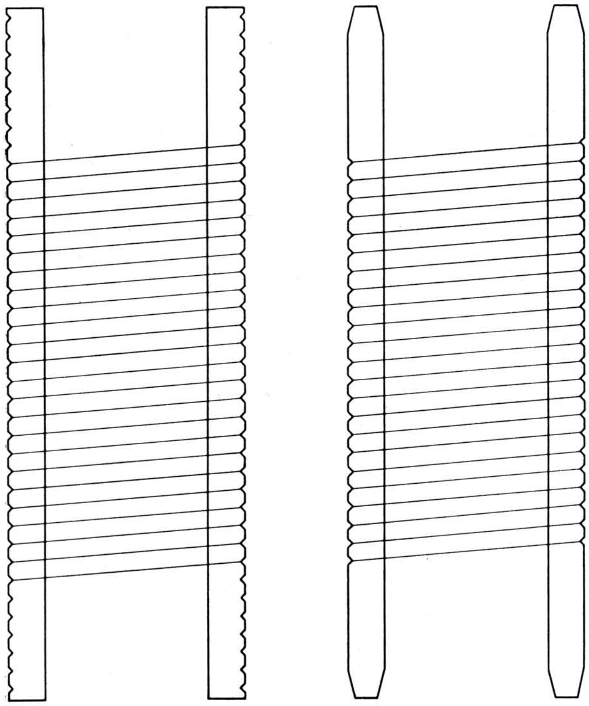
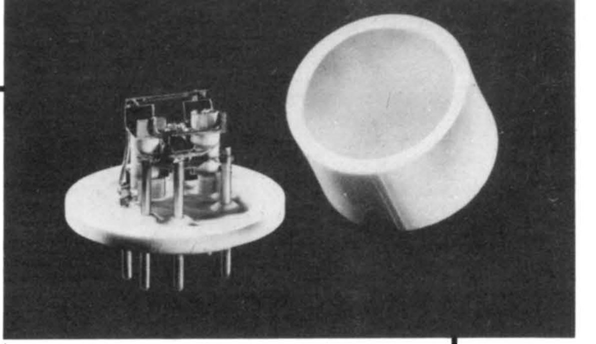


FIG. 1—Comparison of notching in grid side rods. Standard method (left) is to extend notching along entire length. They are eliminated (right) to avoid possibility of sawing action on mica insulators. Also, ends may be tapered.

Tubes for Automatic Assembly



Stacked tube for automatic assembly. Tube has smaller spread of electrical characteristics than those of standard construction.

MAJOR PROGRESS has been made in designing electron tubes for automatic assemby. Sylvania Electric Products Inc., working under a contract sponsored by the Navy Bureau of Ships, has designed the "stacked" tube (*6*) shown in the photograph. This stacked tube uses a ceramic envelope and base joined together with a one-step sealing process. The contact pins are brazed to the base. An exploded view of the tube is shown in the diagram.

Assembly is accomplished by successively dropping over the rivets the various elements and ceramic insulators in the order shown. Spacing between electrodes is controlled by grinding the ceramic spacers and this is done to an accuracy of 0.0005 in.

The cathode is made of flat tubing and is supported in a novel manner that combines rigidity with heat isolation. The supporting loops are made of a 42 nickel-iron alloy. Note that the entire length of the cathode sleeve may be used for emission.

The grids are made with tungsten lateral wires brazed to molybdenum frames with residual tension in the wire. This is much more rugged and hence less susceptible to handling damage than the conventional construction. It is also possible to use finer wire and closer spacings. Very small cathode-control grid spacings are possible because of the high degree of accuracy attainable in the flatness of the frame grid wires. Tests show that transconductance can be held within a much closer statistical spread with the frame-grid construction as compared to tubes made with side rod grids.

