1. GENERAL

1.1 General note

The following directions apply in general to all types of magnetrons. Any deviations for a particular type has been indicated in the relevant data.

1.2 Magnetron definition

A magnetron is a cylindrical high-vacuum diode with a cavity resonator system embedded in the anode. In the presence of suitable crossed electric and magnetic fields the magnetron can be used for the generation of continuous-wave and pulsed signals in the higher frequency bands. The energy available within the cathode/anode zone is coupled out and launched in a coaxial line or waveguide by means of the output probe or antenna. The magnetron should not be regarded as an independent device, but rather as an integral part of the complete circuit. It follows that the operation of the equipment depends on the degree the various components are matched to each other.

1.3 Magnetrons for microwave heating

Magnetrons for microwave heating are designed for CW operation at a frequency of either 2,450 GHz or 2,375 GHz.

1.4 General design considerations

Equipment should be designed around the tube specifications given in the data and not around one particular tube since, due to normal production variations, the electrical and mechanical design parameters may vary around the nominal values.

2. OPERATING CONDITIONS

2.1 Operating characteristics

The values published for these characteristics must be considered as the outcome of measurements on an average magnetron. Individual magnetrons may show a certain spread around the published values, whereas during life the values may be subject to variation.
In the published data the spread and variation during life have in many cases be accounted for by mentioning maximum and/or minimum values of the characteristics.
As the performance of a magnetron is greatly influenced by its load and by the characteristics of the power supply, it is strongly recommended that the magnetron be operated at the published operating conditions only.
Whenever it is considered to operate the magnetron at conditions substantially different from those indicated, the tube manufacturer should be consulted.

2.2 Typical characteristics

The characteristics tabulated under this heading give general information on the magnetron independent of any specific kind of operation. The data should be regarded as pertaining to an average magnetron representative of the particular type. When necessary maximum and/or minimum values of the characteristics have been given to include the spread shown by individual samples and the variation which may occur during life.

2.3 Typical operation (recommended operation)

As the performance and lifetime of a magnetron are greatly influenced by the operating conditions (kind of anode supply, load, cooling, etc.), it is recommended that the magnetron be operated under the conditions "Typical Operation". Designers can consult the manufacturer whenever they consider it necessary to operate a certain tube under conditions different from those stated under "Typical Operation".

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3. LIMITING VALUES

3.1 Rating system

The limiting values should be used in accordance with the 'Absolute maximum rating system' as defined by IEC publication 134.

3.2 Absolute maximum rating system

Absolute maximum ratings are limiting values of operating and environmental conditions applicable to any electronic device of a specified type as defined by its published data, which should not be exceeded under the worst probable conditions.
These values are chosen by the device manufacturer to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environmental variations, and the effects of changes in operating conditions due to variations in the characteristics of the device under consideration and of all other electronic devices in the equipment.
The equipment manufacturer should design so that, initially and throughout life, no absolute maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply voltage variation, equipment component variation, equipment control adjustment, load variations, signal variation, environmental conditions, and variations in characteristics of the device under consideration and of all other electronic devices in the equipment.

3.3 Anode voltage, positive and negative

In some cases (e.g. when the filament is not energized) the anode voltage across the tube may be higher than the nominal operating condition, due to the type of power supply employed. The maximum voltage is specified for individual tubes. It is recommended that a suitable spark gap be connected between the filament connectors and the anode (earth) to prevent this maximum rating being exceeded.

4. CATHODE

4.1 A cathode temperature either too high or too low may lead to unsatisfactory operation such as moding and arcing, involving short life and loss of efficiency. During operation the heater voltage should, therefore, be set as near as possible at the prescribed value. Temporary fluctuations should not exceed the tolerances mentioned in the published data of the individual types. The heater voltage should be measured directly on the terminals of the tube.

4.2 Types of cathode

There are two types of cathode in use and each individual tube data specifies which cathode it uses.

