Magnetrons Preamble

INTRODUCTION

The magnetron is widely used as the high power transmitter in pulsed radar equipments and this Preamble has been written with this particular application in mind. However, it does apply in general to all pulse magnetrons, both fixed frequency and tunable, when they are used for other purposes. Although CW magnetrons operate under rather different conditions, precautions similar to those described herein are still relevant.

ABSOLUTE RATINGS

All the maximum and minimum ratings specified in this section are absolute ratings. This means that the equipment designer is responsible for ensuring that operation outside these ratings is not possible, even momentarily, under any conditions arising from mains fluctuations, surges or tolerances on component values (see British Standard Code of Practice CP1005 (1962): The Use of Electronic Valves).

The operating conditions for magnetrons are interrelated in the ways described below, and it is important that all operating conditions remain within the specified limits when any alteration is made to one of them.

OPERATING Notes

Cathode Temperature

The thermionic cathodes used in magnetrons must be operated at the correct temperature if maximum life is to be achieved.

The magnetron is especially sensitive to low cathode temperatures as the reduced emission can cause unstable operation, that may damage the magnetron, whereas excessively high cathode temperatures lead to rapid deterioration of the cathode.

The combination of magnetic and alternating electric fields in the interaction space between cathode and anode causes a proportion of the electrons emitted to return to the cathode at high velocities. This back bombardment results in the dissipation in the cathode of a proportion of the anode input power. In order to maintain the cathode at the optimum temperature under these conditions, it is generally necessary to reduce the heater voltage; the amount of reduction is dependent upon the input power and is specified in the product data sheets.

Before the anode voltage is applied, the cathode must be raised to the operating temperature by application of the nominal heater voltage for a minimum specified time, and the full voltage must be reapplied if the anode supply is interrupted during operation. In common with other types of thermionic tube, it is bad practice to operate magnetrons for long periods on standby with power applied to the heater only.

Pulse Energy in Heater

When designing the pulse modulator output circuit, precautions should be taken to ensure that none of the pulse energy is dissipated in the magnetron heater. This is more likely to occur if bifilar pulse transformers are used, when imbalance of the windings and asymmetry of the loading may cause appreciable pulse voltages to be applied to the heater

The pulse energy can normally be decoupled by fitting a capacitor across the heater terminals of the magnetron, although in some equipments a more elaborate low-pass filter in the heater lead may be necessary. The connecting leads from the pulse transformer to the magnetron should be as short as possible to keep their inductance to a minimum, and the capacitor connections should be as close as possible to the magnetron and preferably directly across the heater terminals. Where large capacitors must be fitted, they should be shunted by small capacitors (preferably several different values of capacitance in parallel) to minimise the effect of the capacitor lead inductance.

The required capacitor value can best be determined by setting up the circuit shown in Fig. 1. Here the magnetron is replaced by a dummy load (R_L) and the magnetron heater by an electric lamp bulb of similar hot impedance and power rating. R_L should have the same impedance as the magnetron under the proposed operating conditions. The capacitance C1 across R_L should be comparable with the magnetron anode to cathode capacitance, normally of the order of 10 pF. When the pulse is applied to this circuit, the lamp will usually light, indicating that some pulse energy is being dissipated in the lamp. Capacitors (C2) should be added across the lamp until the light is extinguished. In this way, the minimum capacitance required to prevent pulse energy being dissipated in the magnetron heater can be determined.

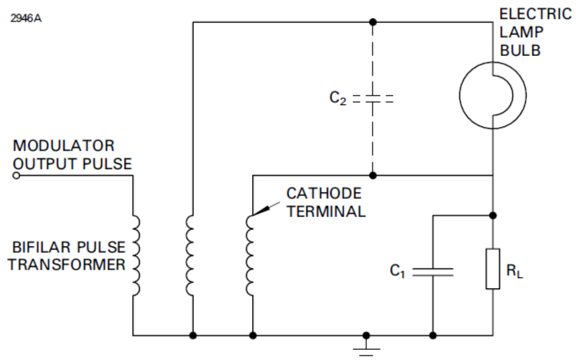

Fig.1 Heater dissipation test circuit

An alternative method, which may be more convenient, is to measure the rms and average values of the heater current simultaneously. Any pulse energy coupled into the heater will modify the ratio of these values (1:1 for a sinusoidal waveform).

