Communications & Power Industries
microwave power products division

APPLICATION NOTES

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MEASURING TEMPERATURE OF POWER-GRID TUBES

OVERVIEW

Before completing any design employing power-grid tubes, EIMAC recommends that temperatures be checked in critical areas, such as metal/ceramic seals and (except for water-cooled types) areas adjacent to the anode cooler, just above and below the cooling fins. Another critical area on many medium and large tubes with coaxial design is the central part of the base, which is often recessed and may need special cooling provisions. Contact to the tube terminals is usually made by copper-beryllium fingerstock, material that must not exceed 150°C for any extended period of time, or loss of spring tension may result. A number of manufacturers make temperature-sensitive paints that are useful for checking temperature in these areas. Conventional temperature-measuring techniques that employ physical contact (such as thermocouples or temperature probes) may be adversely affected by the radio-frequency energy often concentrated in the tube and nearby components; and since all power tubes operate at high voltage, there is danger of electrical shock if any metallic device is employed.

TECHNIQUES

At least one non-electrically-conductive temperature-measuring probe has been developed.(1) It uses a special heat-sensing material located at the tip of a fiber optical cable to obtain accurate temperature measurements, but its high cost makes it primarily useful only as a laboratory tool.

Optical pyrometers using infrared (IR) emissivity are also being introduced and at first glance look attractive for measuring anode temperatures. Although these IR "point-and-shoot" instruments appear to provide an almost instant indication of temperature, they integrate temperature from a fairly wide surface area. This makes them of little value in measuring spot temperatures such as found at ceramic/metal seals on power grid tubes. Most of the inexpensive IR pyrometers presently available are inaccurate below 300°C and they must be calibrated often.

When a temperature-sensitive paint is to be used for measurement of temperature on a power tube, consider that many of the areas of concern are vacuum seals involving relatively thin metal, and it is important the indicator material be noncorrosive. Tempilaq-G©(2) is a phase-changeable paint that meets this requirement; it does not require any calibration, and the accuracy is said to be within a few percent over the life of the material (that is, until it dries in the bottle). Because the appearance of the lacquer is altered permanently after it reaches a specified temperature, an inspection (normally after the tube has cooled off), can visually determine whether the area where the paint was applied has reached or exceeded a known temperature.

Reliable temperature measurements can be made with Tempilaq-G, provided it is applied in very thin coats and over small areas of the surface to be measured. As supplied, it is too thick for use in the presence of forced-air cooling. It should be thinned using only the thinner recommended by the manufacturer, and it may be applied with an airbrush or atomizer through a paper mask to limit the area covered (the amount required to produce a reliable indication is negligible). This is particularly true when making measurements in the presence of forced-air cooling or on glass envelopes where radiant heat may be intercepted by the phase-changing paint.

A convenient set of equipment for making measurements with these temperature-sensitive lacquers is an atomizer with several airtight vials, each containing thinned lacquer for a given temperature. One vial may be filled with thinner for cleaning the atomizer (contact Tempil, Inc. for information on appropriate thinners.)

Temperature-sensitive crayons, available from Tempil, Inc., can be used in some cases. The available special temperature-indicating tapes are generally not useful with tubes where rf energy is involved.(3)

SIGNIFICANT CONSIDERATIONS

Considering the importance of tube temperatures, all design engineers should become familiar with the use of these materials. All power tubes carry an absolute maximum temperature rating for the seals and envelope and, in the case of an external-anode, forced-air-cooled tube, for the anode core itself. Operation above the maximum ratings can cause early tube failure, and where long life and consistent performance are factors, it is normally desirable to maintain tube temperatures comfortably below the rated maximum temperature.

The owner of equipment using either large or small power tubes has the ultimate responsibility of ensuring the tubes are operating within ratings (temperature being one of the most important) and that a phase-change indicator, such as Tempilaq-G, is readily available to verify this. Some power tubes have glass envelopes and an internally mounted anode; high anode temperature can be visually noted, a warning the envelope and seals may also be at a dangerous temperature. Most modern tube designs use a ceramic envelope and an external anode, where a darkened or black cosmetic plating caused by oxidation may be the only visible sign of excessive temperature; at this point, however, significant damage may have already occurred.

