X BAND LINEAR ACCELERATOR MAGNETRONS

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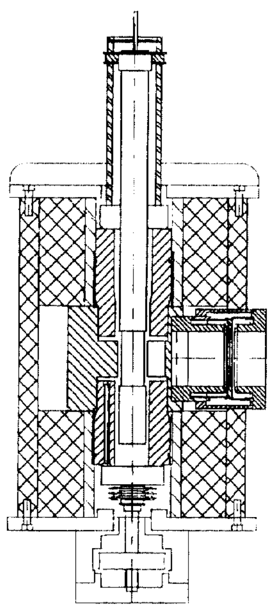
ABSTRACT

Advances in technology have now made possible the production of portable x-ray machines based on linear accelerators. Operating at X-band these can be broken down into suitcase sized components. The microwave power source has to fit into one of these components but still produce high peak and mean powers. This paper describes work carried out at EEV on the first tunable X-band magnetrons designed specifically for this purpose. Despite their small size they have the highest power level of any tunable X-band magnetron yet made.



INTRODUCTION

In the linear accelerator electrons are accelerated down the axis of a series of cavities. These become shorter towards the end as the electrons reach about 0.98c. Each cavity is passed in half a wavelength of the exciting R.F. energy moving to X-band (9.3 GHz) from S-band (2.8 GHz) enables the length to be reduced by 2/3rds.

The pulse length has to be long, as the first .5 μS is used to 'fill' the accelerator. The device has a high 'Q' making accurate tuning of the magnetron essential to allow for thermal drift.

The yield of X-rays is dependent not only on the mean power but also on the 5/4 power of the peak power. The X-ray energy is dependant upon the Linac design but figures around 4 MeV have been obtained.

Work began at EEV over 2 years ago to develop a new magnetron at 9.3 GHz for use with portable linear accelerators. The following minimum specification was required:-

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1 MW peak output power
0.5 kW mean output power
2 us pulse length
$\pm$ 5 MHz tunability
8 Kg weight maximum
110 mm diameter Ø x 250 mm long maximum

The specification was considered to be the minimum required to produce X-rays with enough energy to be of use in an industrial X-ray machine. In reality as much power as possible at the longest pulse length possible is required. A realistic target for the final device was 1.5 MW, 1.5 kW, 4 μS.

The starting point for the project was a 700 kW peak 0.5 kW mean, air cooled, fixed frequency magnetron which, with its electromagnet, weighed approximately 60 Kg and measured 500 mm x 500 mm x 300 mm.

The main problems were expected to be:-

a) Vane tip erosion due to the high pulse energy
b) Cathode erosion leading to short life
c) Unwanted tuner and cathode resonances
d) Size of magnetic circuit
e) Tuning precision
f) Overheating of the cathode structure

DEVELOPMENT

a) Vane Tip Erosion

The vane tips in pulsed magnetrons are liable to erosion by fatigue cracks caused by the continuous temperature cycling. At 40% efficiency and 1.0 MW peak power the peak heating of the vane tips is of the order of 5 GW/m^2. This causes a rapid expansion of the surface layer which is resisted by tensile forces in the metal. In the case of copper these exceed the fatigue strength for 10^8 cycles by a factor of 3. The result is usually cracking through the vane perpendicular to the surface. However, cracks will follow grain boundaries parallel to the surface, causing flaking and melting of the isolated area.

Acceptable lives have been found on magnetrons where the fatigue strength has been exceeded by only a factor of 2. This value has been achieved by substituting molybdenum vane tips on this magnetron.

b) Cathode Erosion

Oxide cathodes used in many X-band magnetrons could not be used at the required voltage and current density.

Initial current is provided by a barium aluminate impregnated tungsten cathode which gives high primary emission. However, this type of cathode is easily destroyed by electron bombardment and gives a low secondary yield. The centre of the cathode is therefore made from solid metal with a good secondary electron emission.

c) Resonance Problems

Cold tests showed the tuner system to be clear of resonances near the π -Mode. If present these could have caused melting problems at this power level.