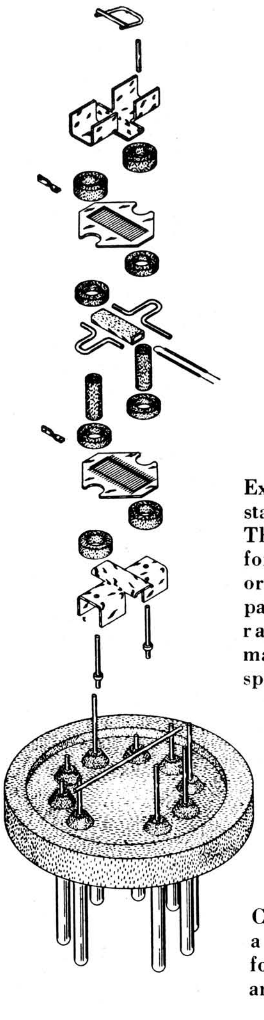
Because it is possible to process these tubes at very high temperatures, they have good life expectancy at high ambient temperatures of 300 C and 400 C.

A tube of unusual design adaptable to automatic machine assembly has been designed by Eitel-McCullough, Inc. for the Air Force (7). It is of all-ceramic construction and has a flat cylindrical shape somewhat like a pill box as shown. Flexible leads are used for direct soldering into the circuit. Eimac expects that the inherent reliability of this tube will eiminate the need for socketing. With tubes more difficult to remove and replace some servicing difficulties may well disappear. Eimac emphasizes that this tube is still in the exploratory stage and although many of its concepts are believed to be fundementally sound much remains to be proven.

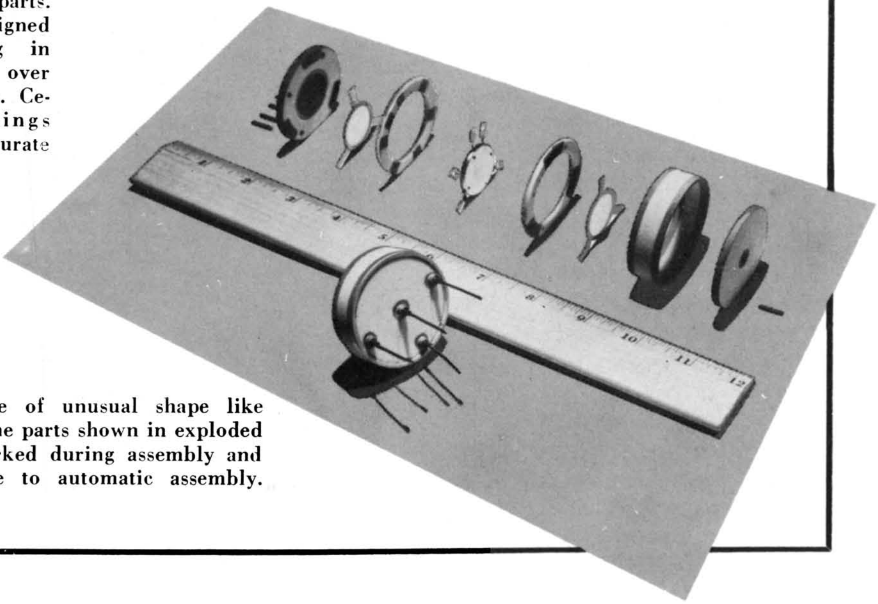
In a twin triode similar to the type 6SN7, ceramic end disks form the anodes. Grids and cathode are separated by ceramic spacer rings, all assembled in stacked relationship in a ceramic envelope cylinder. The grids are made by a photographic electroforming process. The cathode button contains a packaged heater which is a structurally integral part of the unit. Because the heater is integrally formed with the cathode, vibration is minimized. All parts are brazed in position. A feature of this design is that it is adaptable to a variety of tube types. By eliminating the grids the tube becomes a twin diode. By adding grids it becomes a twin tetrode, or a pentode.

A more recently developed version of this tube by Eimac has a considerably simplified design.

Other companies are also working on tubes for automatic production but detailed information is withheld. It should be interesting to speculate on the various approaches which might be under consideration. For instance, will the ceramic envelope win out or will the long predominant glass envelope be retained? Will the electrode structure undergo radical redesign or will a means be found for automatically assembling the conventional structure? Will ceramic parts replace mica for insulation? What will be the effect of synthetic mica?



