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THE DEVELOPMENT OF THE EQUIPOTENTIAL INDIRECTLY HEATED CATHODE AS APPLIED TO RECEIVER TUBES†

*By V. O. ALLEN**

THE successful commercial application of the oxides of the alkali earth metals, as comparatively low temperature emitters on directly heated continuous filament, immediately made possible and practical the indirectly heated emitter and consequently the a-c. operated equipotential cathode. By 1926 there was an insistent demand on the part of set makers and the public for an a-c. operated set to do away with batteries, rectifying equipment for same and other apparatus that was troublesome to maintain, and the spring of 1927 witnessed a real effort by tube manufacturers to supply this demand. The result was the 427 type tube and later the 424.

The initial work in the laboratory was directed towards the production of a five volt tube with approximately the same characteristics as the 401-A and here (Fig. 1) is an illustration of one of the first 427 type tubes to be made up. It is a five volt tube and in order to get the necessary resistance in the filament at this voltage with the materials then available, it was necessary to use double heating elements.

† *Delivered before the Club, May 14, 1930.*
* *DeForest Radio Company.*

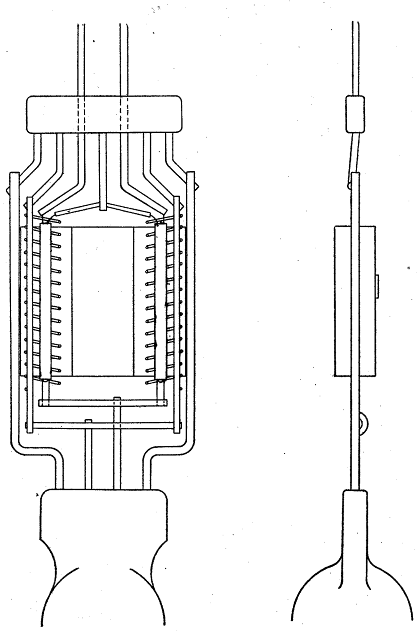

Fig. 1. Early 5-volt heater tube assembly.

The lower operating voltage of present tubes, of course, permits a heavier and short heater wire and here (Fig. 2) is one of the first types to be turned over for regular automatic production. We note the solid plate, short cathode sleeve, no spacers and the fragile heating element; needless to say much grief attended the first production schedule.

The first production gave poor performance. It was non-uniform, noisy, hummed, distorted signals and sometimes failed to detect at all. It was extremely critical during processing and the life was short. In all, the successful production of this type called for intensive research on materials, design and production methods.

One of the first construction changes made, however, considerably improved the functioning of the tubes. This was the use of the mesh plate. In forming the active oxides of barium and strontium on the cathode it is customary to use the carbonates and decompose to the oxide on exhaust. During this process some active material is sprayed over to the grid which emits as soon as it reaches 850 degrees K. A later study of reactions occurring at the cathode which will be discussed later resulted in the development of a coating that does not spray over in this manner.

In order then to overcome this grid emission it was necessary to keep the grid below 850 degrees K. The power radiated by a body is a function of temperature as indicated by these curves (Fig. 3) and varies with different material. We see from these curves (Fig. 4) that solid nickel surface does not radiate .65 watts per square centimeter until it reaches a temperature of 900 degrees K, which is the rate it must radiate in a 427

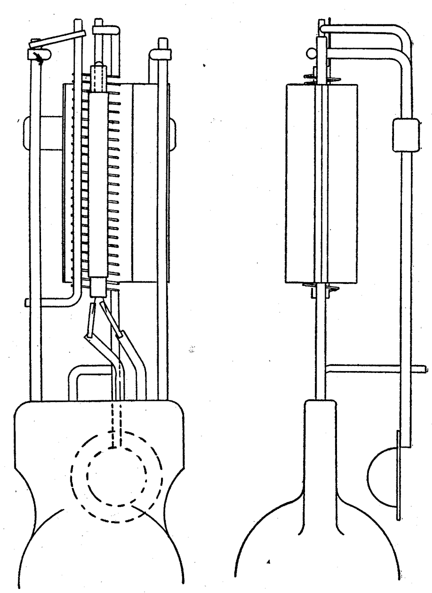

Fig. 2. Heater type tube assembly, for automatic manufacture.

tube. Thus with the solid plate, the grid is running above 900 degrees K. where as with mesh it is running above 750 only, and even though it picks up some active material it does not emit.