A problem was experienced with side arm radiation. This was tackled in two ways:-

i) A resonance in the radiation tube/pole piece region was moved away from the π - mode by changing the pole piece i/d. This reduced the power coupled out down the sidearm.

ii) A choke was built into the cathode pole piece to prevent r.f. escaping down the coaxial path between the cathode stem and the pole piece.

d) Magnet Circuit

Because of the small size and weight requirement it was decided to use Neodymium-Iron-Boron magnets. Having an extremely high energy density it is possible to use about 1/5th of the volume required for Alnico. The material is also mechanically strong, making it possible to handle the large pieces required. This is believed to be the first time that Nd-Fe-B magnets have been used on a magnetron.

The magnet uses 8 blocks of Nd-Fe-B 20 mm x 45 mm x 50 mm and jigging has had to be produced to assemble these safely in the magnetized condition. Forces of about 50 N both repulsive and attractive are experienced during assembly.

Water cooling of the magnetron anode has kept the temperature of the magnets below 70° C and no problem has been experienced with the expected drop in magnetic field.

Experiments have been carried out to control the corrosion of the magnets. Being sintered Nd-Fe-B is slightly porous and has problems associated with rusting, causing loss of magnetic properties and possible disintegration. Attempts at plating with various metals; copper, nickel and zinc have not proved able to withstand salt spray testing. Epoxy coating/painting has been more successful.

It is hoped that future magnet materials will be inherently more resistant to corrosion.

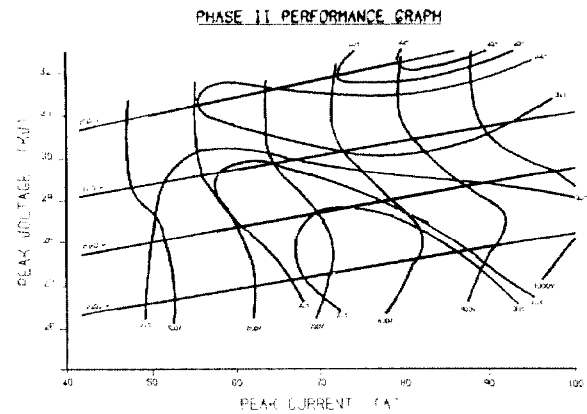
e) Precision Tuning

The magnetron operates over a 10 MHz tuning range. At 9.3 GHz this is only 0.1% and is easily achieved by a simple inductive ring tuner. Use of antibacklash gears on the rotary to linear gearbox makes accurate tuning possible to within 30 KHz.

f) Overheating of the cathode structure

After the problems detailed in a) to e) had been overcome it proved possible to make magnetrons that met the minimum specification of 1 MW, 0.5 kW, 1.5 µS. However increasing the mean power above 0.5 kW caused the efficiency to fall. This was found to be due to the cathode structure overheating and emitting electrons from unwanted areas. These electrons cannot contribute to the output power and are simply lost as heat. This problem was eventually solved by coating the cathode support structure with a non-emissive layer. This has enabled the mean output power to be increased to 1 kW.

Typical Result



Future Work

It is considered that the 1 MW, 1 kW, 3 µS obtained with the present magnetron is close to the limit of what can be achieved with that design.

Efforts have been made to increase the number of cavities to maintain the same peak vane tip power and cathode current density. The cathode stem diameter has been increased to remove the extra heat generated.

The increased number of cavities has caused many more problems. A considerable amount of effort was required to build a magnetron with a mode spectrum that gave stable operation.

Other problems have also been more severe with more cavities. There have been more problems with electrons escaping from the anode melting holes in the pole pieces and possible problems with multipactor discharges in the output.

Recent magnetrons have looked more promising and powers of up to 1.3 MW, 1.3 kW have been obtained on experimental magnetrons. Thus we are still hopeful that the full maximum power will be achieved.

Further improvements in magnet technology may enable the magnet circuit to be reduced in size. The energy density of new materials has been increased from 35 to 40 MG.Oe.

Conclusions

Advances in technology are continuously pushing up the power available from magnetrons. Magnetrons will continue to be preferred whenever a compact high powered, inexpensive power source is needed.

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