- Indirectly heated cathode

A cathode heated by an element, the heater.
A special construction is the dispenser cathode, which is not coated but continuously supplied with suitable emission material from a separate element associated with it.
(bl Directly heated cathode, or filamentary cathode.
A hot cathode usually in the form of a thoriated tungsten wire which is heated by current flowing in it.

4.3 Heater supply

The heater should be operated from a.c. (50 Hz or 60 Hz); DC may be used when specified in the data of a particular type.

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4.4 Heater transformer

It is usual that the magnetron will be operated with the anode at earth potential. Therefore, the heater will be at high potential with respect to earth. Care must be taken to ensure that the secondary winding of this transformer is sufficiently well insulated from the earth and the primary winding.

4.5 Heater/cathode connectors

The connectors specified in the individual data have been designed to give the required electrical and mechanical contact and should be used with the specified magnetron.
The heater voltage should be measured on these connectors.
A coating of high temperature resistant silicone grease is recommended to prevent oxidation. The electrical conductors to the heater/cathode connectors should be flexible to eliminate undue stress on their respective terminals.

4.6 Heater voltage, starting

This is the voltage that should be applied to the heater when the tube is switched on from cold and before the anode voltage is applied.

4.7 Waiting time, or HT delay time

This is the minimum time which must elapse after the heater starting voltage is switched on and before the anode voltage is applied. This is to enable the cathode to reach the operating temperature.

4.8 Heater voltage, operating

This is the voltage at which the heater should be set immediately after applying the anode voltage. For some types information is given of the heater operating voltage related to the mean anode current.

4.9 Heater current

The heater current mentioned in the data is the nominal (typical) value measured when only the starting voltage is applied to the tube and when (thermal) equilibrium is reached. In addition the maximum value of the heater current at the starting voltage is given to assist in transformer design.

4.10 Heater current, peak starting.

During switch-on when the heater starting voltage is applied, the peak current through the heater shall not exceed (at any time) the specified value under any condition of supply voltage waveform. In order to assist in the design of the heater transformer, information is also given in the individual data about the cold filament resistance at room temperature.

4.11 Precautions

Filtering of RF interference
There are national and international regulations concerning RF interference emanating from equipment. Filtering of this interference by capacitive and inductive component associated with the heater connections may be necessary. For tubes having no integral filter these components can influence the proper operation of the magnetron and the tube manufacturer should be consulted for advice and approval.

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Fluctuations in supply voltage
Care should be taken to ensure that fluctuations in the supply voltage to the heater do not exceed the published tolerances for the particular type since too high or too low cathode operating temperatures can result in unsatisfactory magnetron operation e.g. moding, arcing, short life, etc.

5. ANODE POWER SUPPLY AND MODULATORS

5.1 General

The dynamic impedance of magnetrons is in general low; thus small variations in the applied voltage can cause appreciable changes in operating current. In the equipment design it is necessary to ensure that such variations in operating current do not lead to operation outside the published limits.
Current changes result in variation of power, frequency and frequency spectrum quality and con sequent deterioration of equipment performance. This factor should determine the maximum current change inherent in the equipment design under the worst operating conditions.
For some magnetrons, a special type of power supply is published which is recommended for that tube. Design information of these power supplies may be obtained from the tube manufacturer.

5.2 CW type magnetrons

- General

For CW types the amount of smoothing required in the h.t. supply depends on the amount of modulation, resulting from operating current variation, that can be tolerated.

- Power supplies

General information on power supply design and possibly component design, e.g. transformer design, capacitor, etc. may be supplied by the tube manufacturer. The following power supply types are in use for different tubes:
(a) unfiltered three-phase
(b) single-phase full-wave rectification
(c) unfiltered three-phase half-wave rectification
(d) unfiltered three-phase full-wave rectification
(e) LC stabilized
(f) Half-wave doubler, LC stabilized

6 MICROWAVE PERFORMANCE

6.1 General

The magnetron oscillates in the specified frequency range and the power is coupled out from the anode zone intoawaveg1.1ide or coaxial line by means of the output probe or antenna. The coupling of the transmission line to the cavity in which the material is being treated has to be carefully designed to ensure that the magnetron operates correctly.