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Heater Starting Current

The cold resistance of the heater is typically less than $^1/_5$ of the hot resistance. Consequently, a surge of current is taken on application of the full heater voltage, which may result in damage from an interaction between the heater current and the magnetic field. To prevent such damage, the heater starting current must be limited to ensure that the specified maximum value is not exceeded.

Frequency of Heater Supply

The frequency of heater supply (fundamental or harmonic) may excite mechanical resonances of the heater structure which can cause failure. If frequencies other than those quoted in the test specification are to be used, e2v technologies should be consulted.

For some uses, DC or AC synchronised with the pulse repetition frequency may have to be used to avoid frequency modulation of the RF output.

Magnetic Field

The magnetic field required for magnetron operation may be provided either by a separate electromagnet or by a permanent magnet which may be separate or packaged as part of the magnetron

Electromagnets are used mainly for the long-anode types of magnetron, which require the magnetic field to be within specified limits over the full length of the anode. In most cases, suitable electromagnets are available from e2v technologies and a waveguide launching section is usually combined with the structure of the magnet.

Variations in the magnetic field will result in changes in the operating characteristics of the magnetron. It is usually necessary to keep the electromagnet current within ±5% of the design value at all times and to limit the ripple to 1.5%. The magnet coils have considerable inductance and, if supplied from a three-phase full-wave rectifier, additional smoothing should not be needed.

Many of the permanent magnet types are made with the magnet as a separate item; the magnets for these magnetrons are not normally supplied by e2v technologies, but the product data sheets give details of the magnetic field and pole-piece design. Users are invited to consult the Company on the choice of magnets.

The field strength of permanent magnets may be decreased by mechanical shock, close proximity of ferromagnetic materials, and stray magnetic fields. The effect of decreasing the magnetic field is to reduce the operating voltage below the acceptable minimum, with a consequent reduction in efficiency and an increase in back bombardment of the cathode. In most cases, the modulator characteristics are such that, unless it is adjusted, any reduction in magnetron operating voltage will result in an increased peak anode current. This may not be serious with line-type modulators, having a load line with a comparatively steep slope, but with hard tube modulators the peak anode current may increase to a value in excess of the maximum rating and cause arcing instability.

When designing the transmitter, care should be taken to ensure that the magnet is not shunted to any appreciable extent by any ferrous materials used in the construction of the framework. In some cases, stray fields from the magnet may affect the operation of adjacent components. Where it is necessary to use a magnetic shield to prevent undesirable stray field effects, Teledyne e2v should be consulted on the correct spacing of the shield.

Impedance Characteristics

The magnetron has an extremely non-linear current-voltage characteristic; once oscillation starts, the anode voltage is almost constant over a wide range of current. The dynamic impedance near the typical operating current may be less than $^1/_{10}$ of the static impedance value.

The operating voltage is determined by the physical dimensions of the interaction space in the magnetron and by the magnetic field, with a slight correction for the small dynamic impedance. This is shown clearly in Fig. 2, in which AB is a typical V/I curve. As the V/I curve is nearly horizontal, any change in the operating conditions will have little effect on the anode voltage but a large effect on the current.

Thus abnormal operation of a magnetron is shown up most clearly by an incorrect anode current, even though the anode voltage has not varied noticeably.

