

# HIGH POWER MAGNICONS AT DECIMETER WAVELENGTH FOR MUON AND ELECTRON-POSITRON COLLIDERS\*

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## Abstract

The muon collider requires 100 MW, 800 MHz pulsed RF amplifiers for the final stages of acceleration. In addition, the CLIC drive linac requires pulsed RF amplifiers with a power of 100 MW at 937.5 MHz. In this paper conceptual designs of magnicons for these applications are presented. In addition to the typical magnicon advantages in power and efficiency, the designs offers substantially shorter tube length compared to either single- or multiple-beam klystrons.

## INTRODUCTION

The motivation for considering muon colliders is the effective energy advantage of any lepton collider over hadron machines, together with the fact that muons unlike electrons generate negligible synchrotron radiation [1,2]. As a result, a muon collider can be circular and much smaller than the current designs of linear electron/positron colliders, and also much smaller than a hadron machine with the same effective energy. Because muon beam have a large emittance, the accelerator apertures must be large, and consequently low frequency RF should be used for acceleration (200-400 MHz during an initial stage and 800-1300 MHz in a final stage). Due to the short muon decay time, rapid acceleration is required, and consequently high accelerating gradient is necessary. Thus, high power (100 MW) RF sources are required [2].

It is known that pulsed klystrons with powers exceeding 100 MW can be built [3]. The problem is that, at the decimeter wavelengths required for muon colliders, a high-power single-beam klystron (SBK) or even a multiple-beam klystron (MBK) will be unacceptably large. The realistic candidate to fulfill the role of the required RF amplifier is the magnicon. The magnicon is a deflection-modulated RF amplifier, which has already demonstrated the capability of producing multi-megawatt power, high efficiency and high gain in a wide range of frequencies from 915 MHz to 34.3 GHz [4,5,6,7,8]. The interaction mechanism of the magnicon does not require beam bunching, and consequently does not require long drift spaces between the RF cavities. As a result, the RF system of a magnicon can be substantially shorter than the RF systems of either SBK's or MBK's. This advantage is especially significant at high powers, when relativistic beams must be used. To illustrate the difference between these types of RF sources, comparison is presented in

Table 1 of an SBK, an MBK and a magnicon, all at 800 MHz with powers of 120 MW. The parameters of the SBK are obtained by scaling of existing SLAC klystrons having powers of 75 MW and 150 MW [3,9]. The MBK parameters are obtained by scaling from Thales tubes with powers of 10 MW and 47 MW [10,11]. The magnicon parameters are from the design presented in this paper.

Table 1: Lengths of rf systems for different 120 MW, 800 MHz rf amplifiers.

type of rf amplifier	beam voltage, kV	beam current, A	length of rf system, m	reference used for scaling
SBK	550	400	8.5	[3,9]
MBK	300	600	4.5	[10,11]
magnicon	550	360	2.5	this paper

From Table 1 one can see that the SBK simply has unreasonable length. The MBK is still too long, and besides, its scaling was made with assumptions taken from the design example of the CERN MBK with a power of 47 MW [11], where the beam area compression ratio is taken to be 5.6:1; however, this is in contradiction with the current state-of-the-art for MBK guns [12], where the compression does not exceed 2:1. The required current density of 9 A/cm<sup>2</sup> for the MBK is also somewhat on the high side mainly because it will lead to too high electric field in the gun [13].

Preliminary design results presented here shows that no fundamental impediment exists to design and operation of a 120 MW (peak power), 800 MHz magnicon. It can be noted that the same concept may be used for a possible 1.3 GHz high-power RF source for the final accelerating stage of a muon factory. In addition, this concept may be considered to develop a 100 MW, 937.5 MHz RF source for the drive-beam accelerator of the CLIC collider [11].

## 800 MHZ MAGNICON

For the relatively low frequency required for a muon collider, a first harmonic magnicon amplifier is most suitable because it has the smallest dimensions compared to higher harmonic amplifiers at the same output frequency [5]. The major problem for first harmonic magnicon amplifiers is the limitation of output power caused by RF leakage through the beam exit aperture of the output cavity. Increase in the output power requires a beam voltage increase, which in turn leads to an increase

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in diameter of the beam aperture of the output cavity to above cut-off [5]. This effect could be a problem for output powers higher than 20-30 MW unless special measures are taken.