The conventional type of a-c. cathode consists of a twin hole insulator threaded with tungsten or tungsten alloy heating element and the whole inserted or sweated into a metal tube coated with barium and strontium carbonate. Much work has centered about the twin hole insulator and without a doubt it is a vital factor in the life, manufacture and performance of the tube. The insulator must have a fusion point above 2270 degrees K. It must not warp, shrink, break, decompose or interact with the tungsten at this temperature. It must also, of course, be a good dielectric at this temperature with a uniform thermal conductivity and preferably an amorphous structure. The twin holes must be uniform and evenly spaced. It was to secure an insulator having these properties that tube makers searched,

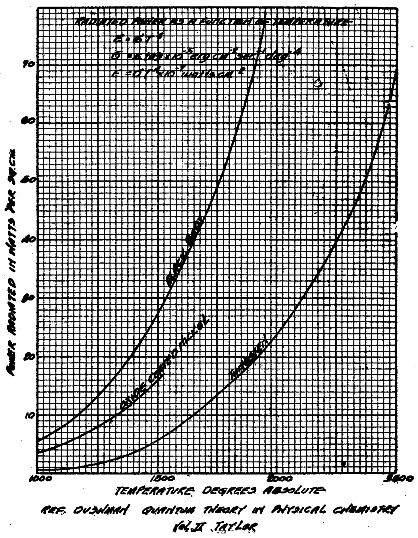

Fig. 3. Power radiation curve.

and it is only within the last six months that magnesia has been commercially available.

The Search for an Insulator

The ceramic industry had never been called upon to supply an insulator to stand up under such severe conditions, and there was surprisingly little data available. Many materials were investigated including silica, alumina, chromite, zircon, titania, thoria, and magnesia, and highly specialized technique had to be developed to extrude and fire these materials.

Production was commenced with ordinary twin hole porcelain, the laboratory life test with which indicated fair life. These life tests, however, were conducted with filament lighted continuously, and when tested intermittently to approximate operating conditions gave extremely poor life.

In order to decompose the carbonates on exhaust it was necessary to have a temperature of at least 1000 degrees K. at the sleeve, which meant that the tungsten had to burn at about 1870 degrees K. to secure the necessary temperature gradient. Now the fusing temperature of porcelain is about 1820 degrees K. so that it was practically impossible to secure good exhaust without tightly fusing the insulator around the tungsten, preventing it from moving freely. This resulted in broken and eroded filaments and the life could be estimated by the amount of fusion. This condition was controlled by the exhaust voltages as indicated by the filament current. The greater the fusion, the faster the conduction of heat from the filament and consequently the more current it would draw.

It was realized at this point that it was absolutely necessary to produce a satisfactory insulator with a much higher fusion point and in the meantime in order to supply the demand, several expedients were resorted to. The exhaust schedule was lengthened and the filament voltage kept as low as possible. The filament was coated with chromium; at first sprayed and later electro-plated. This improved the life considerably. Incidentally, considerable technique was built up in successfully plating tungsten continuously for this purpose.

The chromium acted as a getter for the water vapor in the porcelain, oxidized and thus formed a high fusion point oxide around the tungsten. This was by no means a solution, for exhaust voltages remained extremely critical and at best shrinkage was very high.

The chemical properties of alumina and magnesia immediately brought them under consideration as refractory insulating materials, but much difficulty was experienced in extruding, in finding a satisfactory binder, and in firing. A great improvement was made, however, by the production of a magnesia and magnesium silicate mixture, which had a fusion point above 1920 degrees K. With the use of this material which allowed much less critical exhaust filament voltages and of .25 per cent thoriated tungsten to give greater ductility, fair life was obtained. The problem was attacked also from another angle which resulted in opening up a very interesting field in the way of faster exhaust and better clean up.