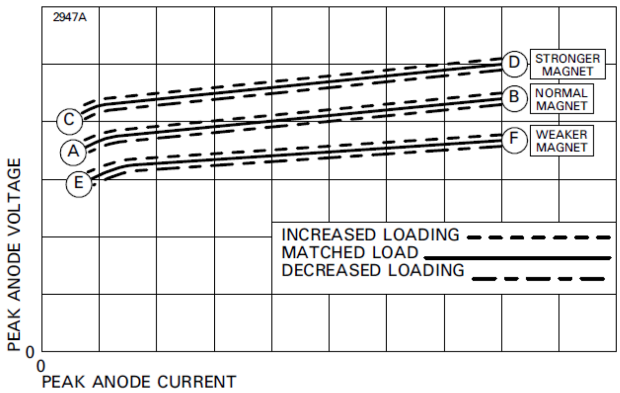

Fig.2 Magnetron impedance characteristics

If the magnetic field is increased, the V/I curve will move upwards to CD, whereas if the field is reduced it will move downwards to EF. A weak field is highly deleterious since it results in high anode current and low output power.

The solid curves in Fig. 2 are for matched loads; the effects of increasing and decreasing the load are also shown.

The determination of the operating point of a line-type modulator is shown in Fig. 3. The normal V/I curve of the magnetron is represented by AB and the load line of the modulator by PR. The operating point is determined by the intersection of AB and PR at Q. If the input to the modulator is increased, the load line will move from PR to LN, giving the new operating point M at the point of intersection with LN. The increase in anode voltage is the increase from V_O to V_O', which is quite small, and it is clear that the operating voltage is determined mainly by the magnetron and the magnetic field. Therefore any appreciable deviation from the correct operating voltage must be the result of either incorrect field strength or an internal defect in the magnetron.

The operating point indicated in Fig. 3 also gives the peak anode current of the magnetron. With line-type modulators, the relatively steep slope of the load line limits the change in anode current arising from a change in anode voltage to a reasonable value. The load line is substantially a straight line with double voltage at zero current and double current at zero voltage.

However, with the hard tube modulator, the internal impedance at the normal operating current can be quite low – of the order of 100 Ohms (see Fig. 4). Two basic types of operation of hard tube modulators are commonly used: Type 'A' above the knee of the tetrode characteristic and type 'B' below the knee, where the I_a/V_a slope is steep. Where good regulation of tetrode power supplies is not possible, it is advisable to use type 'A' operation even though the tetrode voltage drop will be greater in this case. This will minimise the large changes in magnetron current which may be experienced due to power supply regulation as the pulse repetition frequency is varied or the mains input voltage changes.

