LONG-PULSE 1.3 GHZ MAGNICON

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Abstract

A previous design of a 1.3 GHz magnicon amplifier has been extensively modified to make it suitable for TESLA applications. To avoid high voltage breakdown, the new design includes a double anode gun for the generation of a 250 kV, 55 A electron beam with 2 ms pulse length. The RF system is redesigned to have eight low Q, stagger-tuned cavities for increased bandwidth. Steady-state as well as time-dependent magnicon codes were modified for calculation of bandwidth and for better simulation of the transient processes. A collector has been designed with acceptable power load. Numerical calculations show that the amplifier can operate at a maximum efficiency of 73% with 1 MHz 3-dB bandwidth. The maximum output power is 10 MW with 44 dB gain.

1 INTRODUCTION

The design of a long-pulse, high efficiency and high power magnicon amplifier at 1.3 GHz is provided as driver for superconducting linear colliders. The magnicon is a deflection-type microwave amplifier which can operate at extremely high efficiency [1]. In magnicon interaction, the deflection of the electrons is modulated in such a way that all electrons experience about the same decelerating RF field leading to an extremely high efficiency with no bunching of electrons occuring in real space. An initial design [2] of a 1.3 GHz magnicon has been extensively modified to fit the requirements of TESLA. The calculated efficiency of 76% in the initial design applied to one specific set of parameters for the magnicon. The design lacked a dynamic range of operation as well as bandwidth. Furthermore, the maximum electric field in the diode gun of that design exceeded the high voltage breakdown limit. These deficiencies have been corrected in the new design. In the new design, a double anode gun is used to reduce the maximum surface electric field on focus electrode and on first anode well below the breakdown limit. The RF system is designed with 8 low Q stagger-tuned cavities to increase bandwidth and gain. The dynamic range of operation was increased by a careful design of output cavity to obtain similar axial profiles of RF electric and magnetic fields. The new magnicon design provides high efficiency (~73%), high power (~10 MW) and large gain (~44 dB) at 1.3 GHz with 2 ms pulse duration, 10 Hz repetition rate and 1 MHz bandwidth. Details of the magnicon design and numerical simulation results are described below.

2 MAGNICON AMPLIFIER DESIGN

A schematic of the improved magnicon amplifier is shown in Fig.1. The essential features of the design modifications of the four componenets –- electron gun, RF system, magnet system and collector—of the amplifier are highlighted below.

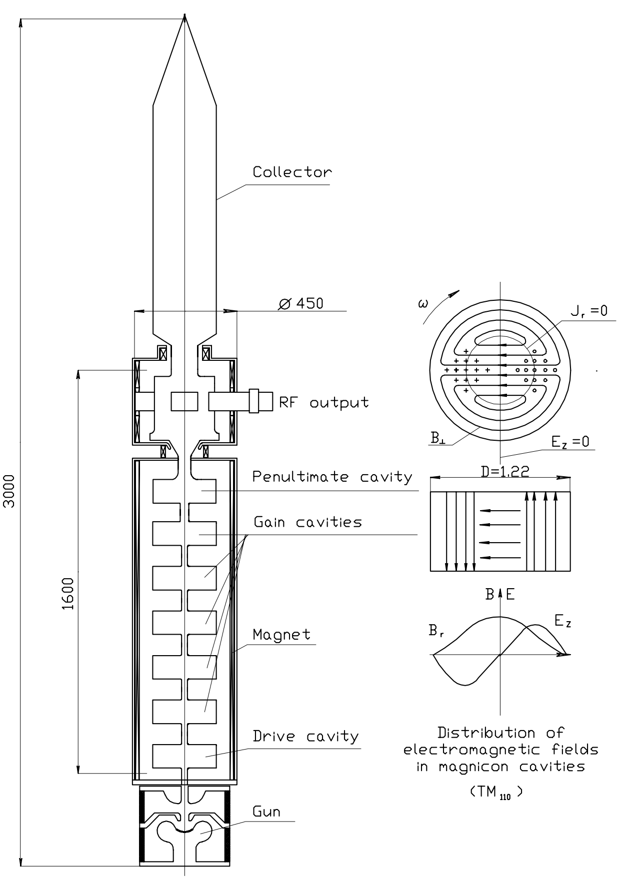

Figure 1: Schematic of a magnicon amplifier

(i) Electron Gun: The diode gun proposed in ref. [2] has been replaced by a double anode gun for operation well below the limit for high voltage breakdown even for DC operation. A double anode gun with a dispenser spherical cathode has been designed to provide a 250 kV, 55 A beam. The voltage between the cathode and the first anode is 100 kV, and that between

