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Perkins Electro-Acoustic Research Laboratory. *Hand-Builders of Fine Music-Reproduction Equipment*

PEARL Tube Coolers—A Quick Start

A TUBE COOLER is a device that reduces the operating temperature of the enclosing, glass envelope of an electron tube. While some elements within the envelope are required to operate at high temperatures, a surrounding enclosure of conventional, "soft" glass is quite vulnerable to elevated temperatures. Through the action of several mechanisms described below, this weakness can result in drastically reduced tube life.

Although common knowledge in other sectors of the electronics industry for decades, this important information seems to have escaped the attention of all designers of tube-type audio gear. We have, with just one notable exception, *never* seen tube coolers factory-fitted to any audio equipment modern or vintage.

The glass envelope, which must act as a high quality vacuum container, is required to perform several functions:

- at high temperatures, it must resist the pressure differential between the internal high-vacuum and external atmospheric pressure,
- it must be chemically inert, neither adsorbing gases during manufacture nor liberating them under high-temperature operation,
- it must withstand high operating temperatures, substantial attendant temperature gradients and consequent physical stress; without failure.

The foregoing being the description of an essentially ideal material, real problems must be anticipated if soft glass is expected to successfully enclose a high vacuum over a long period under the conditions imposed by typical vacuum-tube operation.

While most glasses are quite stable at low temperatures, soft glasses become "porous" and begin to outgas with temperature increases. ***Where long working-life is a primary consideration, over-temperature operation is the main reliability issue encountered in the operation of soft-glass enclosed vacuum tubes.***

Tube manufacturers, the military and many large, commercial users have long been aware of the hazards of such operation and the benefits of reductions in bulb reduction. In particular, tube makers are well aware that tube life is an inverse function of bulb temperature.

The MULLARD OSRAM VALVE CO. in England printed the lettering and the *Gold Lion* logo on their famous KT 66-77-88 series with a temperature-sensitive lacquer that would change colour on any tube run over-temperature. Tubes run too hot were then permanently indicated to be *"…unsuitable for further reliable service"*.

The basic concept of glass envelope tube cooling was developed in the 1950s by International Electronic Research Corp. of Burbank, California working in conjunction with several branches of the US military, Cornell University Engineering Laboratories, various tube manufacturers and numerous large corporations. As a result of extensive research into causes of equipment failure and the remedies required, a large number of technical articles appeared in the literature of the period. Using this substantial and well documented body of work as a starting point, PEARL has developed a new and highly efficient type of cooler for simple, straightforward, retrofit installation to most existing audio equipment.

A BRIEF HISTORICAL OVERVIEW

With increasing equipment complexity during and after WW II, the causes of equipment failure came under intense scrutiny from a number of agencies. The commercial airlines in the USA formed and maintained the non-profit organization, Aeronautical Radio Inc. (ARINC) to coordinate the development of electronic equipment for their use, both ground and airborne. The military in particular, became very dissatisfied with the overall rate of equipment failure it was enduring. The cost of the ongoing maintenance effort required to keep its vast quantities of equipment safely and reliably operational grew to enormous proportions. Seeking to alleviate these problems, numerous tube manufacturers were contracted to produce studies that would detail the reasons for equipment failure in general and tube failure in particular. The consensus of this work was that while resistor and capacitor failures accounted for approximately 7% of failures, an amazing 75% of failures were due to tubes. Subsequent, detailed investigations carried out by numerous, widely separated researchers revealed that tubes will fail in a radically premature manner when forced or simply allowed to operate at excessive bulb temperatures. A study of over 150,000 tubes of 20 different types undertaken by ARINC lists a number of procedures that increase the reliability of vacuum tubes. Foremost amoung these measures is the operation of tubes in a manner that reduces bulb temperature.