6.2 Load or Rieke diagram

In general the published data include a load diagram, a circle diagram in which, for fixed input conditions, the output power and the frequency change of the magnetron are plotted against the magnitude and the phase (varied over 180 electrical degrees) of the voltage standing-wave ratio representing the load as seen by the magnetron.
In some cases the magnitude of the voltage standing-wave ratio (VSWR) has been replaced by the magnitude of the reflection coefficient (-y) these magnitudes being related by the formulae:

$$VSWR = \frac{1 + 'Y}{1 - 'Y} \qquad 'Y = \frac{VSWR - 1}{VSWR + 1}$$

The load diagram provides information on the behavior of the magnetron to load conditions.
With a mismatched load and at a particular phase there is a region on the load diagram which is characterized by high power output and convergence of the frequency contours.
This region is known as "the sink" and the phase of the load at which the magnetron behaves in this manner is known as "the phase of sink". It is recommended that a tube be operated in the direction of sink. A tube should not be operated in the direction of anti-sink.

6.3 Reference plane

This is the plane from which measurements on microwave phase of the VSWR are made. The reference plane corresponds with the zero line in the load diagram. The distanced of an operating point in the diagram gives the position of the minimum of the VSWR with respect to the reference plane. This distance is specified in terms of guide wavelength.

6.4 Voltage standing-wave ratio (VSWR)

6.4.1 VSWR for pulse magnetrons

The anode current range shown in the individual data is related to a VSWR of maximum 1,5 as seen by the magnetron. Operation of the magnetron with a VSWR in excess of 1,5 is not recommended as this may reduce the current range for stable operation and can cause arcing and moding. A ratio near unity will benefit tube life and reliability.
When the length of the transmission line between the magnetron and the load is large compared with the wavelength the maximum permissible value of the VSWR may be reduced due.to the occurrence of so-called long line effects. When a long transmission line cannot be avoided a load isolator must be inserted between the magnetron and the line.

6.4.2. VSWR for CW magnetrons

Under typical operating conditions the tube is operated under specified VSWR and phase conditions. It is most unlikely that these VSWR and phase conditions will be constant and therefore there are two types of VSWR conditions:

(a) Maximum continuous voltage standing-wave ratio

This value shall not be exceeded under any conditions of loading, except those specified in para. 6.4.2.(b). The value for certain equipment may be measured with standard cold measuring techniques (perhaps using a specified measuring probe). In some instances this VSWR value may be limited to particular phase regions of operation and outside these regions a lower VSWR value may be specified. This value shall not be exceeded. Incorrect loading of the tube may cause unstable operation.

(b) Instantaneous maximum voltage standing-wave ratio

Some equipment's use a device for varying the field pattern to produce a more uniform energy distribution in the applicator. This introduces instantaneous VSWR conditions which may exceed the continuous value. With those tubes where it is permissible to exceed the continuous value, the instantaneous value may be up to the specified value for a time of 0,02 sand maximum 20% of the time. It must be followed by a period four times as long during which the VSWR is less than the continuous maximum value.
Under no circumstances should the magnetron be permitted to mode. Amongst other conditions, the moding stability of a magnetron depends on the RF loading conditions such as VSWR, phase of reflection and coupling section. It also depends on peak anode current, mean anode current waveform. See para. 7.2.5.

6.5 Fixed reflection elements

Fixed reflection elements are used to alter the operating position of a magnetron concerning magnitude of VSWR and phase. It may be that an equipment is set up for optimum operation at matched load. A fixed reflection element can alter the operating position to the more efficient position of the phase of sink.

6.6 Microwave accessories

6.6.1.1 Antenna

In some cases the tube manufacturer can supply data on antennae which can be attached to the output of the tube in order to facilitate coupling into a specific waveguide type. In addition, drawings may be available on specific waveguide coupling assemblies.

