e2v technologies

Triodes Preamble

The e2v technologies range of power triodes consists mainly of external anode tubes which are designed for broadcast transmitter service or industrial heating. Most of the types are available with a choice of forced-air or water cooling and some with vapour cooling. All current designs use thoriated tungsten filaments.

CHARACTERISTICS

1. The amplification factor μ indicates the change in anode voltage resulting from a given change in grid voltage, at a constant anode current.

   $$\mu = \frac{\text{change in anode voltage}}{\text{change in grid voltage}} \quad \text{for constant anode current.}$$

   $$\mu = \frac{dV_a}{dV_g} \quad \text{for } I_a \text{ constant.}$$

2. The mutual conductance g_m is the change in anode current resulting from a change in grid voltage, for a constant anode voltage.

   $$g_m = \frac{dI_a}{dV_g} \quad \text{for } V_a \text{ constant.}$$

   g_m is usually measured in mA/V and varies with anode current so that the conditions under which it is measured need to be quoted.

3. The anode resistance R_a is more often used for small tubes and is the change in anode voltage resulting from a change in anode current for a given grid voltage.

   $$R_a = \frac{dV_a}{dI_a} \quad \text{for } V_g \text{ constant.}$$

   From the above, the inter-relationship between g_m and R_a can be seen, i.e.

   $$\mu = g_m \times R_a \qquad \frac{dV_a}{dV_g} = \frac{dI_a}{dV_g} \times \frac{dV_a}{dI_a}$$

   g_m and R_a vary by a factor of 2 or more depending on the value of voltage and current at which they are measured.

4. Sometimes the perveance is quoted. For a triode under space charge limited conditions,

   $$I_k = I_a + I_g = G\left(V_g + \frac{V_a}{\mu}\right)^{3/2}$$

   Thus the perveance is defined as

   $$G = \frac{(I_a + I_g)}{\left(V_g + \frac{V_a}{\mu}\right)^{3/2}}$$

   It is usually measured in $mA/V^{3/2}$

   In a triode the perveance is proportional to the cathode area and inversely proportional to a power of the grid to filament spacing.

5. The current division ratio D is defined as

   $$D = \frac{I_a}{I_g} \times \left(\frac{V_g}{V_a}\right)^{1/2}$$

   over the range of V_a from V_g to 4 x V_g

This is little used in practice but is important in the design of tubes as the efficiency of operation falls if the division ratio becomes too low.

The values of μ and g_m given in tube data sheets are average values and small differences may be expected from tube to tube which will not affect their operation.

COOLING METHODS

When a tube is operating, some of the input power is dissipated within the tube. Most of this is at the anode but some power causes the grid and filament connections to heat up.

For anode dissipation levels below approximately 1.2 kW, the anode may be inside the vacuum envelope and be cooled by radiation. In these cases there needs to be unimpeded access for the air to cool the envelope. In some cases where a higher rating is required, forced-air cooling of the envelope is used. It is always good practice to use higher airflows to give a margin of safety as those quoted are minimum values.

At higher power levels and in certain low power levels with small overall dimensions the tubes are designed with the anode forming part of the external vacuum envelope. This allows direct cooling of the anode by forced-air, water or vapour. In addition to the anode cooling it may be necessary to provide local air cooling for the filament and grid seals (see the tube data sheet).

Where tubes are operated with less than the minimum recommended cooling, it is likely that the operating life will be shorter. In extreme cases the tube will overheat and will cause an early failure. It is good practice on many of the larger tubes to continue the cooling for several minutes after the power has been switched off. Temperature sensitive indicators can be used to check that the maximum permissible temperatures, as indicated by the data sheet are not exceeded.

Choice of cooling method

Forced-air These normally require no external piped supplies for cooling and in general the method is cleaner, though it may take more space. It is more noisy than water cooling which may be a deciding factor in some locations. Air filters are often necessary and under dirty conditions these should be cleaned frequently, with care taken to ensure they are fitted back in the correct direction (usually indicated by an arrow on the side of the filter).