Exploded view of stacked tube parts. They are designed for dropping in order shown over pair of rivets. Ceramic spacings maintain accurate spacing.



Ceramic tube of unusual shape like a pill box. The parts shown in exploded form are stacked during assembly and are adaptable to automatic assembly.

between heater temperature and life. Other failures due largely to high temperature include heater-to-cathode shorts, and shorts between the folds of a folded heater or between turns on a double-helix heater. Heater-to-cathode leakage is also minimized by low temperature.

2. A slight amount of gas within the tube will cause an arc discharge which leads to destruction of the tube. The gas may come from several sources such as an overheated electrode or from small leaks in the envelope.

Poor application of tubes has been a major cause of failure. It should be understandable that if a tube, no matter how well it is designed and manufactured, if used under conditions outside its rating or a condition not considered by the manufacturer, it is not likely to give reliable performance.

As an aid to equipment designers, AGET has established a means by which an equipment manufacturer may obtain the services of qualified tube application engineers to assist in the proper application of tubes in military electronic equipment. Upon request by the service sponsoring the development of the equipment in question, AGET will arrange to have a team of three or four tube application engineers consult with the equipment designer. The purpose is to be as certain as possible that the tube will be properly applied, preferably before equipment production starts. Application engineers are assigned from the various tube companies with regard only for the problem at hand.

As a further aid to equipment designers, the feasibility of setting up a lending library of limit tubes (those having certain characteristics at the extreme ends of the specified range) has been under study by Cornell University with the sponsorship of the Signal Corps Engineering Laboratories. Equipment designers have indicated that such a library would facilitate design of circuits so that they would not be critical with respect to any tube meeting its specification. It would also prevent the design of equipments having circuits requiring the use of selected tubes. Such a library has been shown to be feasible and SCEL is now formulating plans to bring it into being.

The results of the long term program to design and manufacture electron tubes for reliable operation are evident in an examination of some present day tubes. Few of the design changes are radical in nature. Rather, they are refinements, each one a small step and all adding

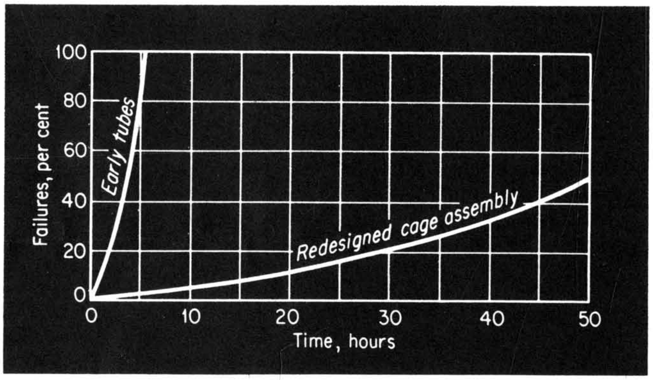


FIG. 3—Comparison of failure rates of early and re-designed tubes on shake table producing "white" vibration.