In order of decreasing adverse effect on tube life, excessive bulb temperature causes:

- the evolution of gas within the tube, which causes the steady reduction of transconductance. Left unremedied, this process can cause the tube to glow with a lovely electric blue colour while acting as a forward biased diode.
- in part, the development of an interface resistance between the surface of the nickel tube that forms the body of the cathode and its electron emitting oxide-coating. This effect is partially the result of over-temperature operation of the cathode and can be caused by:
  - excessive filament current,
  - excessive overall operating temperature,
  - in some types, long periods of operation in a cut-off condition resulting in the development of such a high value of resistance that current flow will not restart when the tube is biased so as to resume current flow. This was a problem with the famous ENIAC (Electronic Numerical Integrator and Computor) developed as part of the Manhattan Project during WW II. Special tube types, 6SN7GTB & 5692 for example, were developed for such applications. Interface resistance is also responsible for reductions of transconductance.
  - grid emission, a prime factor in the noise increases seen as tubes age. A slow accumulation of cathode material on the grid wires initiates an ever increasing, low-density electron flow from the grid to the plate. Flowing from ground through the grid resistor, this fluctuating current develops a noise voltage that appears between the grid and signal-ground. Being thereby applied to the input of the tube in the usual way, this noise voltage is likewise amplified in the usual way.

  By parts, the deposition process is an outcome of the *water cycle* operating in tubes run over-temperature (described later in this article) and also the result of full B+, cold-cathode startups.
- cathode poisoning, resulting in a premature reduction of electron emitting capacity (perveance). One group of researchers states that:

  "*A new and unexpected source of cathode poisoning gas is seen to derive either directly or indirectly from the heated glass envelope. Such gas is more destructive in action than any of the normal gas so far examined This gas is believed to be water vapour which has been shown to have dire effects on cathodes operating in the vicinity of 725°C.*"
- migration of both the getter patch and unflashed getter material, another likely result of the water cycle.
- interelectrode leakage, whereby voltages impressed upon specific elements within the tube wrongly appear on other electrodes. This can be caused by water cycle induced migration of conductive getter metals onto the insulating micas and to the base of the envelope, where the pins exit the tube, causing lowered resistance among the tube's elements.
- contamination, resulting in tiny bits of material coming adrift within the envelope.
- glass failure, with attendant loss of vacuum if not outright failure.
- increased grid temperature that can result in increases in the normal thermionic emission from control grids. In poorly designed circuits this effect can cause *grid runaway*, where normal grid bias is lost and plate current rises to saturation levels in an uncontrolled manner. The typical outcome is the rapid demise of the tube in question.

The glass envelope of a tube presents a significant resistance to the flow of heat from the tube. Glass is a very poor thermal conductor and is virtually opaque to thermal radiation at temperatures below 400°C. Consequently, a glass envelope absorbs nearly all of the heat radiated from the elements contained therein with the result that a hot- spot occurs in the glass adjacent the centre of the plate, the hottest part of the the tube structure. This hot-spot causes a substantial temperature gradient along the length of the envelope that can result in the centre of the envelope running 25 to 100°C. hotter than either of the cooler ends. This creates enormous physical stress within the glass and in extreme cases can result in failure.

An interesting piece of work done by Rogers Majestic Co. of Toronto in 1933 suggests a mechanism whereby something like *atomic osmosis* occurs at high glass temperatures. The hypothesis is that the sodium in the glass becomes mobile and acts as an *electrolyte* thereby facilitating the bodily migration of atoms of atmospheric oxygen through the glass and into the tube. These reduce the usable life of the cathode by combining with its electron-emitting surface, creating oxides that reduce its effectiveness. It is likely that other gases evolve from this poisoning action and these can adversely effect the hard vacuum upon which the tube relies for linear and effective operation.

Noted by workers in the incandescent lamp industry is the fact that glass envelopes will begin to outgas into the evacuated volume when the surface temperature exceeds 100°C. The evolution of gas is bought about by chemical decomposition and release of adsorbed molecules which are, principally, water vapour, carbon dioxide and nitrogen. With further increases in temperature this process dramatically intensifies and usable life is sharply reduced by the initiation of a *water cycle* described below.