It is well known that the addition of carbon to barium carbonate considerably lowers the decomposition temperature by approximately 400 degrees C. and this principle is used in the commercial production of barium oxide according to the following reactions:

$$BaCO3 + C \qquad BaO + 2CO$$

The author of this paper I think was the first to realize the possibilities of adding carbon to the coating to obtain this result and first studied the effects. The problem, however, was somewhat different in forming BaO when applied to filaments in vacuum as there is no oxidizing atmosphere in this case to take care of any excess carbon. Even when the carbon content was accurately calculated to interact according to this equation, erratic results were obtained. It was found that the carbon had to be added in the form of an organic salt of barium, which decomposes below 500 degrees C. with the formation of barium oxide. Evidently the carbon released below 500 degrees C. was very active and the barium oxide acted as a catalyzer in starting the reaction. This process is being used with much success to obtain high-speed exhaust. It completely eliminates trouble from gas. The carbon monoxide liberated instead of carbon dioxide makes an ideal cleaning agent to reduce possible oxidation of the elements, speeds up exhaust, the emission is increased and the carbon monoxide has a greater affinity for the getter. No doubt other improvements can be made by studying the reactions during exhaust. It is also interesting to note that no spraying of the active material occurs with the improved coating and no need arises to use mesh in preference to solid nickel. With this in mind, some manufacturers have investigated the possibility of improving over mesh, which has several objections. It is comparatively expensive; frays at the edges; it is not as rigid as strip metal; it is more difficult to process and clean up, whereas, perforated nickle which has been substituted by some manufacturers, overcomes these objections.

Tube Noise

While improvements were being made in processing and life, jigs speeded up mounting and insured accurate initial alignment, and mica spacers maintained this condition during shipment and life.

The noise factor was investigated and careful analysis made as to causes so that they could be gradually eliminated. The intermittent but persistent cackle that was characteristic with the first 427 was rather elusive, however, in checking. The intermittent nature of the noise led engineers to lay the cause elsewhere, but accurate measurements showed an intermittent discharge from the ends of the insulator.

Practically all manufacturers used a

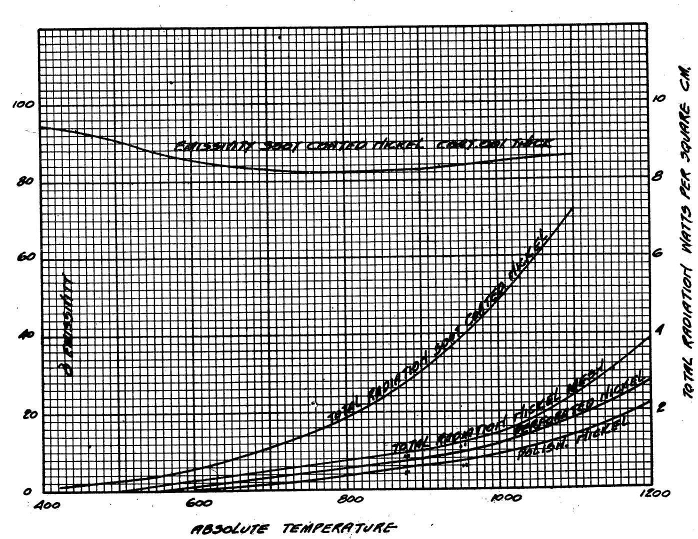

Fig. 4. Emission characteristics, various metal surfaces.

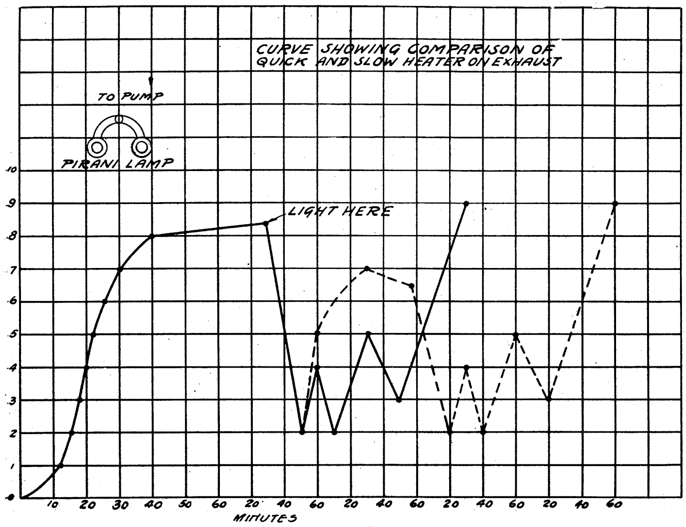

Fig. 5. Curve showing heating time.

