MODIFIED MAGNICON FOR HIGH-GRADIENT ACCELERATOR R&D*

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Abstract

A self-consistent design is described of a modified 34.3 GHz magnicon amplifier with a TE311-mode output cavity, to replace the existing magnicon at Yale Beam Physics Lab Test Facility whose output cavity operates in the TM310 mode. The main goal for the new design is to achieve robust reliable operation. This is expected since for the new design tube performance—according to simulations—is relatively insensitive to the magnitude of external dc magnetic field, including imperfections in magnetic field profile; small changes in gun voltage and current; changes in electron beam radial size; and even poorly matched external circuitry. The new tube, as with its predecessor, is a third harmonic amplifier, with drive and deflection gain cavities operating near 11.424 GHz and output cavity at 34.272 GHz. The design calculations predict stable power output of 20-27 MW at a 10 Hz repetition rate in pulses up to 1.3 microsec long, with a low probability of breakdown in the output cavity because of low electric fields (less than 650 kV/cm).

INTRODUCTION

The 34.3 GHz magnicon, developed by Omega-P beginning in 1996, has been a key element at the Yale University Beam Physics Laboratory. After commissioning in 2003 [2], the tube was able to supply only limited—but diminishing—RF power for a number of advanced accelerator R&D and particle physics experiments. Explanations were found to originate with the design itself, with the processing regimen to which the tube was subjected, and probably to unavoidable internal damage during its eight years of operation.

There exist strongly compelling reasons to rebuild the 34.3 GHz magnicon. The Yale University Beam Physics Lab has already hosted a variety of experiments using power from the magnicon that were aimed at making systematic advances in high-gradient and particle physics research; and demand for use of this unique facility is increasing [1].

In order to have a robust tube working 24/7, with output power ~25 MW in Ka-band, the following steps are planned: (a) as for other tubes designed for high-power, the modified magnicon is to be a fully brazed assembly without ceramics (save for the gun insulator); (b) the design is to allow bake-out up to 600°C to successfully condition it in a reasonable time; and (c) the tube's output cavity is to operate in the TE_{311} mode, allowing a noticeable decrease in the RF field magnitude on the cavity walls, as compared to the presently employed TM_{310} output mode; in addition this allows a significant decrease in the guide magnetic field, and leads to a wider bandwidth—thus making the tube performance far less sensitive to operating parameters, which is critical during conditioning and routine operation. Development of a TE-mode output cavity is the main scientific innovation in this design.

DESIGN OVERVIEW

The modified design (Fig. 1) embodies the same elements as in former magnicons [2], namely (1) electron gun; (2) multi-coil superconducting solenoid with its own liquid helium reservoir and re-liquification system; (3) RF cavity deflection chain consisting of an X-band input cavity and five X-band deflection gain cavities; (4) frequency-tripling Ka-band output cavity; (5) beam collector; (6) kW-level phase-locked 11.4 GHz TWT driver; (7) diagnostics, including RF sampling in drive and deflection cavities; and (8) supporting subsystems such as chilled water for cooling, radiation shielding and monitoring, and a 100-MW pulsed modulator to power the tube.

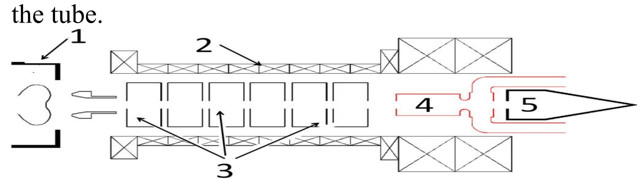

Figure 1: Schematic of the tube (not to scale). See text for description of numbered elements.

The electron beam originates at a 50 mm diameter cathode, is compressed to about 1 mm diameter by virtue of electrostatic gun fields and gradients in the guide magnetic field provided by the solenoid, and travels down the deflection cavity chain. The deflection system consists of one drive cavity, three angle-gain cavities, and two penultimate cavities; in each cavity the beam is deflected radially by a rotating TM_{110}-mode. The resulting scanning beam rotates at 11.424 GHz (the drive frequency), enters the output cavity and radiates coherently at 34.272 GHz, three times the drive frequency. In the first chamber of the output cavity the rotating beam excites the TE_{311} mode. The second chamber of the output cavity is strongly coupled with the first; it is fitted with four WR-28 waveguides that are coupled with the cavity to extract the generated power. Four WR-28 output waveguides are

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to allow installation and operation of up to four user experiments, and to reduce peak fields in each waveguide.

It is planned to use the existing 100 MW gun, except for replacement of its cathode and re-polishing the anode. Even though the gun [3] was designed to operate at 500 kV and 200 A, with high repetition rates and long pulses, experience shows that it operates more reliably at voltages ≤ 450kV. Consequently, the design of the tube is optimized for 450 kV.

