Conceptual Design of a 1MW 175MHz CW Magnetron

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Abstract: *Recent advances in the control of CW magnetrons have raised the possibility of using these devices as the RF power sources for particle accelerators. This paper describes the conceptual design of a 1MW, 175MHz, CW magnetron and compares its performance with tetrode amplifiers.*

Keywords: Magnetron; Conceptual design; Tetrode amplifier.

Introduction

Many proton accelerators require RF power sources capable of generating 1MW CW at frequencies around 200MHz. At present the only power sources available are tetrodes and similar gridded tubes operated as class B or C amplifiers with efficiency in the range 65-70% and gain in the range 10-15dB.

Recent advances in phase-locked CW magnetrons have shown that it is possible to achieve phase stability of better than 1° with a locking power more than 30dB below the output power of the tube [1]. This has raised the possibility of using CW magnetrons as RF power sources for particle accelerators. Figure 1 shows the state of the art of CW magnetrons including data from commercial data sheets and from an experimental tube [2]. Since efficiencies of up to 90% can be obtained at 915MHz it is reasonable to suppose that similar, or better, performance could be obtained at 200MHz. The commercial tubes included in fig.1 have Pf^2 products of up to 84 kW.GHz^2 at 915 MHz and 180 kW.GHz^2 at 2450 MHz. For 1MW at 200MHz the Pf^2 product required is 40 kW.GHz^2 which is well within the limits of current technology.

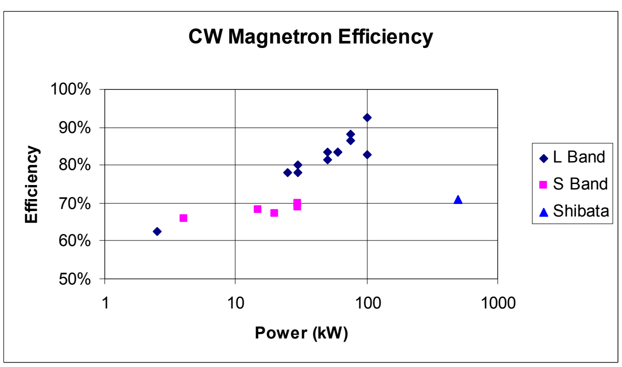

Figure 1. State of the art of CW magnetrons

This paper describes the conceptual design of a 1MW, 175MHz, CW magnetron for IFMIF as a possible alternative to the Thales TH628 Diacrode® which is the baseline design [3].

Magnetron Design

The conceptual design procedures for magnetrons are well understood and can be implemented using a spreadsheet. The calculations described in this paper were implemented on a MathCad worksheet which was been benchmarked against the design calculations in [2] and against other tubes.

Target efficiency: A target efficiency of 90% was assumed. The efficiency of a magnetron increases with the magnetic field approximately as shown in fig.2. It is clear from this graph that efficiencies greater than 90% can only be achieved by using very high magnetic fields which would require large electromagnets and large power supplies. The experimental tube described in [2] used a normalized magnetic field of 6.5 corresponding to a theoretical efficiency of around 80% and a practical efficiency of 72.5%. However, since the actual field required is quite low at 175 MHz, a normalized magnetic field of 20.5 was chosen with a view to obtaining practical efficiency of 90%.

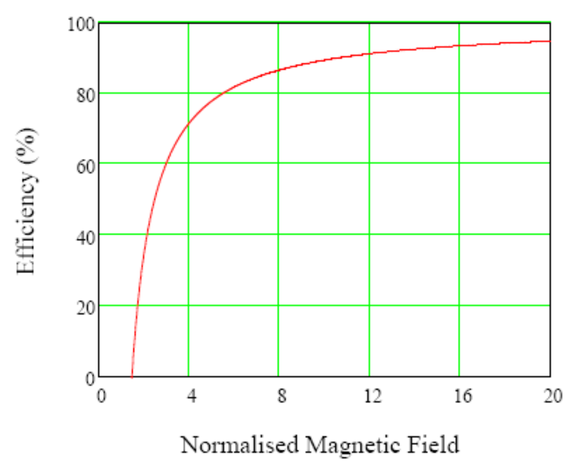

Figure 2. Variation of the efficiency of a magnetron with normalised magnetic field

DC Impedance: The impedances of CW magnetrons are typically in the range 3.0 to 7.0 kΩ. The tube described in [2] had an impedance of 3.0 kΩ. The phase locked loop which would be used to control the magnetron employs pulse width modulation of a switched mode power supply to control the current through the tube. It is desirable to keep the anode voltage as low as possible for compatibility with the high voltage switching devices currently available. An impedance of 3.0 kΩ therefore chosen.