Water These tubes are less costly than similar air cooled tubes but the running costs may be higher. Unless a recirculating water system is used with high purity water then it may be necessary to descale the tube and jacket especially where poor quality water is used. A water cooled equipment generally takes less space than a similar air cooled one.

e2v technologies limited, Waterhouse Lane, Chelmsford, Essex CM1 2QU England Telephone: +44 (0)1245 493493 Facsimile: +44 (0)1245 492492
e-mail: enquiries@e2vtechnologies.com Internet: www.e2vtechnologies.com Holding Company: e2v holdings limited

e2v technologies inc. 4 Westchester Plaza, PO Box 1482, Elmsford, NY10523-1482 USA Telephone: (914) 592-6050 Facsimile: (914) 592-5148
e-mail: enquiries@e2vtechnologies.us

© e2v technologies limited 2003

Vapour This method is able to handle very high powers and in some cases a vapour cooled tube has higher anode dissipation ratings than the air or water cooled version of the same type. This can be of value in industrial applications. Noise, maintenance and running costs are less but the level of demineralised water will need to be maintained periodically.

FORCED-AIR COOLING

Those tubes which are forced-air cooled have finned radiators fitted to the anode, through which the air is sucked. It is recommended that the air is drawn through the radiator fins, away from the filament and grid connections. The tubes can also be cooled with the air blown in through the base of the radiator and up past the filament connections. However this does suffer the disadvantage that hot air is blown onto the grid connection and into the equipment, which may cause overheating of other components. If the air is directed this way, it is recommended that the airflow be increased by approximately 20%.

Information is given on each tube data sheet for the airflow required for various values of anode plus grid dissipation at different air inlet temperatures. Also values of air pressure drop across the radiator are given for various flow rates. These should be used primarily in the selection of a fan or blower and not for exact measurements of anode dissipation.

In deciding the pressure drop required in selecting a fan, remember to take into account the rest of the pressure drops in the system (i.e. air ducting, bends, sudden changes in cross section and air filter)[1][2].

The tube should be seated in an insulating duct and be protected from any vibration from the blower. This can be done by fitting a length of flexible ducting in the ducting to the tube.

The airflow through the radiator may be measured in the following way:

a. Measure the pressure drop across the radiator by using a water manometer connected into the air duct close to the radiator on the blower side.
b. Run the tube under dead loss conditions, i.e. no RF drive or not oscillating. The anode dissipation can be controlled by applying a negative voltage to the grid to adjust the anode current or by varying the anode voltage. See the tube curves in the data sheet for suitable values. Start with a low anode dissipation and increase in steps to approximately 80 to 90% of the maximum dissipation. At each step note the air inlet temperature, air outlet temperature from the radiator, pressure drop across the tube and the anode plus filament dissipation.
c. The airflow can then be calculated from

$$\text{airflow (ft}^3\text{/min)} = \frac{T_{in}\text{ (K) x (Anode + filament dissipation (W))}}{\text{164 x temperature rise across the radiator (°C)}}$$

$$\text{i.e. Q (ft}^3\text{/min)} = \frac{(T_{in} + 273) \times (P_a + P_f)}{164 \times (T_{out} - T_{in})}$$

The airflow rates quoted in the data sheets are for sea level only. At higher altitudes the air density decreases and to maintain the same mass airflow, higher volume air flow rates are required. Air blower performance will vary with altitude also, so consult with the blower manufacturer for details on this.

The airflow rate for an altitude where the pressure is B mbar, the power in W, and T_{out} and T_{in} are in °C, is:

$$\text{Airflow (ft}^3\text{/min)} = \frac{6.021\ (T_{in} + 273) \times (P_a + P_g)}{(T_{out} - T_{in}) \times B}$$

It is recommended that the inlet air is filtered before flowing through the radiator and that the filters are regularly checked. The inlet air should also be free of corrosive fumes including exhaust gases.

Protection

The anode and filament supplies should be fitted with protection circuits to prevent the application of power until there is sufficient airflow. These circuits should also remove power in the event of:

i. The airflow falling below a set minimum
ii. Excessive air inlet temperature or excessive air outlet temperature
iii. Failure of the main blower motor or of the filament seal blower if fitted.

Some larger air cooled tubes have the facility for fitting a thermal fuse which can operate a relay when the anode temperature exceeds a given maximum. This relay should remove the anode and filament voltages. The recommended thermal fuse is listed where applicable in the data sheets.

WATER COOLING

Water cooling is normally used for the anode only and a small air blower used for the filament terminals. For some of the high power tubes water cooling of the filament connectors may also be used.

Some older designs require a separate water jacket. This is usually a casting and is a permanent part of the cooling system. The tube is held by a clamping ring onto an O-ring seal.