6.6.1.2 R.F. gasket or soft copper washer

Gaskets and washers are provided to ensure adequate and proper electrical and RF contact between the tube output structure and the coupling section. When a new tube is installed in an equipment new gaskets and washers must be installed at the same time.

6.6.1.3 Microwave coupling or launching section

In some instances the coupling section for a certain tube is published. It is recommended that that coupling section be used with that tube. In other cases no specific publication of coupling section is given and the tube manufacturer should be consulted, since drawings of a particular coupling section for a particular waveguide may be available. In some instances a transition to
approximately 53,4 Ω coaxial line is published.

7 MEASUREMENTS

7.1 Cold measurements

Cold measurements are carried out to determine the VSWR and phase offered to the magnetron. These measurements should already have been carried out during the development of the applicator.
A measuring probe is available for those magnetrons having an antenna output. This probe replaces the tube in cold measurements. For tubes with a coaxial output structure VSWR measurements can be done with available standard equipment.
The coaxial input of either the measuring probe or applicator can be directly connected to a network analyzer to observe VSWR and phase. The reference plane for the load diagram is fixed to the input of the measuring probe or to the coaxial output structure of the tube (see drawings in the respective data publications). Design information for a network analyzer for the micro wave-heating band is available from the tube manufacturer.

7.2 Hot measurements

Hot measurements are carried out during development, production and servicing of microwave equipment.

7.2.1 Power output in a load

An output power measurement can be made using a defined quantity of water which is heated during a defined time. This check can also be done during production line control and servicing. The power into a cavity is given by the following equation:

$$P_o = q \frac{\Delta T}{14,4} W$$

in which q is the quantity of water being heated (cm3) and T is the temperature rise per minute of the water (K).

7.2.2 Peak heater current

This value must be checked. A suggested method is shown in the following diagram.

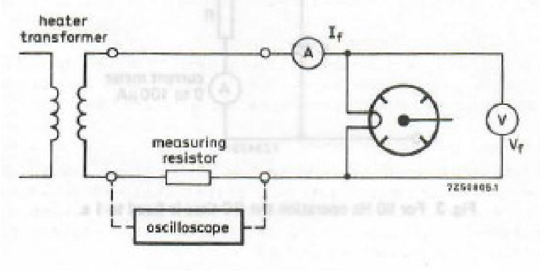

Fig. 1 Heater test circuit.

7.2.3 Heater voltage

The heater voltage - both starting and stand-by - shall be checked under all possible conditions of mains voltage fluctuations. The values shall remain within the published limits.

7.2.4 Anode current/anode voltage

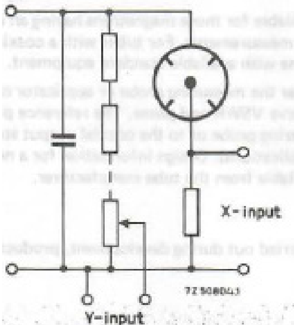

Fig. 2 Anode test circuit.

The circuit shown above enables the peak anode current Ia, the peak anode voltage Va and the
Va to Ia characteristic to be displayed on an oscilloscope. The waveforms show whether the peak values are in accordance with the published data and whether under certain load conditions, the magnetron can mode.
In addition the X-input signal can be read on a moving-coil voltmeter and calibrated in mean current. For measurement of peak anode voltage the following circuit is recommended.

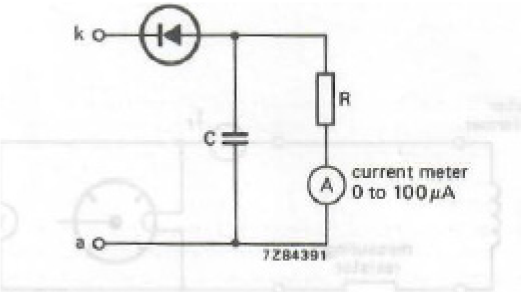

Fig. 3 For 50 Hz operation the RC time is fixed to 1 s.