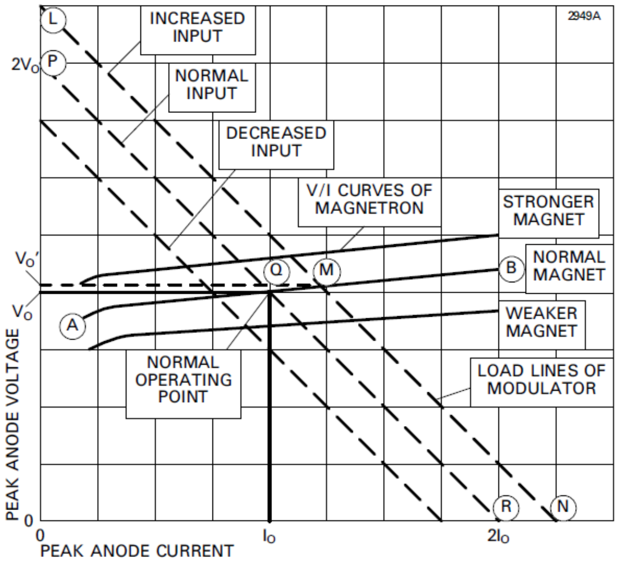

Fig.3 Line-type modulator characteristics

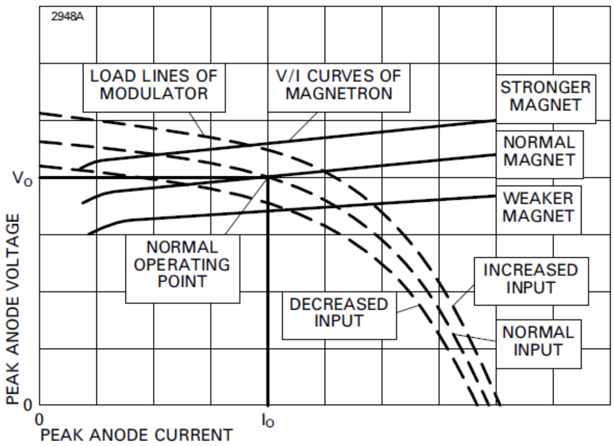

Fig.4 Hard tube modulator characteristics

Under these conditions, it will probably be necessary to adjust the input to the modulator to give the correct anode current and to ensure that any variations in the power supply do not result in large variations in the operating point with consequent excessive changes in the magnetron current.

The modulator design should ensure that the pulse energy delivered to the magnetron, following an arcing pulse, does not greatly exceed the normal.

Pulse Characteristics

Magnetron performance is usually very sensitive to the shape of the applied pulse which can be described by: a) the rate of rise, b) the spike, c) the flat, and d) the rate of fall (see Fig. 5).

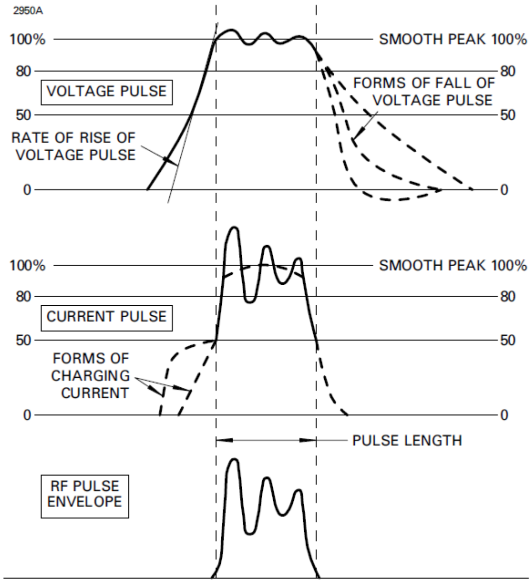

Fig.5 Pulse waveforms

a) **Rate of Rise**. A maximum and a minimum rate of rise of voltage is normally specified for magnetrons. The rate of rise is defined as the slope of the steepest tangent to the leading edge of the voltage pulse above 80% amplitude. Too high or too low a rate of rise may increase the tendency to mode changing with consequent undesirable effects.

b) **Spike**. A high spike on the leading edge of the pulse may cause the magnetron to start in an unwanted mode, and even if this does not happen it can lead to a substantial reduction in life. Therefore, measures should be taken to reduce the spike, while ensuring that the rate of rise of voltage is not reduced below the specified minimum.

c) **Flat**. The top of the voltage pulse should be flat and free from ripple or droop. Any small voltage ripples or droop tend to produce large variations in current as the dynamic impedance of the magnetron is low. Such variations in current give rise to frequency pushing effects with consequent frequency modulation during the pulse.

d) **Rate of Fall** The voltage pulse must fall rapidly at least to the value where oscillation ceases so as to reduce frequency pushing during periods of operation below full current. Oscillation usually ceases when the voltage has fallen to about 80% of the peak value. Although a lower rate of fall is permissible after oscillation has ceased, a significant amount of noise will be generated and the increase in 'waste' current may result in the overloading of the cathode.

In radar applications, the duration of the RF pulse, which is similar to that of the current pulse, is of major interest; both the RF and current pulses are shorter than the voltage pulse. The pulse duration is defined as the time interval between the points on the current pulse where the instantaneous current is 50% of the smooth peak current.

Any departure from the ideal flat top of the voltage pulse should be maintained at less than 1% so as to limit variations in the current to 10% or less.