Most water cooled tubes are fitted with an integral water jacket. The water jacket or the anode have helical grooves which channel the water from the bottom of the anode to the top, past the anode flange and then back to the outlet connection. To avoid air locks the water must enter at the bottom of the anode. Where the connection inlet is not clear, the connections are marked 1 and 2 and the data sheet indicates that 1 is the inlet for anode down and 2 the inlet for anode up.

Water Connection

As the anode and water jacket are operating at a high voltage, an insulated mounting is necessary for the jacket and it is also necessary to use either insulating carbon-free hose or Durapipe or an equivalent. This should be sufficiently long to reduce the leakage current through the water to an acceptable level. A length of 1 metre per kV of anode voltage should be adequate. If shorter lengths are used then the electrolytic corrosion caused by higher leakage currents may be significant. The leakage current will depend on the pipe bore and length and also on the conductivity of the water. If very pure water is used the insulating pipe length may be reduced considerably. Some systems use demineralised water for cooling the tube and here the water is then cooled in either a water to mains water or water to air heat exchanger. The closed circuit system requires a continuously operating pump, and a covered reservoir as well as the heat exchanger.

© e2v technologies

Water Purity

To avoid a build-up of lime scale on the jacket or anode and to avoid blocking the water channel it is important to use high purity water. This should have a resistivity of greater than 3.3 kΩcm, an inorganic solids content of less than 30 parts per million and a low dissolved oxygen content. If low resistivity water is used then considerable corrosion and scaling will occur. It is preferable for the resistivity to exceed 10 kΩcm.

To clean a water cooling system from scale formation a 10% citric acid solution should be used. It is left in the system for a few hours to react with the lime scale and then thoroughly washed out.

Flow Rate

The flow rate, temperature rise and dissipation are related by the following expression:

$$\text{Water flow (l/min)} = \frac{15 \times (\text{anode} + \text{filament dissipation (kW)})}{\text{temperature rise across the jacket } (^\circ\text{C})}$$

$$\text{i.e.} \quad \frac{15 \times (P_a + P_f)}{\Delta T}$$

Protection

The anode and filament supplies should be fitted with protection circuits to prevent the application of power until there is sufficient water flow. These circuits should also remove power in the event of:

i. Water flow falling below the minimum

ii. Excessive outlet water temperature

iii. Failure of the filament connector blower if fitted.

Some tubes have the facility for fitting a thermal fuse which can be connected to operate a relay when the anode temperature exceeds a given maximum. This relay should remove the anode and filament voltage. The recommended thermal fuse is listed where applicable in the data sheet.

Flow meters of a fail safe design should be used because if a differential pressure type flow meter is used, the orifice can block with water borne solids and the switch will not work in case of a water failure. Such a switch should only be chosen with a reasonably large orifice.

VAPOUR COOLING

A separate information sheet on vapour cooling is available on request.

OPERATING NOTES

Filament Supplies

High power triodes use thoriated tungsten filaments which should always be operated at the correct voltage to maintain the correct operating temperature. As the life of the tube is primarily related to this temperature the voltage should never exceed ±5% but ±1% is recommended. A 5% increase in filament voltage will reduce the expected life by half, due to the increase in filament temperature. It is recommended that the filament voltage be measured at the tube terminals with an accurate moving iron meter or a true rms digital meter. If it is operated above, the life will be reduced and if operated too much below the correct voltage the cathode emission will deteriorate.

Switching on at full filament voltage is permissible provided that the peak surge filament current where stated is not exceeded. This value is given on most of the higher power tube data sheets, as well as the resistance of the cold filament. The surge current can be limited by using a resistance in the primary of the filament transformer which is then shorted out by a delay switch. Another method is to use a high leakage reactance filament transformer specified to limit at the peak surge current.

Both of the filament terminals should be at the same RF potential. This is usually done by connecting a capacitor with low reactance at the operating frequency across the filament terminals. The capacitor value should be chosen so that the resonant frequency of the capacitor and filament structure is clearly below the operating frequency.

Frequent switching of the filament voltage on and off may cause filament distortion and reduce the expected life of the tube. Where an equipment using the tube is to be switched off and will be operated again within one hour, it is recommended that the filament supply and related cooling supplies be left switched on. When the filament is switched off it is recommended that the cooling for the anode and terminals is maintained for 3 to 5 minutes to remove the stored heat in the electrodes.