7.2.5 Va to Ia characteristic

Excessive VSWR and/or current values may lead to moding of the magnetron which can be detected by displaying the Va to tel..characteristic on an oscilloscope for the various load conditions. This should be part of production line inspection but should also be checked during field inspection and after tube replacement. The normal Va to la characteristic should be similar to the normal magnetron characteristic as drawn below. The appearance of a second line or parts thereof distinctly above the first line indicates undesired modes of oscillation that can rapidly lead to failure of the tube.

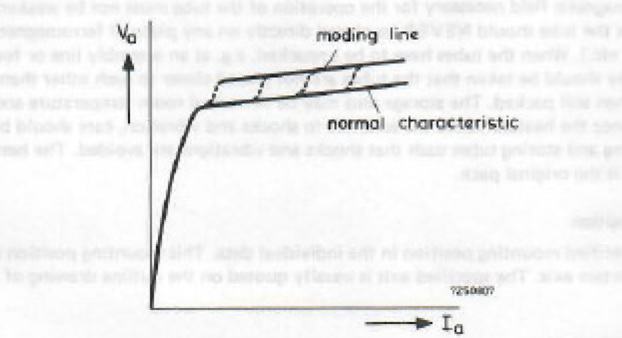

Fig. 4 X-Y display of magnetron characteristic (unfiltered supply).

In such cases the operating conditions, including the VSWR, must be checked and the tube replaced if, under correct operating conditions, moding still occurs.

7.2.6 Seal temperature

The temperature of the specified points shall not exceed the published ratings. If the flow of coolant is reduced or blocked, the thermoswitch must switch off the equipment before the maximum seal temperature is reached.

7.2.7 Stray magnetic fields

During development, the proximity of other magnetic materials should be checked concerning the influence on the magnetic field of the operating magnetron. This can be detected with the circuit for peak anode voltage (see 7.2.4).

7.2.8 Stray microwave leakage

During development, production and servicing care should be taken to ensure that the micro· wave leakage from the equipment is below the standards for particular countries concerned. Generally this isa cavity design problem but sometimes energy can leak from the RF couplings associated with the tube.

8 HANDLING AND MOUNTING

8.2 General

The magnetron is a delicate electronic tube and has parts made of glass and/or ceramic. Care must be taken in handling, installation, carriage (transport), storage, etc.

8.3 Handling and storage

The original packing should be used for transporting and storing the tube. Shipment of the tube mounted in equipment is not permitted unless specifically authorized by the tube manufacturer.
The strong magnetic field necessary for the operation of the tube must not be weakened permanently. Therefore the tube should NEVER be placed directly on any piece of ferromagnetic material (steel shelfs, etc.).
When the tubes have to be unpacked, e.g. at an assembly line or for measuring purposes, care should be taken that the tubes are not placed closer to each other than they would be placed when still packed. The storage area may be at normal room temperature and average humidity. Since the heater/filament is sensitive to shocks and vibration, care should be taken
when handling and storing tubes such that shocks and vibrations are avoided. The best protection for the tube is the original pack.

8.4 Mounting position

There is a specified mounting position in the individual data. This mounting position normally refers to a certain axis. The specified axis is usually quoted on the outline drawing of the relevant magnetron.

8.5 Fixing or holding points

The fixing/holding/supporting points are generally specified on the outline drawing. The RF output coupling of the tube should not be used as the only means of supporting the tube. Adjust ment should be available in the supporting brackets in the three directions of freedom to allow for manufacturing tolerances.

8.6 Electrical connections

The individual electrode connections to the tube should be flexible. Special places for the anode (earth) connection are indicated. These places are unpainted and therefore direct earth connections. Other places might not be electrically satisfactory.

8.7 Proximity of other magnets or ferromagnetic materials

The influence of other magnets or ferromagnetic materials on the magnetron magnetic field can result in degraded performance of the tube. Therefore magnets and stray magnetic field generators, either constant or varying, e.g. transformer cores, should be kept away at the specified distance from the magnetron in question.