Developers of equipment that use power-grid tubes should take into account worst-case cooling, such as reduced airflow (or water flow in the case of liquid-cooled tubes) caused by filters that become partially plugged over time.

A good design program will test an entire electronics system at elevated temperatures anticipated under adverse conditions. An example is broadcast and communications equipment that may be housed in remotely located shelters, where air temperature can reach 50°C (122°F) if air conditioning is not present. By operating tube-based equipment in a small tent or sealed room and allowing the air to be gradually self-heated as it is recycled, conditions similar to those that may occur in the field can be established. Using temperature-indicating paint at appropriate points on a tube while it is operated under these conditions will indicate whether sufficient airflow is being provided to maintain seal temperatures well below 250°C, the typical absolute maximum temperature rating for most power-grid tubes. It should be noted that a few power-grid tubes use solder to attach filament leads, and these tubes have a maximum rating of 150°C at those points. This type of conservative design testing has been adopted by manufacturers of MIL-spec and high-quality commercial equipment and should be considered before committing a new design to production. This type of exhaustive testing helps ensure that tube life will not be compromised when used under extreme environmental conditions.

A thorough test method will first require selecting several temperature-indicating paints. Specific temperatures of 177°C, 184°C, and 191°C (350°F, 363°F, and 375°F), being actual Tempilaq-G products, will allow for a margin that ranges from 73°C down to 50°C below the absolute maximum rating. Since the actual operating temperature may vary somewhat around the outside diameter of a tube's anode cooler, it is suggested that small amounts of the selected paints be placed in groups at four quadrants. A simple sketch that indicates the location of these paints will be useful later as a reference after the tube has been operated and an inspection is performed to see whether any phase change has occurred. Other temperatures available in Tempilaq-G are 204°C, 218°C, 232°C and 253°C (400°F, 425°F, 450°F, and 487°F). The 253°C paint is especially useful, as it will indicate whether or not temperature has exceeded the maximum rating of 250°C.

Where there is any doubt whatsoever as to the adequacy of cooling for a power tube, EIMAC highly recommends the use of the materials and techniques discussed above for temperature verification.

NOTES:

(1) Luxtron Corp., Santa Clara, CA.

(2) Tempilaq-G© is available from laboratory supply houses and is manufactured by Tempil, Inc., 2901 Hamilton Blvd., South Plainfield, NJ 07080 (see their website: http://www.tempil.com for additional information).

(3) Some reports regarding temperature-sensitive labels indicate that under the presence of rf fields at VHF, one or more of the indicators may change as a result of rf heating, not due to thermal heating. The label form of temperature indicator should be evaluated carefully if used in or near rf fields. Lacquer-based indicator paints, such as Tempilaq-G©, have been used reliably on power-grid tubes since their introduction.

SUPPLEMENTAL INFORMATION

The following material was written by E. Kimmel, director of research and development for Tempil, Inc., and was published March, 1983, in "Heat Treating Magazine":

> When a crystalline solid is heated, a temperature will be reached at which that solid changes sharply to a liquid. This melting point has a definite, reproducible value that is virtually unaffected by ambient conditions that may cause errors in other temperature-sensing methods. For example, fusible temperature indicators are applicable in induction heating and in the presence of static electricity or ionized air about electrical equipment, where electrical means of measuring temperatures often function erratically.
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> The most popular of the fusible indicators is a temperature-sensitive stick of calibrated melting point, a stick closely resembling a crayon. These crayon-type indicators are made in 100 different specified temperature ratings in the range of 100°F to 2500°F; each has a temperature-indicating accuracy within one percent of its rating. The workpiece to be tested is marked with crayon. When the workpiece attains the predetermined melting point of the crayon mark, the mark instantly changes from a solid to a liquid phase (liquefies), notifying the observer that the work-piece has reached that temperature.
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> Under certain circumstances, pre-marking with a crayon is not practical. This is often the case when (1) a prolonged heating period is experienced, or (2) if the surface is highly polished and does not readily accept a crayon mark, or (3) the material being marked is one which gradually absorbs the liquid phase of the crayon. In such instances, the operator strokes the workpiece with the crayon frequently. The point at which the surface achieves the desired temperature is determined by noting when one ceases to make dry marks, and begins to leave a liquid smear.
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> A similar procedure can be employed to indicate temperature during a cooling cycle. A melted mark, on cooling, will not solidify at the exact same temperature at which it melted,

so solidification of a melted crayon mark cannot be relied on for temperature indication (as you might expect).