Cathode Current

The total cathode current is the sum of the anode and grid currents. For most tubes the maximum ratings quoted are for both the mean anode current and the peak usable cathode current. The peak usable cathode current is determined by the emission capability of the cathode and if this rating is exceeded in service, the cathode life will be reduced.

GRID PARAMETERS

Grid Voltage

When the tubes are to be used in parallel or in push-pull circuits, it is recommended that each tube has a separate grid resistor and grid current metering. Even if the tubes are matched when new, unequal sharing of the load is likely to occur during life, unless the individual grid bias can be adjusted. Should this not be possible, the anode current should be derated by 10%.

Grid Current

The grid current values and ratings given in the data sheets are measured at the grid terminal. Thus the user is not required to make an allowance for the effect of secondary emission of the grid.

Grid driving power

The driving power is the sum of the powers dissipated in the grid and in the bias source.

The grid driving power may be taken approximately as the product of the peak positive value of the driving voltage and the DC grid current. The peak value of the voltage on the grid may be calculated as the sum of the bias voltage and the peak positive voltage, which may be measured with a peak reading meter.

The effective driving power may be greater than the calculated value as a result of tolerances in tube characteristics, electron transit time losses and other factors.

Anode Voltage

The anode voltage is normally supplied by a multi-phase rectifier with some form of regulation. For broadcast amplifiers smoothing filters will be required, but in most other cases the ripple content of a 3-phase full wave or equivalent rectifier is acceptable.

Anode dissipation

The anode dissipation is the difference between the anode input power and the output power. For water or forced-air cooled tubes, the anode dissipation can be calculated from the flow rate and the temperature rise of the coolant.

Output Power

The output power can be measured at several points with the lowest value being at the load. The output given in the data sheet is the total RF power developed in the anode circuit. For an oscillator, the power developed in the anode circuit less the drive power is usually quoted as the oscillator output from the anode. To estimate the output from the terminals of an industrial heating equipment,it is customary to multiply the oscillator output by 0.85. For an oscillator:

$P_{load} = \eta_a \times (P_{out} - P_{drive})$

where P_{load} = power delivered to the load

η_a = anode circuit efficiency (often taken as 0.85)

P_{out} = output power of the tube to the anode circuit

P_{drive} = drive power fed back to the grid circuit

For an amplifier the above P_{drive} is zero, as the grid drive power is not derived from the anode circuit.

Efficiency

The efficiency is the output of the tube divided by the DC input power. The values given in the data sheet are derived from calculations of typical operating conditions.

Ceramics

Care should be taken to keep the ceramic surfaces clean. In some industrial applications they can become coated with conducting dust. Where such a problem occurs, try removing this dust with a mild abrasive cleaning powder, taking care afterwards to rinse thoroughly with water and dry off.

Connectors

It is necessary to ensure a clean contact surface for all electrode connectors. They must also be a good fit to avoid hot spots due to uneven current distribution around their circumference. Make sure connectors are correctly lined up before tightening.

Protection

The tube should be protected against damage arising from a flashover by a high speed trip which rapidly removes all the electrode voltages. On some data sheets, information is given for the diameter of a piece of copper wire which can be used to test whether the voltage trip is sufficiently rapid. To do this test, remove the tube and connect a length of copper wire of the stated diameter (about 2 to 3 cm per kV of anode voltage) from the HT connection to the tube to the cathode earth. Switch on the HT and if the wire does not fuse, the trip is sufficiently rapid.

Tube Life

Early catastrophic failure is unusual in large triodes, but it may result from exceeding the ratings or mechanical shock or impact. Most of these tubes exhibit a gradual loss of emission towards the end of their life and this eventually results in the output power falling below the required level. The ratings of each tube type are chosen to give a long operating life, but in all cases the life expectancy can be considerably increased by operating at reduced anode current levels.

Maximum ratings

Unless otherwise stated, all the maximum ratings in the data are absolute ratings. To ensure a good service life and reliability, the ratings should not be exceeded under any circumstances such as might occur with mains fluctuations, surges, variable load, component tolerances or environmental conditions. Each individual maximum value has to be observed even if other maximum ratings will not be reached. The 'Absolute maximum rating system' is defined by IEC publication 134.