The existing solenoid can be used as is. Because of having chosen a TE_{311} operating mode in the output cavity, with its low loaded Q-factor and a relatively short chamber length, the generated power is remarkably insensitive to moderate changes in the coil currents near the output cavity, as will be shown below. This is in striking contrast to the original magnicon, with its extreme sensitivity to adjustment of coil currents.

The deflection cavity system for the new tube has, as at present, six cavities. The first five existing cavities should remain as is, except for slightly modified detunings. The sizes of the last cavity are adjusted to allow for a large deflection angle at beam energies of ~450keV.

The new tube will have a modified beam collector. The collector internal geometry will be unchanged from the present version, but the present ceramic insulator will be eliminated. This is principally to allow high-temperature bakeout, but also to eliminate a suspected trapping site near the insulator where generation of spurious oscillations could well have occurred. The penalty to be paid is in giving up direct measurement of transmitted current.

NEW OUTPUT CAVITY

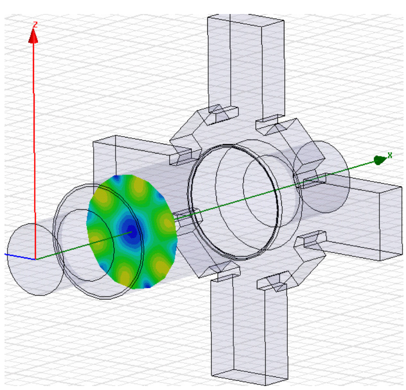

Figure 2: New output cavity.

The new output cavity (see Fig. 2) will be used following the deflection cavities. The design is a novel two-chamber combination whose loaded Q-factor is low (~200), with its first chamber being ~2 cm long and operating in the TE_{311} mode, rather than in the present TM_{310} mode. Solutions have been found with beam dynamics showing efficient transfer of beam power to RF power, good extraction of the produced RF power from the cavity *via* waveguides connected to the second cavity chamber, and detuning of higher- and lower-order modes so as to not interfere with power production at or near 34.272 GHz.

As the new cavity is the most crucial new element, major design efforts have been dedicated to its design. The new design should exhibit the following features: (a) acceptable magnitude of surface electrical fields inside the cavity, giving lowered breakdown probability; (b) low sensitivity to the static solenoidal guide field adjustment; and (c) acceptable sensitivity to changes in loaded Q-factor, to changes in the size of the beam, and to variations in gun voltage.

DESIGN PARAMETERS AND PERFORMANCES

The design parameters predicted for the tube are listed in Table 1. Figs. 3-6 show the tube performance. The overall conclusion we have reached is that the modified tube should allow reliable 24/7 operation without sensitivity to operating settings, thus making it a desired source of RF power as needed for a test facility.

Table 1: Design parameters of the modified magnicon

operating frequency (MHz)	34,272
output power (MW)	20-27
pulse duration, min-max range, μsec	0.25 – 1.3
repetition rate, Hz	10
electronic efficiency (%)	24 – 33
gain (dB)	52.3 – 51.3
drive frequency (MHz)	11,427.6
drive power (W)	115-200
beam power (MW)	84.15
beam energy (keV)	450
beam current (A)	187
beam diameter after compression (mm)	0.9
magnetic field in deflection system (kG)	11.87 – 10.28
magnetic field in output cavity (kG)	10.28 – 10.50

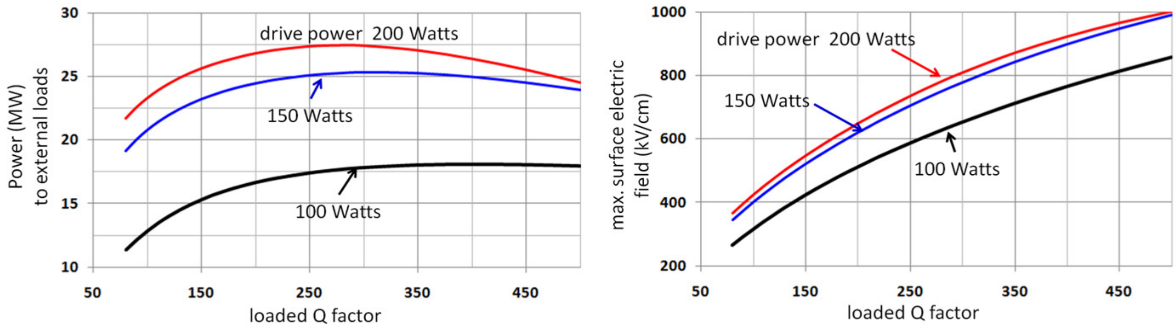

Figure 3: Power going to external loads (at left), and maximum surface field in the output cavity (at right), both as functions of output cavity Q.