Cooling

Pulse magnetrons usually dissipate appreciable amounts of power at the anode, typically half of the mean input power, so that most types require some form of assisted cooling.
Maximum temperature ratings are usually given for the anode and the cathode terminal assembly. In some cases, data sheets give full details of the cooling requirements, but for many of the smaller types natural convection cooling may be sufficient, depending on the layout of the equipment around the magnetron and other individual factors; in these cases, only the temperature ratings are quoted. At higher power levels, the output window of the magnetron may also require cooling. Where assisted cooling is required for the cathode insulator, output window or tuner assembly, the data sheet will generally give full details.

Air cooling systems must have adequate cooling capacity to allow for variations in ambient temperature and, where appropriate, altitude. It may also be necessary to filter the air.
Water cooling is used for the anodes and electromagnets of many high power magnetrons; the water used must be free from impurities so that no measurable furring occurs when it is heated. If anti-freeze additives are used, they must not be corrosive to brass or copper. Vapour phase cooling can also be used, with the advantage of greater frequency stability by virtue of the nearly constant anode temperature over a wide range of dissipation levels. However, variations in atmospheric pressure will affect the temperature of a vapour-cooled anode.

Protection Devices

If a magnetron is to achieve its full life expectancy in an equipment, it must be protected from the consequences both of its own minor malfunctions and of failures in associated components. This is especially important in high power equipments, where dissipation levels may be so high as to ensure rapid destruction of the magnetron if operated incorrectly.

The following list of protection requirements is included as an indication of what may be necessary; it applies to a high power, tunable magnetron operating in an electromagnet, water cooling being used for both the magnet and the anode of the tube.

a) If the magnetron presents either a short-circuit or an open-circuit to a pulse or group of pulses, the modulator must not deliver appreciably more than the normal pulse energy. This may require the following features:

   I. a spark gap, to prevent over-voltage,
   II. a limitation on the stored energy in the modulator,
   III. an interlock, operated by the overswing diode circuit, to cut off the modulator if the magnetron arcs for 25 consecutive pulses

b) Anode pulses must also be cut off in the event of:
   I. failure of electromagnet current,
   II. anode water flow falling below minimum,
   III. anode water outlet temperature exceeding maximum,
   IV. output window air pressure falling below minimum,
   V. output window air cooling flow falling below minimum.

c) In addition, the heater power must be cut off if the anode water fails. The electromagnet current must be cut off if the electromagnet water fails.

d) A slipping clutch or similar device must be fitted in the tuner drive, to prevent the application of excessive torque to the tuner.

FACTORS AFFECTING PERFORMANCE

The performance and life of a pulse magnetron are dependent to a large extent upon the conditions imposed upon it by the equipment and environment in which it operates. A number of the more important parameters and the ways in which they may vary are described in this section.

Frequency of Oscillation

The normal oscillating frequency of a magnetron is the resonant frequency of the cavity structure when operating in the π mode – i.e. when fields in adjacent cavities are in antiphase. The magnetron may deviate from this frequency for several reasons and, in general, any such deviation is undesirable.

Thermal Effects

The temperature of the anode block directly affects the size, and thereby the resonant frequency, of the cavity structure. The anode temperature at which the frequency is tested may be given in data sheets, and for most tubes a maximum value for the temperature coefficient of frequency is specified.

The anode temperature itself is a function of a great many factors, each of which can therefore have an indirect effect on the frequency; the use of coolant flow rates well above the recommended minimum will reduce the temperature variations. Vapour cooling almost eliminates temperature variations, except that due to the effect of atmospheric pressure changes on the boiling point of the coolant.

Frequency Pushing

The oscillating frequency is affected by the electron density in the interaction space of the magnetron, and this is a function of the anode current. If the peak of the current pulse is not flat, this will result in modulation of the frequency as well as the power level.

The data sheets for some types include maximum limits on frequency pushing, expressed in MHz/A over a specified current range. Unless otherwise specified, the frequency pushing is measured with the magnetron feeding a matched load, and can be considerably greater under mismatched conditions.