A schematic of the magnicon amplifier is shown in Fig. 1. It is composed of an electron gun, RF and magnet systems, and a beam collector. The RF system consists of a deflection system and an output cavity. The deflection system is composed of a drive cavity and four gain cavities, including the penultimate cavity. All cavities of the RF system oscillate in the circularly polarized  $TM_{110}$  mode at 800 MHz. The output cavity contains a special choke cavity in order to prevent RF radiation from passing through the output beam aperture, whose diameter substantially exceeds the cut-off limit. Both RF electric and magnetic fields are very small beyond the choke within a frequency band of at least 3 MHz.

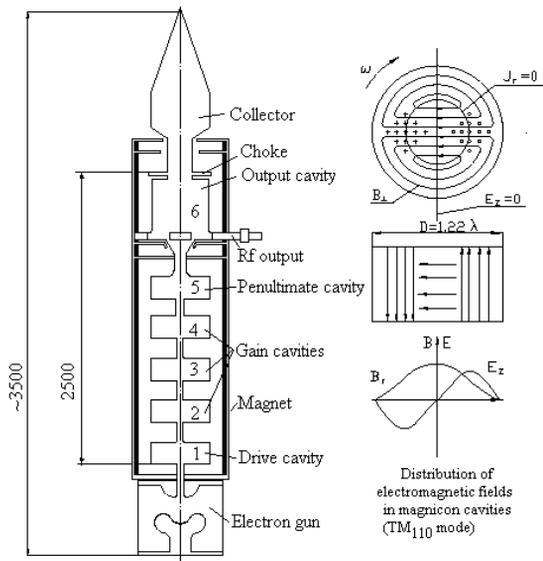


Figure 1: Schematic of a magnicon amplifier.

Fig. 2 shows the magnetic field profile in the tube.

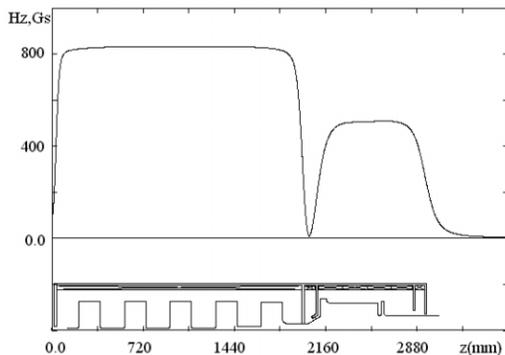


Figure 2: Axial magnetic field profile (top), coils, iron yoke and cavities layout (bottom).

Fig. 3 shows results of steady-state computations for the axial evolution of radial orbit displacement and particle

energy. Beam dynamics for the finite thickness beam have been optimized using realistic magnetic fields and realistic cavity geometries. Physical models and computer codes have been used which can provide start-to-end self-consistent simulations of a magnicon [14].

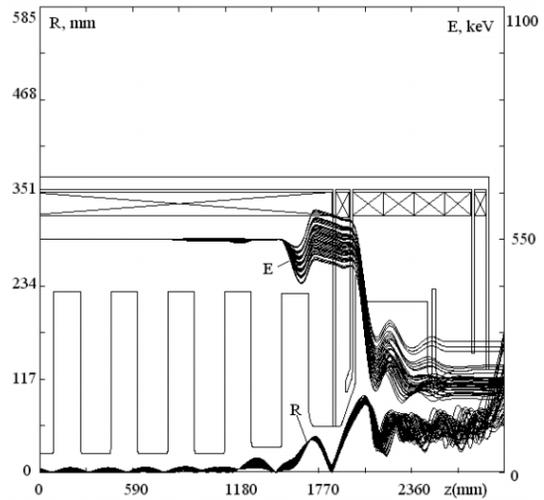


Figure 3: Results of preliminary simulations for 120 MW, 800 MHz magnicon. Shown is an outline of the RF cavities, energy  $E$  and radial coordinates of beam electrons  $R$ , all as functions of coordinate  $z$  along the axis of the tube.

The calculated drive curve is shown in Fig. 4. Magnicon output power vs drive frequency is shown in Fig. 5.

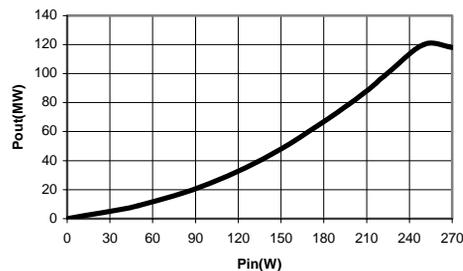


Figure 4: Output power vs. input power.