For another form of application, a phase-changing fluid—a fusible temperature-indicating lacquer—offers the greatest flexibility. This lacquer-type fluid has a solid material of calibrated melting point suspended in an inert, volatile nonflammable vehicle. As with crayon-type indicators, there are 100 different temperature ratings, covering the range from 100°F to 2500°F; the temperature-indicating accuracy is within plus or minus one percent.

The lacquer is, supplied in the proper consistency for brushing. If spraying or dipping is desirable as the mode of application, a special thinner is available to alter the viscosity without impairing the temperature-indicating accuracy.

Phase-changing lacquers are often used when a very smooth or soft surface is to, be tested, or in instances where the surface is not readily accessible for application of a crayon mark during the heating process. Within seconds after application, the lacquer dries to a dull matte finish, and responds rapidly when the temperature to be indicated is reached. The response delay of a lacquer mark is only a fraction of a second. This time can be reduced to milliseconds by applying a mark of minimal thickness.

Upon reaching its temperature rating, the lacquer mark will liquefy. On subsequent cooling, however, the fluid will not revert to its original un-melted appearance but, rather, to a glossy or crystalline coating, which is evidence of its having reached the required temperature. Temperature indicating lacquers, upon cooling, will not re-solidify at the same temperature at which they melted.

If spraying of the phase-change lacquer is to be the sole means of application, the operator may find it more convenient to use the aerosol-packaged form of this material. An aerosol phase-change temperature indicator is identical to the brush-on material in performance and interpretation. The aerosol packaging is particularly useful in such operations as the non-destructive testing of honeycomb panels and the monitoring of the operating temperature of reaction vessels. The first commercial form of the fusible indicator was the pellet, which continues to be useful in certain applications. Pellets are most frequently employed when extended heating periods are involved, or where a greater bulk of indicator material is necessary. They are also useful when observations must be made from a distance and when air-space temperatures are to be monitored. A typical application is the monitoring of heat zones in furnaces. Phase-change temperature-indicator pellets are available in flat tablets, 7/16-inch in diameter and 1/8-inch thick. For special applications, miniature pellets, 1/8-inch x 1/8-inch, are also available. The range of 100°F to 2500°F covered by the crayon and lacquer-type is also covered by the pellets and, in addition, pellets may be obtained whose coverage extends up to 3200°F. For temperature measurements in hydrogen, carbon monoxide, or other reducing environments, a special series of pellets is available.

Another variation of the phase-change indicators is the temperature-sensitive label. These adhesive-backed monitors consist of one or more heat-sensitive indicators sealed under transparent, heat-resistant windows. The centers of the indicator circles turn from white to black at the temperature ratings shown on the label. The change to black is irreversible, representing absorption of the temperature-sensitive substance into its backing material. After registering the temperature history of the workpiece, the exposed monitor label can then be removed, and affixed to a service report, to remain part of a permanent record. Fusible temperature indicators have at least three major advantages over other methods of determining surface temperature: First, the temperature indications obtained are unquestionably those of the surface being tested. There are no problems of equilibrating a relatively massive probe with the surface, or conducting heat away from the region being tested, or of correlating the values obtained with actual surface temperature. Second, there is no delay in obtaining a signal. Because a mark left by a crayon or a lacquer is of extremely small mass, it attains rapid equilibrium with the surface. There is no conduction of heat away from the surface, which prolongs response time and results in erroneously low temperature readings. Nor is there any dependency on the duration of heating.

Third, the technique is simple and economical. Determination of surface temperature by most other means requires a technical competence and skill and, in many cases, sophisticated instrumentation. Accurate surface temperature readings can be obtained with fusible indicators with little effort, training and expense. There are numerous instances, particularly in determining heat distribution, in complex systems, in which the relative simplicity of fusible indicators make surface temperature investigations feasible.