8.8 Tools and instruments

All tools such as screwdrivers, wrenches, etc. used close to or in contact with the magnetron should be made of non-magnetic materials such as beryllium copper, brass or plastics to avoid unwanted attraction and possible mechanical damage to glass or ceramic parts as well as short circuiting of the magnetic flux. Sensitive instruments may be influenced or damaged by being positioned too close to the magnetron.

8.9 General precautions

The tube, and particularly the RF output coupling, should be kept clean and should be inspected before installation. Any foreign matter, especially metal particles inside the coaxial line and dirt on the ceramic insulation may cause electrical breakdown during operation.
The magnetron should never be held by the cathode radiator because this might result in mechanical damage to the tube. When a magnetron is removed from service every effort should be made to put it back into its original packing.

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8.10 Tube cleanliness

The ceramic parts of the input and output structures of the tube must be kept clean during operation. A protective cover of suitable material should be placed over the tube output if the output if the tube is inserted directly into a microwave cavity.

9 COOLING

9.2 General

In general, cooling of the filament terminals, anode block and output is necessary and individual data specify the extent to which cooling by air, forced air or water is required. Overheating of the tube due to insufficient cooling may damage the tube. The coupling requirements stated in the individual data refer to magnetrons operated under open bench conditions. In order to keep within the limiting temperatures for anode block, cathode terminal assembly and output seal,
where appropriate, it may be necessary in the practical equipment to provide additional coolant on account of high environmental temperatures due to restrictions imposed by the cabinet and to
high ambient temperatures at the equipment location.
The residual heat of the cathode on switch-off may raise the seal temperature above its permitted maximum. This danger can be avoided either by continuing the air flow after removal of cathode heater power or by using sufficient air during operation to keep the temperature of the cathode so low that the rise in seal temperature on switch-off can be accommodated.

9.3 Air cooling

Forced air cooling, when required, shall be in accordance with the information given under typical cooling air requirements. In addition a cooling air diagram (if available) indicates the variation of temperature at a certain point and the air pressure drop as a function of air flow rate. It is recommended that the cooling air temperature at the entrance to the tube cooling radiator does not exceed 40 °c. Care should be taken that air filters do not become blocked so that the flow rate is inhibited and the cooling air is heated to a too high temperature by surrounding dissipative components such as mains high-voltage transformer. It is important that the air should not contain dust, moisture or oil. If an air filter is incorporated in the system, allowance must be made for the pressure drop across the filter and ducting when choosing a blower.

9.4 Water cooling

Water cooling in accordance with the specified flow rate should be supplied to the tube. The cooling diagram specifies the inlet water temperature and pressure drop as a function of water flow rate. Closed or open water circuits may be used and the minimum water inlet temperature is 4 oc. Re-circulating systems are preferred, since, apart from saving water, they help to ensure a high standard of purity.
Some of the requirements for satisfactory cooling-water are that it should not be corrosive or deposit scale, should not contain insoluble material that might cause blockages and sh9uld have a high electrical resistance to prevent electrolysis. Its mineral content and electrical conductivity should therefore be periodically checked, especially when it is not drawn from a circulating system. A non-corrosive water should be low in chlorides, oxygen and carbon dioxide.
Scale formation may be avoided by maintaining a low amount of silica and bicarbonates, especially calcium bicarbonate. The total carbonate hardness should not exceed a value of 50 dH. No exact figures can be given for impurities as they are interdependent. However, in a circulating system the water should be as free as possible from all solid matter, and the dissolved oxygen content should be low. Whenever possible a closed water system using distilled or demineralized water should be employed. In this case the following should be added:

9.4.6 700 mg of a 24% solution hydrazin hydrate (approx. 0,7 ml per litre of water) to avoid corrosion.

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9.4.7 Approximately 700 mg sodium silicate per litre of water to increase the pH value (hydrogen ion concentration). The additives will reduce the electrical conductivity of the water to below 300 µn·1 cm·1 (resistivity> 3,3 kn per cm3) and also increase the pH value. A pH value of 7 to 9 is recommended). It is also recommended that the quality of the cooling water be checked after starting operations, and at regular intervals thereafter.