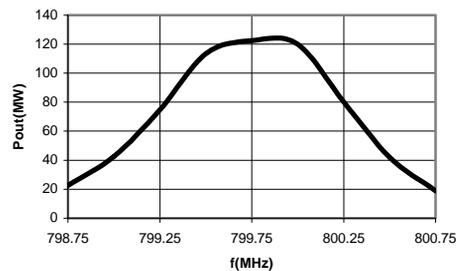


Figure 5: Output power vs. frequency.

Preliminary design parameters of this magnicon are presented in Table 2.

Table 2: Design parameters of 120 MW, 800 MHz magnicon amplifier.

frequency, MHz	800
output power, MW	120
pulse duration, $\mu\text{sec}$	10
repetition rate, Hz	15
efficiency, %	60
gain, dB	57
bandwidth at $-3$ dB level, MHz	1.3
beam voltage, kV	550
beam current, A	363
maximum field on the focus electrode, kV/cm	90
maximal current density on the cathode, $\text{A}/\text{cm}^2$	5.5
magnetic field in deflecting system, Gauss	800
magnetic field in the output cavity, Gauss	500
maximum surface rf electric field in the cavities, kV/cm	70

### 937.5 MHz MAGNICON FOR CLIC DRIVE LINAC

A drive-beam RF power generation system for one CLIC drive linac requires about 90 RF modules providing 100 MW each, during a 100  $\mu\text{sec}$  pulse with a repetition rate of 100 Hz. The original CLIC design is based on use of two 50 MW MBK for each station [11].

A magnicon can be built with the peak power of 100 MW and an average power of 1 MW, consequently replacing two MBK's.

Schematically it looks similar to the 800 MHz tube (Fig. 1). The tube design was optimised in order to reach an efficiency of 65% for an output power of 100 MW at a beam voltage of 500 kV. Design parameters of a 937.5 MHz magnicon are presented in Table 3. The length of RF system is equal to 2.1 m, as compared to 2.8 m for one 47 MW MBK designed by Thales [11].

Table 3: Design parameters of 937.5 MHz magnicon.

frequency, MHz	937.5
output power, MW	100
pulse duration, $\mu\text{sec}$	100
repetition rate, Hz	100
average power, MW	1
efficiency, %	65
gain, dB	55
beam voltage, kV	500
beam current, A	308
maximum field on the focus electrode, kV/cm	83
maximal current density on the cathode, $\text{A}/\text{cm}^2$	5
magnetic field in deflecting system, Gauss	900
magnetic field in the output cavity, Gauss	520
maximum surface rf electric field in the cavities, kV/cm	80

The major challenge is the electron gun design. For a 100  $\mu\text{sec}$  pulse, the  $E_{\text{max}} \cdot V$  product (electric field  $\times$  beam voltage) should be less than 2300  $(\text{kV})^2/\text{mm}$  [13]. The two-gap gun design (Fig. 6) allows one to satisfy this  $E_{\text{max}} \cdot V$  requirement, while preserving excellent optics.

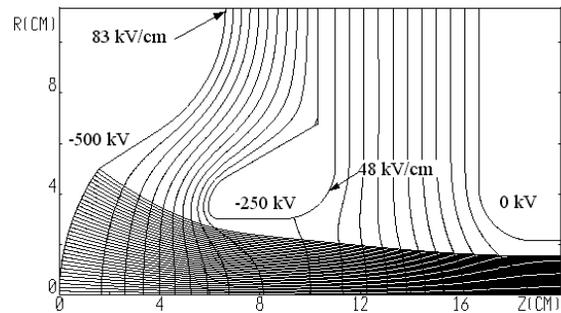


Figure 6: The gun layout, trajectories and equipotential lines.

The magnicon cavities have relatively large diameter ( $\sim 390$  mm), and Ohmic losses in the all cavities are less than 5 kW, which makes the cooling very simple. The collector would not seem to be a problem either, since the CW CERN SBK has already been built with an output power up to 1.3 MW.

### CONCLUSION

The examples shown in this paper of decimeter wavelength magnicons demonstrate that magnicons are an excellent alternative to either SBK's or MBK's for a wide range of accelerator applications, especially where high peak and average power are required.

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