short cathode sleeve, leaving the ends of the insulator unscreened, which were found to accumulate a charge, probably a piezzo electric effect. By completely screening the insulator with a long sleeve this cackle was entirely eliminated and the performance of the tube approached perfection.

The Alumina Insulator Not Satisfactory

About this time, research, after much effort, produced the alumina insulator. The extruding difficulties had been overcome and initial results were very encouraging. Owing to its high specific heat and fusion point, a filament was designed to burn at 1800–1900 degrees C. which condition permitted the use of a heavy, rugged tungsten hairpin. After a few hours operation, however, the tubes became distinctly noisy and investigation showed that the filament burning at 1800 degrees C. had actually interacted with the alumina reducing it to free aluminum and forming the yellow tungsten oxide. Now this oxide of tungsten gives a high vapor pressure and when formed in the tube reacts in the same way as a gas. It was found that this reaction took place above 1500 degrees C. and since at this temperature the tube would take entirely too long to heat up alumina was entirely eliminated as an insulator.

Magnesia Meets Requirements

Finally magnesia was produced and this was found to be the ideal material although tungsten will also reduce this at temperatures above 2000 degrees C. 1900 degrees C. then presents the highest temperature at which tungsten can be permitted to operate in combination with any insulator tested so far, to secure good life with good performance.

The availability of the magnesia insulator eliminated entirely the critical exhaust conditions and high shrinkages and we have now the perfected slow heater audion. We note the mica spacers, long sleeve, rigid close fitting insulator, heavy rugged filament tightly drawn, accurate spacing and clean cut construction.

The slow heating type usually takes from thirty to fifty seconds from the time of applying power to reach operating temperature, the lag depending on the thermal conductivity, specific heat, total mass of insulator, sleeve and coating and the temperature of the heating element. It is distinctly desirable and advantageous to obtain quick heating both from a standpoint of popular demand and economic production, as these curves show (Fig. 5). We see here that the time taken to heat the insulator is wasted on the pumps and pumping vacuum is costly.

The problems involved in overcoming this time lag center about the following:

1. Reduction of the mass of the insulator, either by cutting the cubical contents or decreasing the density of the insulating material or of the fired product.
2. Elimination of the insulating ceramic entirely except for two spacing plugs.
3. Development of a material with low specific heat and high thermal conductivity.
4. Securing as high a temperature gradient as possible between sleeve and heating element.
5. Reduction of mass of insulator by cutting or notching to permit direct radiation from heating element to cathode.

Several types of construction have been on the market that have been developed along these lines, but in most cases the perfection obtained in the slow heater has been sacrificed in obtaining quick heating. This is especially true when considering rigidity, and microphonic characteristics which make them wholly unsuitable for use in automobile sets or wherever the set is subject to jarring. For purposes of discussion, we can classify these types according to the method of transferring the heat from the filament to the sleeve as follows:

1. Conduction.
2. Radiation.
3. Radiation and conduction.

Under the first classification comes the tight fitting low density insulator, which is identical with the perfected slow heater except that the mass of the insulator is reduced by decreasing the density of the fired product. It is produced by mixing a bulky organic material with the regular mix to be extruded and the organic material burnt away during firing, to leave a light cellular structure. When the density is reduced to a minimum in this manner, heating time is cut to fifteen to twenty-seconds but the insulator is much weaker and harder to handle resulting in high shrinkage.