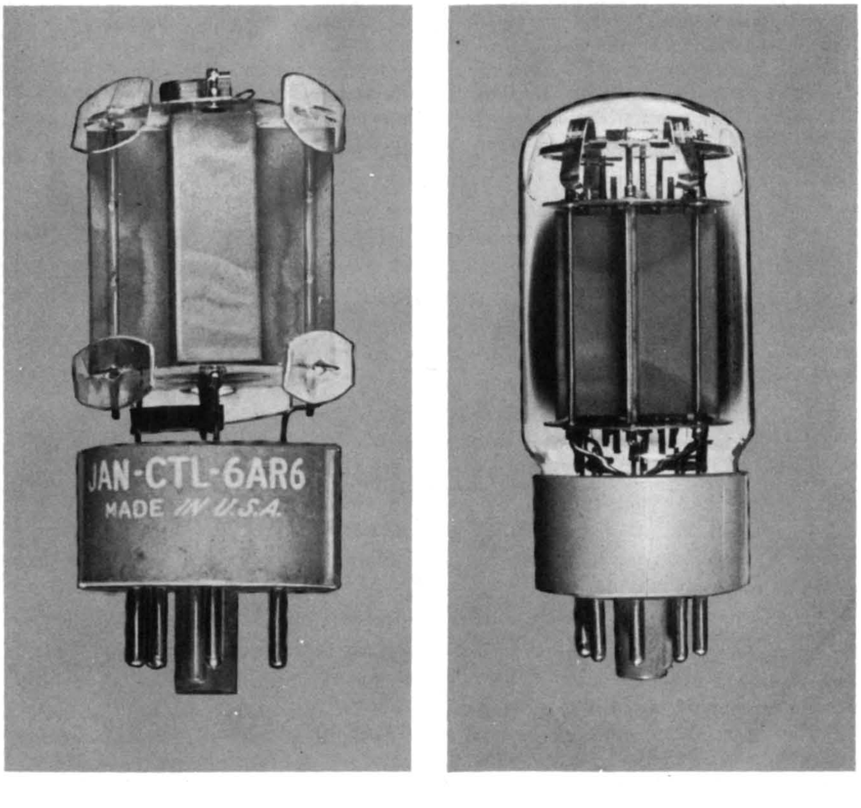
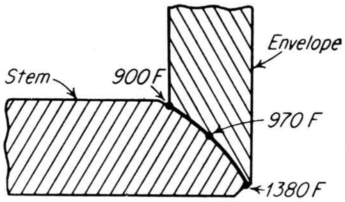


FIG. 2 — Early (left) and recent designs of 6AR6. Note metallic springs at top in new tube. Shock and vibration resistance has been greatly increased.

Low Temperature Glass Sealing

Contamination of electrodes, especially the cathode, is an important limiting factor in the life expectancy of tubes. Engineers of Compagnie Generale de Telegraphie sans Fil (CSF) of France believe that heating the tube before air is almost completely evacuated from the tube is responsible for much cathode contamination and shortened life. They have devised a means of heat sealing the glass envelope and stem after the air has been evacuated. Useful lives of 80,000 hr have been obtained in tubes sealed in this manner.

The CSF method, called Polyoptic sealing, takes advantage of the well known property of materials that when two very highly polished surfaces are placed in intimate contact, a molecular migration takes place between the two surfaces. If left undisturbed for a sufficient length of time, or if the temperature is elevated to a suitable value, a strong bond develops. In the case of glass, a permanent vacuum-tight bond is formed rapidly at a temperature of about 900 F. This is much below the temperature used in the conventional glass-sealing process which is about 1300 F. The temperatures reached in the seal are shown in the diagram. Tubes made with Polyoptic sealing show an improvement of about 15 per cent in emission plus a much narrower spread of emission value over a large number of tubes. A tube made by this process is shown in the photograph.



Tube sealed using optical polishing of envelope and stem to permit relatively low temperature for sealing. Note sharp corner at bottom of envelope.

Cross section of seal made by Polyoptic process. Inside temperature is much lower than in standard sealing.

up to an impressive total. Some of the more representative refinements are described in the accompanying case histories.

Design Refinements

Improved reliability of electron tubes in military and critical commercial applications has resulted from numerous design refinements. A brief review of some of the more pertinent is given below.

Heater. A major source of trouble has been the heater or the filament. Heater burnouts had been particularly bad in the early production of type 6AK5. About one-third of the failures due to structural weaknesses were caused by open heaters. Among the design refinements intended to eliminate or minimize this weakness were: (a) Redesign of the heater and cathode for operation at a somewhat lower temperature, about 1470 K rather than close to 1600 K; (b) recoating of the heater wire with insulating coating (alundum) at the end folds in folded heaters to prevent shorts between folds or with the cathode sleeve and (c) improved techniques for welding the heater wire to the lead wires.