*Permanent address: Budker INP, Novosibirsk 630090, Russia the two anodes is 150 kV. For pulse lengths longer than 1 ms, an empirical relation on the high voltage breakdown condition is given by $E_S V_e$<800 kV^2/mm where E_S is surface electric field on the electrode at lower potential and V_e is the voltage between two electrodes [3]. In the present gun design E_S=45 kV/cm on the focus electrode and $E_S V_e$=450 kV^2/mm between the first anode and the focus electrode. On the first anode E_S=45 kV/cm and $E_S V_e$=675 kV^2/mm between the two anodes. These values are well below the breakdown limit. The gun design optimization and matching to the magnicon magnet system were performed using SuperSAM [4]. Beam dynamics were simulated in a realistic magnetic field obtained from SAM [5]. The optimized gun geometry with electron trajectories is shown in Fig. 2.

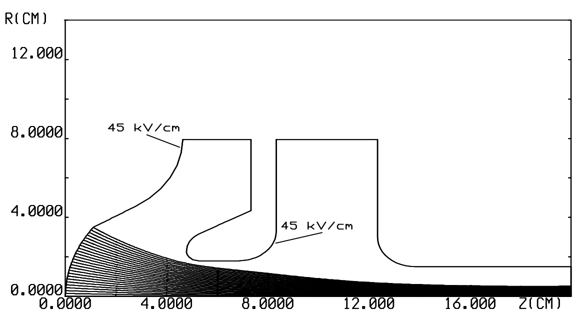

Figure 2: The gun layout and electron trajectories.

Calculated beam r.m.s. emittance from geometrical aberrations is less than 5.5π mm-mrad which is small compared to the estimated thermal emittance of 20π mm-mrad. The beam quality of the gun will be limited mostly by the thermal emittance. The points of maximum surface electric field on the focus electrode and the first anode are indicated in Fig. 2.

(ii) RF System: RF system is comprised of low Q cavities which are stagger-tuned to increase the bandwidth. The RF systems requires 8 cavities (drive cavity, 6 gain cavities including penultimate cavity, and output cavity) to obtain 1 MHz bandwidth with 44 dB gain. The shifts of resonant frequencies of the six gain cavities from the operating frequency of 1.3 GHz are 1.55, 0.8, 2.3, 0.35, 2.75, 1.05, 2.05, -0.4 MHz, respectively. The beam-loaded Q of the deflection cavities is around 800 and the external Q of the output cavity is about 220. The penultimate cavity is a single cavity instead of a double-gap cavity as in ref. [2]. For the parameters pertaining to TESLA operation, a single penultimate cavity design is simpler than a double-gap cavity without loss in efficiency and has lower wall losses. The shapes of the cavities are carefully designed to get high efficiency with the smallest possible RF field in the cavities. The maximum surface electric fields in the penultimate and output cavities are, respectively, 68.2 and 76.7 kV/cm, These fields are well below the breakdown level which is above 100 kV/cm. For efficient interaction with a reasonable dynamic range of operation, the RF electric and magnetic fields in the output cavity must have similar profiles along the axis, as shown in Fig. 3. In that case, the axial force is very small and the axial velocity remains fairly constant. Such profiles were obtained by increasing the diameter of the cavity near its entrance as can be seen in Fig. 3

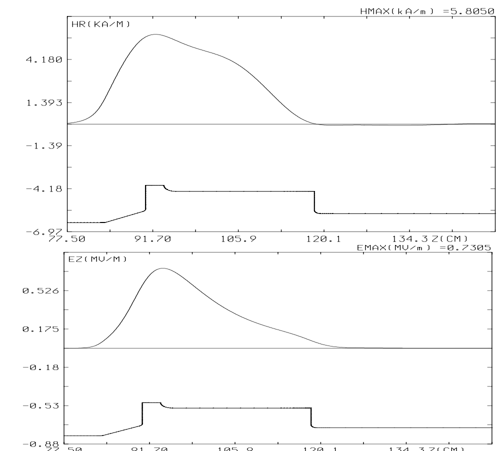

Figure 3: Profile of *H* and *E* along the cavity axis.

(iii) Magnet System: The magnetic field requirement is very modest. The field is about 870 G in the deflection cavities and 650 G in the output cavity. There is a region between the penultimate cavity and the output cavity which is free of both DC magnetic and RF fields. Beam spreading will occur in this region due to unbalanced space charge forces. However, the field free region is small and the deleterious effect of beam spreading on the device efficiency is more than compensated by other advantages, e.g., larger deflection angle with lower RF fields and lower wall loss. The magnetic field will be produced by coils with independent current supplies with relevant magnetic shields. The mechanical design of the magnet system is developed to match the power source and to keep power dissipation in the coils to a minimum. The electron gun has to be properly matched with the magnet system.