Under the second classification comes the spaced single coil, double wound spiral, spaced hairpin and it is at once apparent that this type cannot compare with the perfected type slow heater for rigidity and certainty under all conditions. The problem of preventing filament reaction is entirely eliminated and the tungsten may be operated around 2400 degrees C, thus

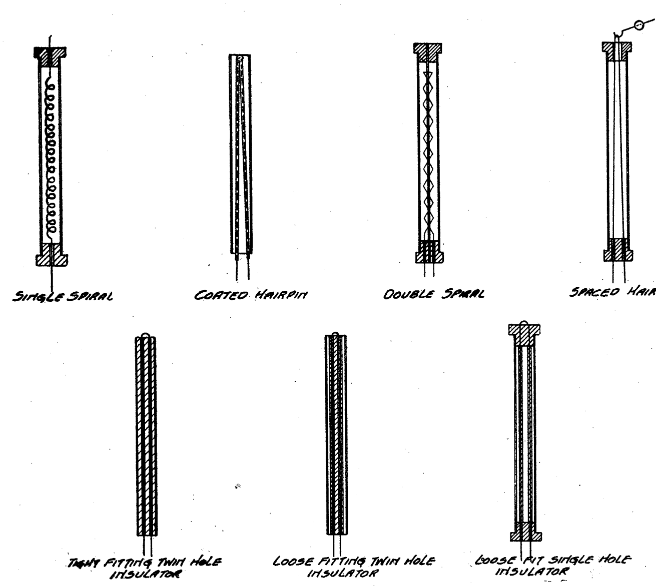

Fig. 6. Types of construction of heating filament.

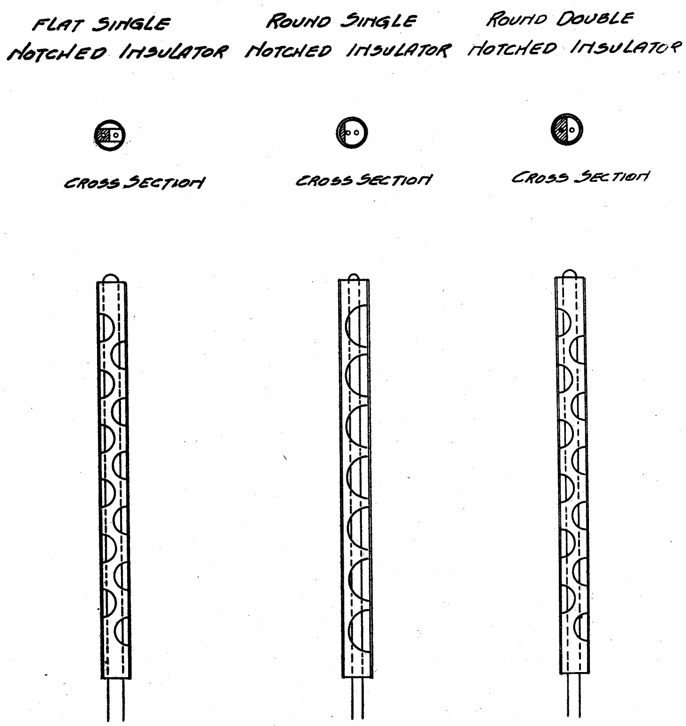

Fig. 7. Notched twin-hole insulator.

producing a very steep temperature gradient between the filament and sleeve and heating in 5 to 8 seconds. They are quite likely to be microphonic, however, and are not well adapted to production methods. This is not the only objection, however, in considering the single coil type. The concentrated coil creates a strong inductive field, which influences electronic flow, and further, necessitates an unscreened a-c. loop to complete the filament circuit. A theoretical consideration of these conditions at once suggests the possibility of hum, and actual tests show this to be the case. Many tests tend to prove that for noiseless operation, the a-c. heating circuit must be of the hairpin type or non-inductively wound spiral, and entirely screened.