Maximum Anode Rating

In most cases this is an absolute rating but tubes intended for industrial use may be given a nominal rating which allows for normal mains fluctuations and component tolerances in the equipment. However the rating should not be exceeded under off load conditions. These limiting values are DC voltages and if an unsmoothed DC supply is used then a suitable derating should be applied (see page 5).

Current Ratings

The maximum anode current rating applies to the mean value of the anode current. Where a maximum grid current rating is given, this also applies to the mean value as measured by a mean reading meter. The peak usable cathode current is the maximum peak cathode current that may be used in operation. It consists of the peak anode and grid currents which may be used. Currents in excess of this figure will seriously reduce life even though the electrode dissipations may be within their limits.

© e2v technologies

Maximum Anode Dissipation

This is the maximum allowable steady anode dissipation and is determined by the permissible thermal loading of the anode. Exceeding this maximum value may lead to a loss of vacuum, melting of the anode and ultimate loss of the tube. To prevent such over-dissipation when the tube drops out of oscillation, a relay in the HT supply should remove the anode voltage in 50 ms or less. The permissible anode dissipation specified is for continuous operation and is not usually the limiting factor.

Maximum Grid Dissipation

This is the maximum grid dissipation which may be used. If this limit is exceeded the grid structure may become distorted and result in a change of characteristics, evolution of gas and grid emission which will reduce the operating life. In normal class C operation the grid dissipation is calculated from:

Grid dissipation = Grid driving power − loss in the bias source.

Maximum Frequency

The ratings for each tube include a maximum frequency above which other ratings must be reduced. In some cases information on the reduction required is given on the data sheet. For other types consult e2v technologies if operation at higher frequencies is required.

Derating Factors

When the data sheet for a tube gives ratings for Class C unmodulated operation only, and it is required to use a different class of operation the derating factors in the following table may be used as a guide.

Operating Condition	V_a	I_a	Input Power	Anode dissipation	Grid Current
Class C RF telegraphy	1	1	1	1	1
Anode modulation	0.8	0.833	0.67	0.67	1
Class B RF	1	0.833	0.67	1	1
Class A or B Audio amplifier	1	1	1	1	1

Unfiltered Power Supplies

The power supplies used in industrial oscillators often consist of the minimum essentials. The HT may be unregulated, unfiltered and even not rectified and each of these factors requires a reduction in the normal operating voltage and current levels, so that the absolute limits are not exceeded under worst case conditions. For preliminary design purposes the following table may be used as a guide to the derating factors necessary. These are relative to the ratings for Class C telegraphy.

Power Supply	Anode Voltage	Anode Current	Input Power	Anode Dissipation	Grid Current
Regulated, filtered and fully protected	0.95	0.95	0.9	0.95	0.9
No overload protection	0.8	0.8	0.65	0.6	0.8
Single phase full wave, no regulation, filtering or overload protection	0.7	0.7	0.5	0.6	0.7
Self-rectifying	0.8 (r.m.s.)	0.4	0.3	0.6	0.4

Intermittent Operation

Frequent heat cycling of the filament by switching on and off may adversely affect the life of the tube by causing distortion. Where the time when the filament will be off is less than one hour, it is advisable to leave the filament switched on.

For intermittent operation of forced-air cooled tubes it is important that the airflow used has a good margin to allow for any reduction over a period of time due to filters becoming blocked, etc.

CALCULATION OF OPERATING CONDITIONS

The method of calculating the operating conditions described here is one developed by R.I. Sarbacher[3]. It uses the constant current curves on the tube data sheet, an e2v technologies calculator and a design sheet with instructions.

The operating line or load line will be a straight line when drawn on the constant current curves. The point at one end of the load line is determined by the anode supply voltage and the grid bias voltage. The point at the other end of the line is fixed by the minimum anode voltage and the maximum grid voltage.

Selection of the load line

The cut-off end of the line may be decided easily but the other end is likely to be reached by successive approximations requiring several test calculations.

DC grid bias

The anode voltage is decided first, then the grid bias voltage chosen. For most class C operations the best results are obtained with a bias voltage of 1.6 to 2.0 times the cut-off voltage. As an approximate guide the bias voltage can be chosen as $2 \times \frac{\text{Anode voltage}}{\text{Amplification factor}}$.

Higher efficiencies are obtained if the factor 2 is increased, but care must be taken that the peak negative voltage on the grid does not become too high and cause occasional grid to filament flashover. The values chosen for the anode voltage and grid bias fix one end of the load line.