Nonuniformity of coated heaters is sometimes a problem because of differences in the thickness of the alundum insulation. Too little coating increases the chances of excessive heater-cathode leakage and shorts. Too much increases the thermal capacity and increases the heating time. Such variations have been minimized by Tung-Sol by passing the coated wire through an automatic photoelectric micrometer. If the insulation diameter over the insulation is more or less than predetermined limits, the wire is stopped and an alarm given to the operator.

Cathodes. The high level of performance demanded of tubes has necessitated in some cases extremely close spacing between the cathode and the control grid. It may be so small, of the order of 0.0015 in., that the degree of smoothness of the cathode coating becomes an important factor. Some tube companies apply a small excess of cathode material to the sleeve and then remove it by grinding or shaving to form a smoother surface. Others say that surface smoothness has not been a problem.

Grids. Improved techniques have permitted closer tolerances in the minor diameter (the important one) of grids than was possible just a few years ago. This permits the use of smaller spacing between the cathode and control grid and, perhaps more important, enables the tube's electrical characteristics to be held to closer tolerances.

Grids have been made by placing notches in the supporting side rods in which to lay the lateral wires. Heretofore, the notches were placed along the complete length of the side rods, including that beyond the area of the lateral wires as shown in Fig. 1. Some tube engineers believe that when the side rod is pushed through the hole in the support mica, the notches have a tendency to produce a sawing action on the mica and enlarge the hole slightly. By eliminating the extra notches, such action and hole enlargement can be eliminated. Along with the smooth side rods the mica holes are made slightly undersize so that there will be a snug fit. In some cases the ends of the side rods are slightly pointed to ease their insertion into the undersize holes. Others, it must be said, feel that the notched side rods do not have a detrimental effect on the mica holes.

Mica Insulators. Mica has long been used as a supporting and insulating material in electron tubes. The electrodes are held in place by inserting supporting rods or ears through holes in the mica. Sometimes the holes are slightly larger than they should be or out of alignment. This permits the electrodes to vibrate or to be out of proper alignment. In an effort to overcome this, two mica insulators are used in place of one. The effect of the two mica insulators is that if the corresponding holes in the adjacent micas are slightly out of size or position, the two together will be much better than one alone. Also, the chances are that if one mica does not hold the side rod firmly, the other will. The practical result is that the electrode assembly is held much tighter.

One of the functions of the mica insulators is to hold the tube firmly within the glass envelope. For many years this has been done by means of small points around the periphery of the mica. As the electrode assembly is pushed into the envelope the points crush slightly and provide a cushioning effect to reduce the effects of vibration and shock on the electrodes. This has been satisfactory except when the side walls of the envelope were not parallel with the portion near the dome larger than the other end. In this case the points are crushed while inserting the electrode assembly and they do not recover to give support when fully inserted. This has been circumvented by the simple device of making the envelope slightly tapered. The points are then progressively crushed and give full support in the completed tube.

Synthetic mica (*4* and *5*) has been used in experimental tubes by Sylvania. Better life test results were achieved at elevated temperatures than was the case for a control lot of tubes made with natural mica. Commercial production of synthetic mica is planned for the near future in a plant now under construction by the Synthetic Mica Corporation, a subsidiary of Mycalex Corporation of America.

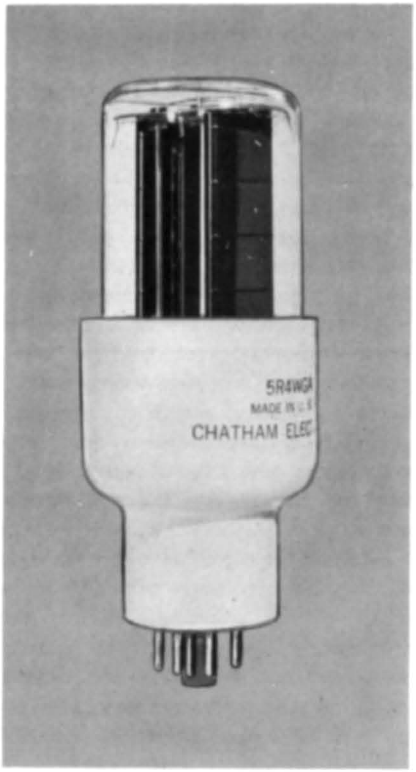


FIG. 4—Deep base is used to minimize effects of vibration.