Anode Design: The tube described in [2] had a coaxial cavity coupled to the anode vanes. However, the coaxial magnetron has the disadvantage that it is much larger than a conventional magnetron so that the size, weight, power requirements and self inductance of the electromagnet are increased. Other existing tubes at power levels which would scale to 1 MW at 175 MHz have conventional strapped anodes and that choice has been made in the design calculations. The choice of the number of vanes depends on a number of factors including: Cathode current density; Anode temperature; DC voltage breakdown and Stability. In general the first three criteria are easier to meet when the number of vanes is increased while the stability criterion (excitation of other modes of the anode) is harder to meet. The diameter of the anode increases with the number of vanes and so, therefore, does the size of the electromagnet. Calculations showed that cathode loading and voltage breakdown should not pose problems but that care would be needed with the thermal design of the anode. It was concluded that an anode with 10 vanes should be suitable.

Electromagnet: The magnetic field would be provided by a solenoid electromagnet surrounding the anode. The diameter of the anode controls the inside diameter of the windings and the height of the solenoid must be greater than that of the anode to provide for the anode end-space and cathode end hats. The current density in the windings was taken to be 1 A/mm^2. Previous experience suggests that this is a conservative choice and could be increased if necessary. It is desirable to minimize the self inductance and the working voltage in order to achieve the fastest possible rate of change of magnetic field as a way of controlling the output power. The results of these calculations are summarized in Table I.

Table I: Solenoid options

Target efficiency	90%	85%
Magnetic flux density	885 G	435 G
Number of turns	400	400
Solenoid current	50 A	24 A
Solenoid voltage	29 V	14 V
Solenoid power	1.42 kW	340 W
Solenoid inductance	0.94 H	0.94 H
Voltage change to produce 1% change of output power in 100 msec	94 V	23 V

Stability: Magnetrons are liable to problems with the excitation of unwanted modes of the anode, especially the π -1 and π + 1 modes which are closest in frequency to the desired mode of operation. Careful design of the strapping of the anode can raise the frequencies of both these modes well above the frequency of operation so that no problems are envisaged with the number of anode vanes chosen. The operating point was chosen so that application of the correct working voltage should ensure that the desired mode of operation is selected preferentially. Stability of operation is further ensured by the phase locked loop. The output coupler could be designed to further increase the stability of the desired mode.

Cathode and tube life: High power CW magnetrons generally have directly heated thermionic cathodes made of tungsten wire. The current flowing in the wire produces a magnetic field which could disturb the operation of the magnetron. Possible alternatives might be an indirectly heated cathode or a 'cold' oxidized aluminium cathode (as in some crossed-field amplifiers). The back-bombardment of the cathode deposits between 2% and 5% of the input DC power on the cathode in the form of heat. It would therefore be necessary to provide cooling of the cathode [2]. Research would be needed to optimise the design of the tube to achieve long cathode life.

Conclusion

Table II shows the main operating parameters of the proposed magnetron with those of the TH628 Diacrode for comparison.

Table II

	Diacrode	Magnetron
Anode voltage	14 kV	60 kV
Anode current	103 A	20 A
Efficiency	71%	90 %
Gain	13 dB	> 30 dB
Drive power	50 kW	< 1 kW
Cooling	Anode	Anode and (probably) cathode
Electromagnet	No	Yes

The study showed that it should be possible to develop a 1MW, 175MHz, CW magnetron which would have appreciably higher efficiency and gain than an amplifier using a gridded tube. The power supply required is similar to those already in use for other purposes.

References

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