Water vapour is dissociated by the hot internal elements within the lamp or tube into hydrogen and oxygen. As well as reacting with the cathode material of the tube, the oxygen will react with the other metallic surfaces such as the getter patch and any unflashed getter material, with some of these areas being hot enough to blow off an oxide that can then deposit on various cooler surfaces. Meanwhile, the highly reductive hydrogen migrates to the deposit, reduces it—liberates the oxygen from the oxide—and leaves the deposit as recombined water vapour ready to begin the cycle all over again.

In its ionized form, the hydrogen acts to reduce the electrical resistivity of the vacuum by turning it into a partially conductive medium, thereby subtly, yet continuously, decreasing the tube's ability to accurately control electron flow through itself.

While gas penetration and out-gassing are significant mechanisms by which the vacuum is spoiled, excessive temperatures can cause various gases to evolve from the elements within the tube structure itself, particularly from the plate. We suspect that these actions are responsible for the slight dimunition in sound quality often heard from tubes run too hot during the first few hundred hours of life even though conventional "usable life testing" will indicate that the tube is fine. It must be stressed that the various mechanisms of deterioration can operate as a higher-order exponential function of temperature increase. If the tube hot spot temperature is reduced 25 to 150°C. the rate of these various contaminating and poisoning actions can be reduced 2 to 50 fold. In other words, *small decreases in bulb temperature often result in seemingly disproportionately large increases in tube life.* In dozens of studies, tube life has been shown to dramatically increase as overall bulb temperature is reduced. However this must be achieved by means that substantially eliminate the temperature gradient along the bulb length. For this reason simple fan cooling, while effectively reducing the ambient temperature within equipments (and thus the *average* temperature of the envelope), cannot approach the results obtained by a properly designed tube cooler.

We spent 18 months researching the effects of glass temperature reduction and the development of our present coolers resulted from that work. We consider this project to have been successful in that the sorts temperature reductions and gradient elimination repeatedly shown to substantially increase tube life have been achieved.

Numerous military, institutional and commercial studies involving thousands of tubes in scores of operating environments and conditions have shown that bulb temperature reductions on the order of those achieved by Pearl coolers yield tube life in the many thousands of hours. While many of these studies showed increases in tube life of 5 to 50 times, none showed improvements less than a *doubling* of previous life.

Illustrative of the sort of reliability gains obtainable by reducing bulb temperature is a study undertaken Arinc. This was a two year long field observation of an equipment using 6-6005 miniature tubes. Prior to the commencement of the study, the average-tube-life was under 1000 hours. By simply outfitting the gear with heat-dissipating tube shields the average-tube-life skyrocketed to 12,000 hours.

Several manufacturers of audio equipment list the expected life of power amplifier output tubes in the 1-2000 hr. range. By the simple application of tube coolers these short life expectancies can be at least doubled. Being a low-cost, reusable, one-time investment, tube coolers can yield substantial savings, not only in tube replacement costs but by way of a reduction in concern over the condition of the tubes in ones equipment. With tubes, particularly the fine NOS types, and tube gear fetching considerable sums, no one's needs are well served by ongoing tube deterioration and the need for costly tube replacement every year or two.

All Pearl tube coolers consist of an accordian-pleated, blackened copper sleeve, an inner, heat conducting and vibration damping carbon fiber sleeve and two high temperature resistant o-rings. These are seen in Fig. 1 to the right.

To fit a cooler onto a tube we recommend that the component parts of the cooler be pre-assembled as shown in Fig. 2 below.

That done the cooler assembly can be held in one hand while the tube is carefully inserted into the carbon fiber sleeve, being sure put a finger over top of the cooler to keep the carbon fiber sleeve from being pushed out by the tube. Typically, it takes a little practice to get this right so if you have some difficulty be patient and try again.

Once the tube is started into the cooler, the tube and cooler slide together quite easily. It then remains to adjust the o-rings' position to give a good appearance.