Frequency Pulling

Frequency pulling denotes the changes in frequency produced by changes in the output conditions and provides a measure of the effect of the external circuit, particularly reflecting discontinuities, on the magnetron. The frequency pulling figure is the maximum change of oscillation frequency caused by variation through all phases of reflection from a discontinuity in an otherwise matched output feeder. The VSWR specified is 1.5:1 for nearly all magnetrons.

Long output feeders may produce two particular cases of frequency pulling. Variation of the phase of a distant discontinuity may cause frequency jumps in CW magnetrons, whereas in pulse tubes the frequency may change between successive pulses, or groups of pulses, giving two frequency spectra; this is known as frequency splitting. The effect on a tunable magnetron is a gap in the frequency range which cannot be tuned into from either direction.

To overcome these long line effects, an isolator may be fitted in the output, next to the magnetron.

OUTPUT POWER

The peak output power of a pulse magnetron is the product of the peak input power and the efficiency of the magnetron when oscillating. The input power is determined by the modulator design and is usually variable to some extent; the efficiency depends upon a number of factors of which the most important are the strength and uniformity of the magnetic field, the VSWR and phase presented to the magnetron by the load, and the shape of the input pulse.

As a general rule, increasing the magnetic field strength will increase the efficiency, both output power and peak voltage increasing while the anode current is reduced (see Figs. 3 and 4). Magnetic field variation is not normally used to control the magnetron, although it may be necessary if it is required to vary the peak output power over a wide range. In other cases the field, whether from permanent magnets or electromagnets, is set to a fixed value and precautions must be taken to ensure that it is not reduced.

The mismatch presented to a magnetron by its load is limited by a maximum rating, usually to a VSWR of 1.5:1. Although operation at this maximum rating may not harm the magnetron, it can result in a considerable reduction in output power. In general, the load should be designed and adjusted to give a much better match than the maximum rating.

The shape of the voltage pulse may have appreciable influence on the efficiency, particularly if the rates of rise and fall are low enough to permit oscillation in useless modes before or after the main RF pulse. In general, any departure from a rectangular pulse leads to reduced efficiency, and ripple on the flat peak of the pulse can cause large variations in the instantaneous power level (see Fig. 5).

Stability of Oscillation

In the ideal case, every pulse applied to the magnetron would result in an RF output pulse of the correct length, power and frequency. In practice, any pulse in which the RF energy content in the specified frequency band is less than 70% of the normal value is considered to be missing; there are several ways in which this can happen.

Arcing

A magnetron can suffer internal arcs as in other high voltage electron tubes. When this happens, the path of the arc is influenced by the magnetic field but the voltage is so much lower than normal that no useful RF power is generated. A small amount of arcing is not dangerous to the magnetron, but in extreme cases it lowers the cathode temperature (since there is no back bombardment from an arc) and this increases the probability of further arcs. Persistent arcing for this or any other reason may destroy the magnetron.

Arcing is likely when a magnetron is first operated after a period of storage, and it is advisable to operate at reduced power input until the arcing is reduced to normal levels. Other factors likely to cause arcing are an excessively high rate of rise of voltage and low cathode temperature.

Moding

It is usually possible for a magnetron to oscillate in modes other than the preferred π mode, resulting in an RF output pulse which is not usable by the system. Moding may be detected by a random incidence of different amplitude voltage or current pulses, or by missing lines on a spectrum analyser display. It can be caused by an equipment fault such as high or low rates of rise of voltage or excessive load mismatch.

Operation in the wrong mode causes increased back bombardment of the cathode which may be harmful over an extended period.

Bandwidth

The frequency spectrum of the RF output includes a main lobe of useful power and sidelobes which are useless in most applications. For optimum system performance, the main lobe should have a narrow bandwidth and this is usually one of the parameters tested on every magnetron. The pulse shape is particularly important in this respect, as any departure from a flat top results in frequency modulation, and a low rate of fall at the end of the pulse will also contribute to the bandwidth.