Lint. Lint has long been a problem in tube manufacture. Small pieces of whatever might be floating in the air get into a tube and sometimes lie across the electrodes. During processing the tube parts become very hot under various degrees of vacuum and the lint carbonizes to form a conductive path between elements. This then causes leakage or shorts in the finished tubes.

The tube manufacturer minimizes effects of lint by continual filtering of the air in critical areas of assembly, covering of the partially assembled units or placing them in plastic bags, and prohibiting the entry of certain types of clothing into these areas. A frequent lint count is important.

Cage Assembly. The assemblage of electrodes and mica supports is called the cage assembly. In the reliable versions of electron tubes it has been greatly strengthened by such things as using double micas as mentioned above and mechanical devices to hold the electrodes firmly in place. An extra mica shield is placed between the upper mica insulator and the getter. This prevents the getter vapor from condensing on the insulating mica and causing a leakage path to form.

Improved mechanical design of the cage assembly within the envelope has brought about a considerable improvement in performance under conditions of heavy vibration. Figure 2 shows some of the differences of the supporting elements as designed by Tung-Sol Electric, Inc. in the type 6AR6. The micas of an early version (left) have been replaced with a structure making use of metal spring elements. All electrodes are held in place by metal ears or tabs embedded in the double top and bottom micas. The results of this type of improvement are graphically illustrated in Fig. 3. The vibration test set used produced what is called a "white" vibration because it contains vibrations of many different frequencies and repetitive mechanical shocking. Early tubes failed after a very short exposure to the white vibration of this test set. Mechanically redesigned tubes showed a many-fold improvement in the rate of failures. This work was done under a contract from the Signal Corps Engineering Laboratories.

Chatham Electronics uses a deep base, as shown in Fig. 4 to reduce the effects of vibration. By extending the side wall of the base far up on the envelope, the tube is held very firmly. ○○○

Acknowledgments

Many groups in government agencies, electron tube manufacturers and other organizations in the field have contributed much information for the preparation of this article. Their assistance is gratefully acknowledged. They include the following: Office of the Deputy Assistant Secretary of Defense for Applications Engineering; Bureau of Ships and Office of Naval Research, U. S. Navy; Thermionics Branch, Signal Corps Engineering Laboratories; Bureau of Standards; Advisory Group of Electron Tubes; Aeronautical Radio, Inc.; CBS-Hytron; Chatham Electronics; Compagnie Generale de Telegraphie sans Fil(CSF) and its affiliated American Radio Company; Eitel-McCullough, Inc.; Radio

"Special Red" Tubes

IN 1948 RCA introduced a line of tubes known as Special Red tubes which were intended for use in industrial applications where long life, rigid construction, uniformity, and stability were prime requisites. They are general purpose tubes and their electrical characteristics were chosen to be useful in a wide variety of industrial equipment.