Both the pleated, blackened copper sleeve and the inner, carbon fiber damper are electrically conductive so be certan that neither comes in contact with any part of the electrical circuitry.

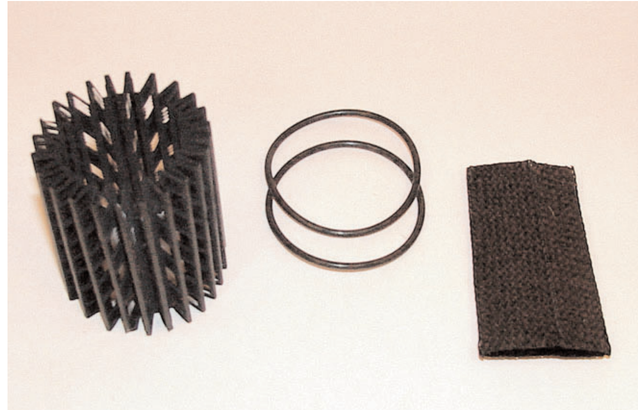

Fig. 1. The components of a PEARL tube cooler are shown above.

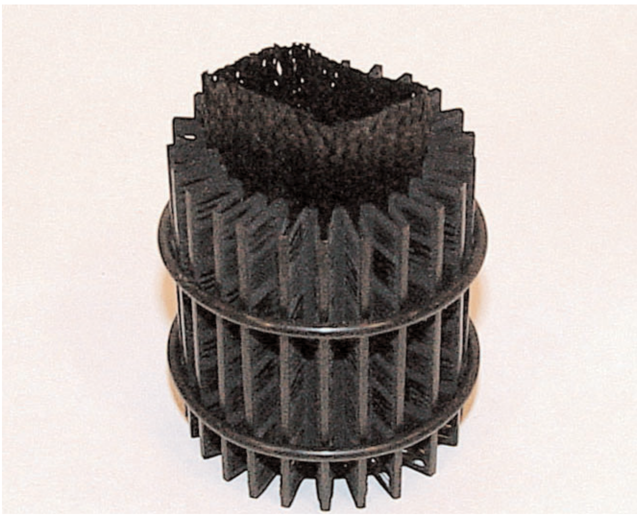

Fig. 2. Prior to fitting, assemble the components as shown.

Fig. 3. Start the tube into the sleeve first, being sure not to push it out of the cooler. If necessary put a finger at its top end . . .

Fig. 4. Here, the cooler and sleeve combination can be seen properly fitting onto the tube.

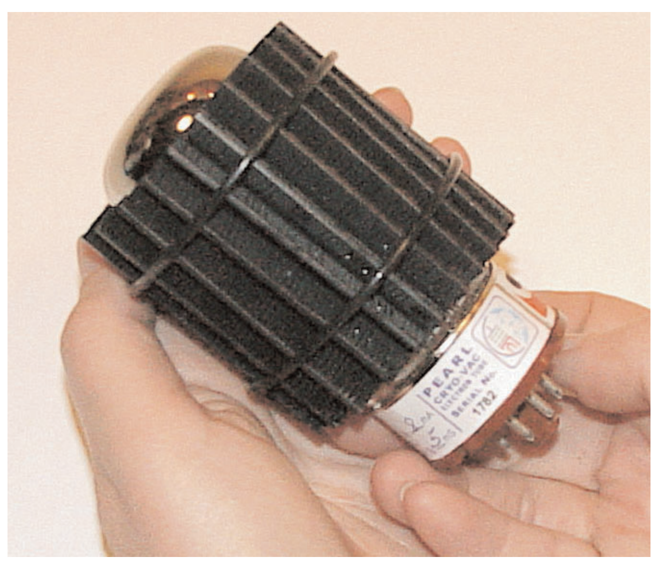

Fig. 5. Having centered the cooler/sleeve on the glass envelope, adjust the o-rings for a good appearance and insert into your gear.