Peak Anode Current

A good method of determining the peak anode current is as follows:

a) Assume a reasonable efficiency of say 75% for an oscillator i.e. 75% of the input power becomes output power and 25% is dissipated in the anode.

b) Thus P_{in} = 4 x rated anode dissipation.

c) DC Anode current = $\frac{\text{Input power}}{V_a}$

Note that I_a and P_{in} must not exceed the maximum limits stated on the data sheet.

d) The ratio of the peak anode current to DC anode current varies from 3.5 to 4.5 depending on the angle of flow. As a starting point assume that

Peak anode current = 4 x I_a

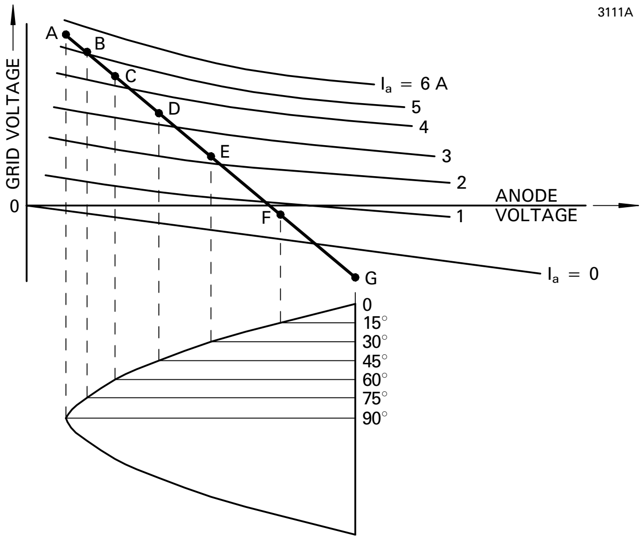
Minimum Anode Voltage

This is usually chosen as being 8% to 15% of the DC anode voltage. The peak positive grid voltage should be chosen to give the required DC anode current. Care needs to be taken to avoid choosing too low a minimum DC voltage and too high a peak positive grid voltage which results in exceeding the maximum permissible grid dissipation.

DC Anode Current

Draw the load line between the 2 points described above. The anode current can now be calculated using the e2v technologies calculator and the design sheet following the instructions on the calculator. If the result is not satisfactory then carry out another test calculation with either a different minimum anode voltage or peak positive grid voltage. When the DC anode current is satisfactory, use the calculator to determine the other parameters and compare with the maximum ratings where appropriate. The calculations give the output power for an amplifier. For an oscillator the output power will be the calculated output power of the amplifier minus the grid driving power.

How the Calculator Works



If the operating line AG of an oscillator or class C amplifier is drawn on the constant current characteristics of the tube to be used, then any point on this line will give the conditions prevailing in the circuit at that instant in the electrical cycle. Instantaneous values of the grid and anode voltages can be read off the curves at that point. If several such points A, B, C, D, E and F are considered, each corresponding to 15° intervals, then taking the instantaneous currents at these points and using them in the following formulae, the DC current over the whole cycle and the peak value of the fundamental current are readily calculated.

DC current = $^1/_{12}$ (0.5 A + B + C + D + E + F)

Peak fundamental current = $^1/_{12}$ (A + 1.93.B + 1.73.C + 1.41.D + E + 0.52F).

The e2v technologies calculator is a simple device which enables the required values to be read off curves in a simple manner. The design sheets supplied are arranged so that the current values and calculations can be written down in a logical sequence.

© e2v technologies

RECEIPT, STORAGE AND INSTALLATION

Receipt of a tube

Open the packing and visually check for any signs of transportation damage. Check the inside and outside of the pack and any shock indicators if fitted. Use a continuity meter to check for open circuit between the electrodes and for continuity of the filament. In case of any damage refer to the instruction sheet enclosed with the tube, and where necessary it is advisable to file a provisional transit damage claim with the transporter, within the time allowed for making such claims.

Lift the tube carefully from the pack. Handle with great care as thoriated tungsten filaments are fragile. Avoid knocking one tube against another or against the edge of a bench etc. Always put the tube down carefully on any hard surface.

Storage

Tubes should be stored in their original packing where possible or in suitable racks designed to protect the tubes from excessive shock or vibration. Ensure that no stresses are imposed on the vacuum envelope or seals. Where possible they should be stored vertically with the filament connections at the top. Keep the tube in a dry place and protect from dust by retaining the plastic bags or other wrappings.