(iv) Collector: Pulse heating of the collector surface in high energy pulsed operation can limit the life of a collector. A new code has been developed to design a suitable collector having a low power load. The code determines the shape and length of the collector to minimize the pulsed power density on the collector surface. For undeflected beam in the absence of drive signal, the maximum power load is 92 W/cm^2 and for the beam deflected by RF field, the maximum power load is 52 W/cm^2.

(v) Design parameters: The variations of output power, P_{out}, and phase with Q of the output cavity are plotted in Fig. 4 at a frequency of 1.3 GHz.

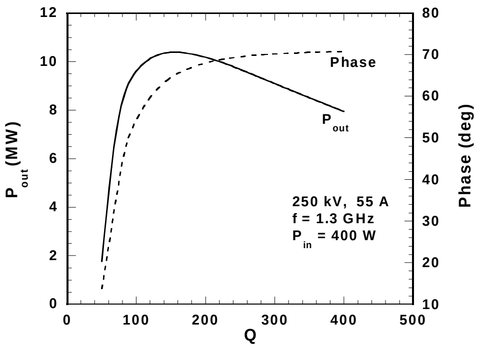

Figure 4: Output power and phase vs *Q* of output cavity

The input power, P_{in}, is 400 W. For Q=220, we get an output power of 10.04 MW with 73% efficiency and 44 dB gain. A maximum efficiency of 76% occurs at Q=150. The output cavity is designed to operate with Q ~ 220 to increase the dynamic range of operation. The output power as a function of frequency is plotted in Fig. 5 to determine the bandwidth. The simulations are done

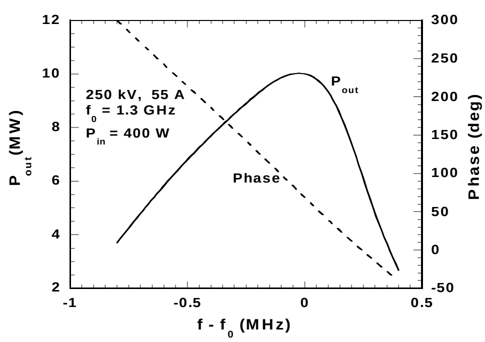

Figure 5: Output power and phase vs $f-f_0$

for output cavity Q=220 and P_{in}=400W. The FWHM of the curve is 1 MHz with maximum power of 10 MW and maximum efficiency of 73% at 1.3 GHz. The phase decreases almost linearly with frequency. The drive curve is shown in Fig. 6. The output power increases

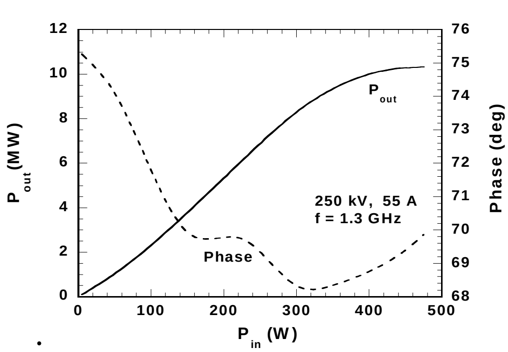

Figure 6: Output power and phase vs input power

almost linearly with input power in the range of 1 to 300 W and then shows signs of saturation. The phase varies smoothly with input power. The optimized design parameters found to date are given in Table I below.

Table 1

Operating frequency	1.3	GHz
Output power	10.0	MW
Pulse duration	2.0	ms
Repetition rate	10.0	Hz
Duty factor	2.0	%
Av RF power	~ 200.0	kW
Beam voltage	250.0	kV
Beam current	55.0	A
Microperveance	~ 0.44	
Peak power of beam	13.75	MW
Efficiency	73.0	%
Gain	44.0	dB
3 dB bandwidth	1.0	MHz
RF drive power	400.0	W

3 SUMMARY

A 1.3 GHz magnicon amplifier has been designed for TESLA applications. The cavities were designed such that self excitation of the penultimate cavity, harmonic generation and other instabilities in the penultimate and output cavities are eliminated. Simulations show that an output power of 10 MW at 73% efficiency can be provided by a magnicon amplifier with 2 ms pulse duration and a 3-dB bandwidth of 1 MHz. The gain is 44 dB. The amplifier has other useful applications such as driving accelerators used in pollution control, nuclear waste remediation and spallation neutron sources.

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