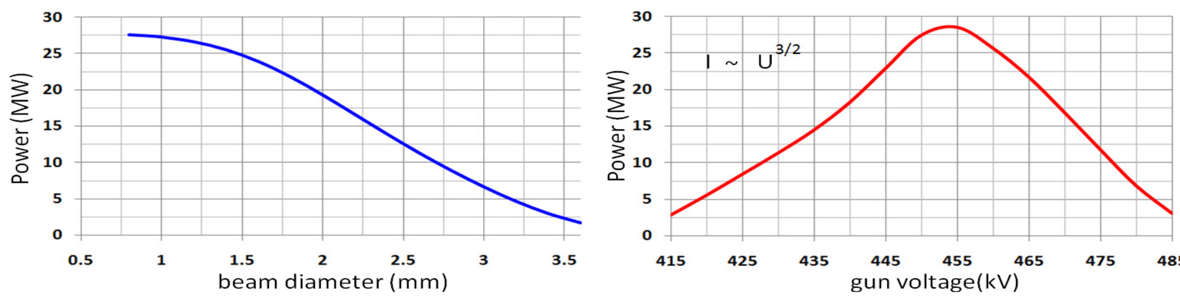

Figure 4: (left) Dependence of the power (MW) extracted from the electron beam *versus* beam diameter in mm; or (at right) *versus* gun voltage (kV). the guide magnetic field is not adjusted to maintain synchronism.

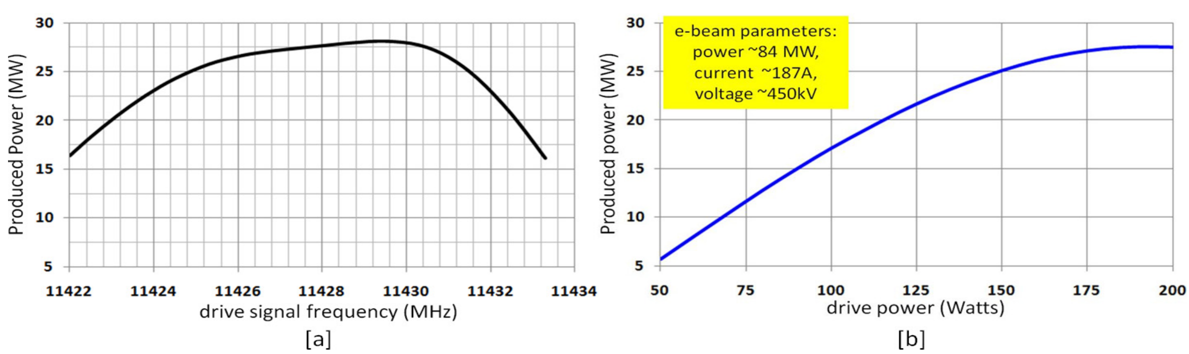

Figure 5: (a) Power generated *versus* frequency of the drive signal, at a drive power of 200 Watts; (b) Power generated when the drive signal power changes (the drive curve).

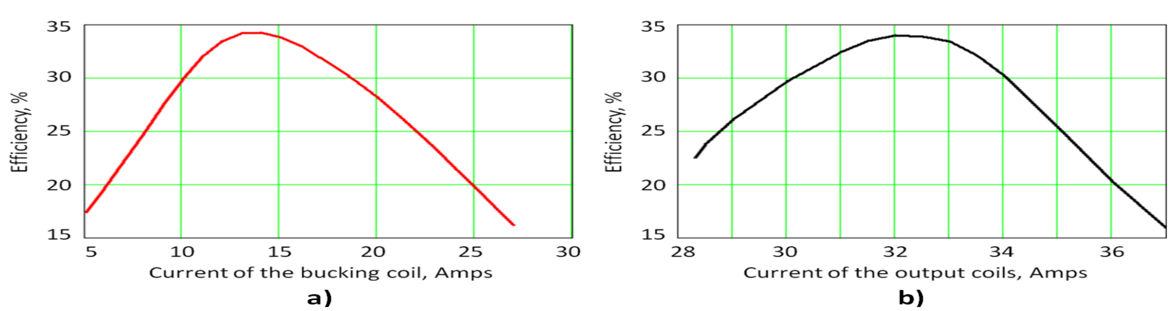

Figure 6: (a) Efficiency *versus* the current of the bucking coil; and (b) efficiency *versus* the current of the output coils wired together in series (in total there are 3 coils).

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