Life

Unlike most types of electron tube, it is not usually possible to extend the life of a magnetron by operating at reduced power levels. Maximum life is normally achieved by operating at or near the recommended conditions and maintaining them accurately. Under good conditions, the eventual failure of the tube results from falling cathode emission which causes a fall in output power and increased instability. The magnetron is considered to have reached the end of its life when it no longer meets the specified end of life criteria, although it may be operating satisfactorily in other respects.

MEASUREMENT OF OPERATING CONDITIONS AND PERFORMANCE

During the development of a magnetron installation, it may be necessary to measure as many parameters as possible, but once an equipment is in service, measurements are normally limited to monitoring values that determine the end of life. Pulse operation leads to difficulty in measuring some of the more important parameters, and it is necessary to use the same methods as the tube manufacturer when working to a specification.

It cannot be emphasised too strongly that a magnetron is a highly non-linear device, and any measurements carried out with a dummy load substituted for the magnetron should be regarded as a first-order approximation only.

Heater Voltage

For high power magnetrons, it is advisable to measure the heater voltage individually at the terminals on the magnetron, and adjust if necessary to the specified values. This is less important with low power types, but it should be done if practicable. If a saturable reactor is used to control the heater voltage, the true rms value must be measured regardless of waveform distortion.

Anode Voltage

A simple peak-reading diode voltmeter is used for this measurement; if accuracies greater than ± 3% are required, it is necessary to allow for the pulse characteristics when calibrating the meter.

Anode Current

Test specifications are usually written in terms of average rather than peak, anode current. The average current is measured quite simply with a meter in the cathode circuit (with appropriate pulse bypass capacitors), but if it is required to measure the peak current, or observe the current waveform, a small non-inductive resistance must be placed between the magnetron anode and its mounting. This may be difficult to arrange, and a display of the rectified RF pulse will often give all the information that is needed.

Frequency

A cavity wavemeter is adequate for most radar applications, as it gives an accuracy of ± 0.01% (i.e. within 1 MHz at X-band)

Frequency Pushing

In order to eliminate thermal effects from the measurement, it is necessary to maintain a constant anode temperature by varying the anode current rapidly about the normal operating value. This may be done by applying alternate pulses at two current levels, and the frequency change must be measured by an equipment with a suitably rapid response, such as a spectrum analyser.

Anode Temperature

The anode temperature of a magnetron can be measured readily with a thermocouple while operating, since the anode is normally at earth potential. Many of the lower power magnetrons can operate with convection cooling only if the natural convection is not obstructed, and it is particularly important to check the operating temperatures of all parts of these types when new or modified equipment is developed.

Output Power

The peak output power of a pulse magnetron cannot be measured directly; many specifications are based on the average output power which can be measured accurately in a calorimeter. Bolometer or thermistor loads can be used, although they require careful calibration, but crystal detectors are too unstable for power measurement. A monitor diode may be used to give an indication of power output and a display of the RF pulse shape.

Rate of Rise of Voltage

A special definition of rate of rise is used for this purpose, to suit the characteristics of the pulse magnetron. It is the slope of the steepest tangent to the leading edge of the voltage pulse above 80% amplitude, as measured on an oscilloscope display (see Fig. 5).

This measurement should be made on a broadband system with a low input capacitance (6 pF or less) and high impedance. The rate of rise of voltage is a very important parameter in magnetron operation and should be measured accurately during the development of an equipment.

Pulse Duration

The pulse duration should be measured on either the current pulse, at 50% amplitude or on the RF pulse envelope at the half power (-3dB) amplitude.

STORAGE AND INSTALLATION

Storage

Magnetrons should be stored in their original packaging or in suitable racks designed to protect the tube from excessive shock or vibration and to ensure that no stresses are imposed on the envelope or seals.

To prevent interaction between magnets and the possibility of some permanent demagnetisation, integral magnet tubes stored in racks must not be positioned closer than the distance set by the size of the original packaging. The racks must be made of non-magnetic materials.