Care must be taken that the glass or ceramic parts of a tube are kept clean and do not touch any metallic object.

Any metal part rubbing against a ceramic may leave a metallic trace that can lead to arcing when a high voltage is applied. Dirty ceramics are best cleaned with a domestic cleaning powder and a damp toothbrush. The ceramic should then be thoroughly rinsed with water and completely dried.

Cold Filament Resistance

The higher power tubes are accompanied by a card giving the value of cold filament resistance measured with a Kelvin bridge at a current of 1.0 A. Fracture of a filament strand will increase the resistance. This is often 5% or more, depending on the filament dimensions.

Installation

It is often worth examining the old tube to see if there are any circuit faults that require correcting before the new tube is fitted. Check for any evidence of poorly fitting connectors, insufficient cooling, any signs of high voltage arcing and check any contact fingers to ensure there are no broken fingers left loose in the socket.

It is important that the larger tubes are mounted vertically. On installing a new water cooled tube, use the new sealing ring if applicable. Tubes operating at high voltage will produce strong electric fields near the envelope, and when operating at radio frequencies there may be strong electromagnetic fields not only around the tuned circuits but in the general region of the tube. In general any metal in this area should be kept to a minimum. Especially to be avoided are sharp edged conductors which may provoke corona discharges, and closed conducting circuits which will dissipate power and reduce the efficiency. Where flexible leads are used for filament and grid connections they should not have sharp bends especially near the tube.

For use in industrial oscillators for dielectric heating the cathode connection to earth should be made with low inductance copper straps.

(See e2v technologies leaflet 'General Guidance Notes on the use of Vacuum Tubes').

Conditioning

If the tube storage is less than 2 years, it may be run at full power when first installed.

Tubes which have been stored for a longer period than 2 years should be run for 15 minutes with filament power only before applying the anode voltage. All cooling supplies must be on while the filament is energised. Where a tube has been stored for more than 4 years the filament should be run for 30 minutes on filament power only. If the tube brings out the HT trips on application of full voltage, the voltage should be reduced to approximately 60% and the tube run for 15 minutes before re-application of full power.

REFERENCES

Mentioned in the text

1. A. G. Nekut. 'Blower selection for forced-air cooled tubes'. Electronics, August 1950, p. 88.
2. W. E. Pannett. 'Radio Installations. Their design and maintenance'. Chapman & Hall, 1951.
3. R. I. Sarbacher. 'Graphical determination of power amplifier performance'. Electronics, Vol. 15, December 1942, p. 52.

Further References

4. E. E. Spitzer. 'Principles of the electrical rating of high-vacuum power tubes'. Proc. I.R.E., Vol. 39, No. 3, April 1951, p. 60.
5. H. P. Thomas, 'Determination of grid driving power in radio frequency power amplifiers'. Proc. I.R.E., Vol. 21, No. 8, August 1933, p. 1134.
6. W. G. Wagener. 'Simplified methods for computing performance of transmitting tubes'. Proc. I.R.E., Vol. 25, January 1937, p. 47. Analysis of current pulses and performance calculations without using constant current curves.
7. F. E. Terman. 'Radio Engineers' Handbook', McGraw-Hill, 1943.
8. F. E. Terman and W. C. Roake. 'Calculation and design of Class C amplifiers'. Proc. I.R.E., Vol. 24, 1956, p. 620.
9. H. J. Scott. 'A note on Class C power amplifier design'. Proc. I.R.E., Vol. 40, October 1952, p. 1250.
10. L. T. Apps. 'Class C amplifier and oscillator design . . . . a simplified method'. Electronic Engineering, Vol. 27, January 1955, p. 30.
11. E. May, 'Industrial High Frequency Electric Power'. Chapman & Hall, 1949.
12. M. T. Elvy. 'Electronic heating and the woodworking industry'. Journal British I.R.E., Vol. 14, No. 11, November 1954, p. 547. This article gives a very extensive bibliography on the subject of dielectric heating.

Whilst e2v technologies has taken care to ensure the accuracy of the information contained herein it accepts no responsibility for the consequences of any use thereof and also reserves the right to change the specification of goods without notice. e2v technologies accepts no liability beyond that set out in its standard conditions of sale in respect of infringement of third party patents arising from the use of tubes or other devices in accordance with information contained herein.