The cooling water must also be free from all traces of greasy substances since a small amount may form a dangerous heat barrier on the anode cooler, causing excessive anode temperature despite an apparently adequate water flow. These greasy or oily films may be removed by repeated flushing of the cooling channels with a domestic liquid detergent or slight soapy water to which a small quantity of industrial alcohol and 33% ammonia has been added (approx. 10 cc/l of each). The cleaning process should be completed by repeated flushing with demineralized water. The cause of such greasy deposits will usually be found elsewhere in the cooling system as the result of, for example, leaky pump glands. After the necessary repairs have been carried out, the whole system must be cleaned in a similar manner to prevent deposits forming again. The cooling water system must be interlocked with all electrical supplies to the tube. As an added safeguard, the interlocks should be activated if the water outlet temperature exceeds the indicated upper limit. To prevent the tube from running dry in the event of minor leakages in the system, the reservoir should always be above the level of the tube.

9.5 Thermoswitches

A thermoswitch must be used with each magnetron to protect the tube from overheating as a result of failure of the cooling system. The thermoswitch is normally 'closed' and opens when the temperature at the particular reference point exceeds the specified limit. The thermoswitch controls the power supply via a protection circuit and switches it off in the event of overheating.

A thermoswitch must be chosen which opens at the particular specified temperature when mounted at the specified place. In specifying the operating (opening) temperature, the temperature drop across the thermoswitch holder should be taken into account with respect to the temperature limit; under typical conditions this is about 5 K. Details of suggested thermoswitches can be supplied on request.

9.6 Temperature limits

Temperature reference points and maximum temperature limits are specified in the data. Under no circumstances shall these limits be exceeded. As for the limiting temperatures, measurements should be made in the development stage of the equipment, using suitable measuring methods.

9.7 Cooling during stand-by

Some forced-air or water cooling may be necessary during stand-by or starting filament heater voltage operation only. Tests should be carried out during the development of the equipment to ensure that sufficient cooling, even under extreme conditions, is available to keep the temperature of specified places below the maximum limit.

10 ACCESSORIES

10.2 General

The accessories recommended for use with relevant magnetrons should be used whenever possible. If an equipment maker considers it necessary to use other accessories he should ask the opinion of the tube manufacturer.

10.3 Fixed reflection elements

Fixed reflection elements are designed to adapt the operating position (in phase and VSWR) of the magnetron to a better position in the Rieke diagram (load diagram) to obtain more useful results, particularly with respect to power output. These accessories are not supplied by the tube manufacturer but drawings are given to facilitate manufacture if the use of these fixed reflection elements is recommended.

10.4 Gaskets and washers

Gaskets and washers are provided to ensure adequate and proper electrical and r.f. contact between the elements concerned. Generally, when a tube is installed, or re-installed, new gaskets and washers must be used.

10.5 Measuring probe

When available, the measuring probe should be used in place of the tube in development, production and servicing to ensure that the correct microwave impedance (phase and VSWR) is presented to the tube. See 7.1.

11 SAFETY ASPECTS

11.2 X-radiation

Power electron tubes operating at voltages in excess of 5 kV are possible sources of X-radiation, progressively so with increasing voltage levels. The envelope of the tubes offers only a limited shielding for such radiation. The equipment manufacturer should provide suitable additional shielding in his design. The level of X-radiation should be checked periodically.

11.3 RF-radiation

Exposure to strong RF fields may cause health-hazard, progressively so with increasing frequency. As such fields will exist in the vicinity of power electron tubes, the equipment manufacturer should provide suitable shielding in his design to reduce r.f. fields, in the neighborhood of the equipment, to acceptable levels.

REFERENCE:

"Magnetrons for Microwave Heating." PHILIPS Data Handbook. Electronic Components and Materials. Book T4. 1989.

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