The third classification includes the thinly insulated heater loosely suspended in the sleeve, the low mass, loose-fitting twin hole insulator and the loose fitting single holed insulator, all of the hairpin shaped type. Several brands have appeared using the coated wire, but here again we have to make the criticism of microphonic action and leakage between the heater and sleeve. It is a very difficult to form an insulation on a wire especially tungsten without using a low fusing binder or such product. Tungsten is subject to oxidation and embritterment at medium temperatures, and also reacts and actually reduces aluminum oxide which is commonly employed. The several types of low mass loose-fitting insulators perform fairly well but are subject to microphonic distortion of insulator and sleeve, causing shorts. They are difficult to manufacture, fragile and do not attain very fast heating. After working many months on the cathode problem, we believe that the solution is to be found in the notched or cut-away twin hole insulator illustrated in Fig. 7. This design for quick heating retains all of the desirable characteristics of the slow heater. It is rigid, free from hum and noise, non-microphonic and long lived.

The insulator is made with large twin holes, the threading of which does not create an eye hazard to the assembler. The material has a high density giving strength and rigidity, and so adjusted as to permit the exposed portion of the heater to burn at the same temperature as the covered. The high specific heat and low thermal conductivity permits the initial heating energy to be radiated to the sleeve instead of being conducted to the insulator. Heating is thus secured in 5 or 10 seconds. The heavy filament is designed to burn at under 2000 degrees C. giving a steep gradient with ample life and freedom from interaction with the insulator. Fig. 8 shows a perfected quick heater audion.

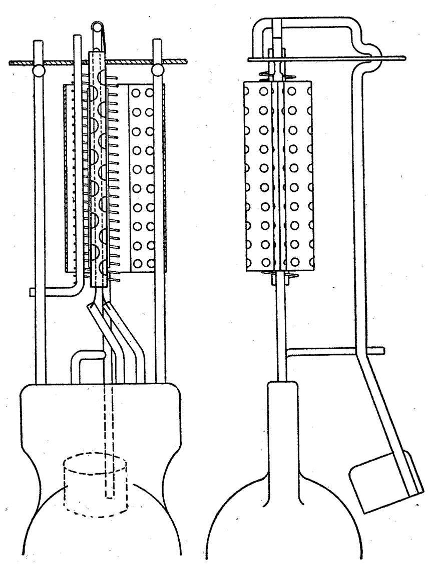

Fig. 8. Construction of perfected quick-heater audion.

It has indeed been a pleasure to trace the development of the equipotential indirectly heated cathode as applied to receiving tubes. To those who have had the opportunity to play a part in the development, the subject has been most fascinating. I sincerely hope that this visualized summary has been of interest.

▲

DISCUSSION ON AUTOMOBILE RADIO RECEIVER *

By O. H. Caldwell

Although the designers of modern automobile radio sets have incorporated every possible efficiency of pickup and have made these new dashboard sets marvels of radio sensitiveness, still the purchasers of such radio-equipped automobiles must not expect to obtain radio reception on distant roads and in vacation places far from cities, which will be comparable with the reception they get from their city home receivers.

The average car owner will perhaps make his first test of his new automobile radio on a summer noonday picnic 75 or 100 miles from home. His automobile set may have worked very well in the city within a few miles of a local broadcast station that same morning. But when he gets away off into vacation land and pulls up in a mossy dell to enjoy lunch to the accompaniment of radio music, he is likely to find "nothing in the air." Instead of radio music, he will hear only the crash and roar of static—for the radio signals from the distant stations cannot override these atmospheric bombardments.

There are vast areas of New England, New York State, the Adirondacks and other vacation regions where during summer daylight hours no radio programs whatever can be picked up,—even though, after sunset, one or two high-power stations can be faintly heard filtering through summer-night static.

The only solution for the situation confronting the automobile-radio user is higher power for broadcasting stations. Everything possible has been done by the receiving-set engineers to make the new auto sets efficient. *They will pick up anything that is in the air,* but they cannot operate on radio waves that are non-existent in the far places, or are drowned beneath a sea of static.

Any further engineering attack on the problem of the automobile receiver must be to increase the powers of broadcast stations themselves. In this way only can adequate signal strengths be laid down in the woods, mountains and lake regions. Only by higher station powers can our great outlying vacation areas be covered at all and the thousands of automobile owners who start out on radio-equipped tours this summer, be saved from inevitable disappointment.

* *June Issue of Proceedings.*

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