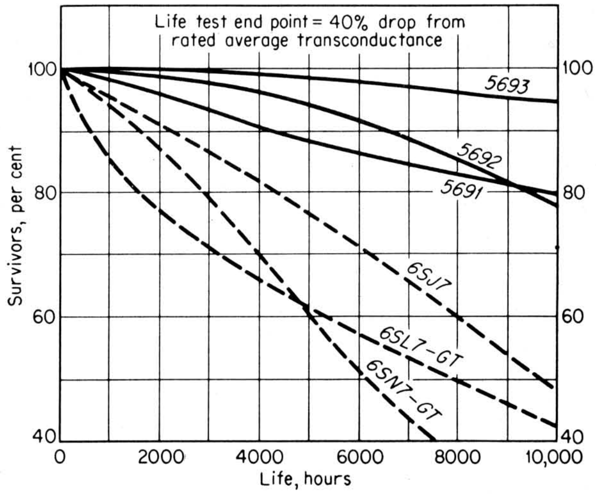
The 6SL7GT high-mu twin triode was selected as the prototype for the 5691, the 6SN7GT medium-mu twin triode for the 5692, and the 6SJ7 sharp cutoff pentode for the 5793. Also included in this line of tubes is the 5690, a full-wave vacuum rectifier. Although the electrical characteristics are essentially the same as for the prototypes, the mechanical structures are much stronger and resistant to vibration and shock, the materials are more carefully chosen, and the processing is controlled to a much higher degree (*8*). Also, the tolerances on characteristics are held much more closely. For instance, for the 5692 (6SN7GT) the tolerance on heater current is ± 3 per cent with sampling tests to assure that 75 per cent of the tubes will be within ± 2 per cent. Transconductance is held to ± 17 per cent as compared to ± 22 per cent. Heater-cathode leakage is specified to be one quarter of that allowable in the prototype, 5 microamp as compared with 20 microamp.

Among the design features incorporated into the Special Red tubes to give long life are the following: (a) "A-frame" is used to give electrode structure high mechanical strength for resistance against shock and vibration, (b) twelve reinforcing eyelets give a firm bond between the mica insulators and supporting rods, (c) nickel sleeves are placed over the heater legs prior to welding for greater mechanical strength, (d) cathode sleeves are locked to the mica insulator, (e) mechanical stops are placed on the grid side rods to prevent vertical motion of the grids, (f) the plates are held firmly in place by ears wedged into the mica and (g) two getters are used to give a greater life expectancy before released gases reduce performance.

In addition to the usual 500-hr life test normally given to regular tubes, these tubes have been subjected to a series of 10,000-hr tests. A comparison of the performance of the Special Red tubes and their prototypes is given in the accompanying curves. Each of the six types was subjected to the maximum rated plate voltage and plate power dissipation. The life end points were considered to be when the measured transconductance was 40 per cent below the initial rated value. Examination of the curves shows that the Special Red tubes are very much superior to the regular types.

It is interesting to note that the Special Red tubes were designed to offer the greatest resistance to the greatest variety of severe environmental operating conditions. They were intended for reliable operation under any conditions likely to arise in industrial use, including long periods of cutoff or standby operation.

In cases where high resistance to all environmental conditions is not needed, it is relatively simple to design the tubes without that resistance. For example, tubes for computer use must have long life and low interface formation, but need not be highly resistant to shock, vibration or high ambient temperature.



Comparison of Special Red and standard tubes on 10,000-hr life test. End of life occurs when transconductance drops 40 per cent from rated value.

Corporation of America; Raytheon Manufacturing Co.; Sylvania Electric Products Inc.; Tung-Sol Electric, Inc.

Cited References

1. General Report No. 1, "Investigation of Electron Tube Reliability in Military Applications," January 4, 1954, Aeronautical Radio, Inc., Washington 6, D. C.

2. "Investigation of Electron Tube Reliability on Commercial Airline Applications," Progress Report No. 1. Aeronautical Radio, Inc., Washington 6, D. C., p 4.

3. "Hard Glass Electronic Tube for High Temperature," ELECTRICAL MANUFACTURING, Vol. 53, No. 5, May 1954, p 326.

4. "Progress in Synthetic Mica," R. D. Jackel, March 1950, ELECTRICAL MANUFACTURING, p 99.

5. "Synthetic Mica Adds Advantage to Glass-Bonded Mica," A. J. Monack, October 1952, ELECTRICAL MANUFACTURING, p 146.

6. "Reliable Receiving Tubes Designed for Automatic Production," W. R. Wheeler and T. L. Evans, Electronic Components Symposium, May 1954.

7. "Advance Work on Electron Tube Reliability," Harold E. Sorg, National Conference on Airborne Electronics, May 1954.

8. "Performance Evaluation of Special Red Tubes," H. J. Prager, RCA Review, Vol. XIV, No. 3, September 1953, p 413.

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