The ambient temperature of the storage area must be maintained at least 10^{0}C above the dew point or the tubes must be stored in protective packaging containing desiccants. The original packaging includes a vapour-proof envelope and this should not be opened until the tube is required for test or service.

Magnetrons should always be transported to and from the stores in the packaging designed for the purpose.

Shelf Life

Correctly stored magnetrons will normally suffer no harm from many years of storage in a non-operating condition. However, some users may wish to carry out periodic checks on tubes in store; this is most commonly required at remote sites using large, high power magnetrons at a very low annual rate. The spares holding can be safely minimised if the tubes in store are given a regular functional test in the equipment for which they are spares.

It is important that the test is carried out in a way that will minimise the risk of internal damage from arcing. This can be achieved by operating initially at reduced input power, about 80% of normal. This will allow the tube to clean up any traces of gas released internally during storage, without damage. A period of about 30 minutes operation at this reduced power level is recommended, after which the tube should not suffer excessive arcing when full power is applied for test purposes.

After testing, the magnetron should be returned to the normal conditions of storage. Water- or vapour-cooled types must have all traces of water removed from their cooling circuits before returning to store.

Installation

Care must be taken in removing the magnetron from its packaging, bearing in mind that it is a vulnerable article and liable to permanent damage if subjected to mechanical shocks. Prior to installation, the magnetron should be visually inspected, taking care to handle it by the mounting flange and not by the cathode or output sidearms. All glass and ceramic parts should be examined for cracks; any dirt, grease or moisture on the external insulator surfaces or terminals must be carefully removed, but at no time must steel wool be used for the purpose.

If the magnet is not integral, the tube must be handled carefully when it is fitted in the magnet to avoid mechanical shocks. Iron, nickel or other magnetic materials must be kept from close contact with the magnet and non-magnetic tools must be used for installation purposes. In the case of integral magnet types, the magnet must never be removed from the magnetron.

The electrical connections to the cathode and heater terminals and to the output should be sufficiently tight for reliable contact, but not so rigid that the glass-to-metal seals are strained. The cathode and heater terminals may operate at a relatively high temperature and provision must be made for thermal expansion. To prevent anode current and transients passing through the heater and possibly causing burnout, the anode voltage supply return must be connected to the cathode terminal.

It is important to avoid any undue stressing of the output section as deformation of the metal or breakage of the glass or ceramic vacuum seals may result. Any mechanical pressure should be applied uniformly, and a section of flexible waveguide should be fitted close to the magnetron. It may be desirable to operate the magnetron initially under reduced input conditions to clean up any gas that may be present and so reduce the risk of excessive arcing. This is particularly important when the magnetron has not been in service for an appreciable time.

Further advice on the installation and operation of magnetrons or any other problems arising from their use is available on request.

WARNING

All magnetrons operate with anode voltages high enough to be lethal and suitable safety interlocks should be provided. In many cases, radiation hazards may also be significant.

RF Leakage

Sufficient RF power may be radiated through the cathode stem and other apertures to interfere with adjacent circuit components. In some cases, the radiation may be sufficiently intense to cause damage to the human body, particularly to the eyes when observations of cathode temperature or arcing are being made. Such observations should be made through a small hole or an attenuator tube set in the wall of the output waveguide. Where this is not possible, adequate RF screening, such as copper gauze with a mesh small compared with the wavelength, should be provided.

If the cathode sidearm is completely screened, care must be taken to ensure that the screening does not cause overheating. The cathode sidearm temperature may be monitored by the use of temperature sensitive paints.

X-Rays

High voltage magnetrons emit a significant intensity of X-rays, not only from the region of the cathode insulator, but also from the output waveguide. These X-rays can constitute a health hazard unless adequate shielding is provided. This is a characteristic of all magnetrons and the X-rays emitted correspond to a voltage much higher than the anode voltage applied.