STATUS OF 34 GHZ PULSED MAGNICON PROJECT

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Abstract

A high efficiency, high power magnicon amplifier at 34.272 GHz has been designed as a radiation source to drive a multi-TeV electron-positron linear collider. Simulations predict a peak output power of 45 MW in a 1.5 microsecond pulse with an efficiency of 45% and a gain of 55 dB. The amplifier is a frequency tripler, or third harmonic amplifier, in that the output frequency of 34.272 GHz is three times the input drive frequency of 11.424 GHz. Thus the rotating TM_{110} modes in the drive cavity, 3 gain cavities and 2 penultimate cavities are resonant near 11.424 GHz; and the rotating TM_{310} mode in the output cavity is resonant at 34.272 GHz. A 500 kV, 215 A high area compression electron gun will provide an electron beam with a diameter less then 1 mm. A superconducting solenoid magnet will provide a magnetic field of 13 kG in the deflection system and 23 kG in the output cavity.

1 INTRODUCTION

In order to achieve high gradients and consequently to keep a future multi-Tev linear collider length within reasonable bounds one has to operate in the millimeter wavelength domain. For example, a 1.0 TeV c.m. collider at 11.424 GHz is expected to have a loaded gradient of 64 MV/m, a length of 17.7 km, and a wall-plug power of 180 MW [1]. In contrast, a 34.272 GHz upgrade to NLC would have a loaded gradient of 189 MV/m, so that each 1.0 TeV of additional c.m. energy would require an extra length of about 6 km and extra wall-plug power of about 90 MW, once a 34.272 GHz amplifier with 45% efficiency becomes available. In the case of two-beam linear collider (e.g. CLIC [2]) it is also desirable to have a high power RF source in order to test accelerating structures and RF components, and to determine limits in breakdown and metal fatigue (see, e.g. [3]).

The magnicon is a RF source, based on a circular deflection of electron beam, whose main features are high power and high efficiency [4,5]. These properties make the tube especially attractive for accelerator applications. Furthermore, since RF cavities in the magnicon are significantly larger than in a klystron at the same operating frequency, magnicons can be designed for the higher peak and average power.

The first magnicon developed at Budker INP was a fundamental harmonic amplifier at 915 MHz; it operated with an efficiency of 73% using a 300 kV, 12A electron beam [6]. The measured output power was 2.6 MW and pulse width was 30 μsec. In experimental tests also at Budker INP [7], a second harmonic magnicon amplifier operating at 7.0 GHz achieved an output power of 55 MW in a 1.1 μsec pulse and a repetition rate of 3 Hz, with a gain of 72 dB and efficiency of 56%. This device is driven at 3.5 GHz and uses 430 kV, 230 A beam with an area compression ratio of about 2300:1 [8]. The demonstrated performance of the second harmonic magnicon operation strongly indicates that a third harmonic magnicon amplifier could be a viable high power source at high frequencies for a future linear colliders.

2 THIRD HARMONIC MAGNICON AMPLIFIER

In scaling magnicon amplifiers to higher frequencies (consequently, smaller physical dimensions), a few design problems arise at high power due to the limitations imposed by cathode loading, breakdown field and pulse heating of the cavity walls. The concept of a third harmonic magnicon amplifier is introduced to overcome these limitations [9].

In general, a magnicon (as a klystron) consists of four major components, namely: electron gun, magnet, RF system and beam collector. The electron gun injects a 500 kV, 215 A beam with a diameter of 0.8 mm into a chain of cavities forming the RF system. The deflection system consists of a drive cavity, three gain cavities and two “penultimate” cavities (working in “angle summing” mode [10]). The external magnetic field provides both beam focussing and interaction between the electrons and the RF fields in the cavities. The electron beam is radially deflected by the RF magnetic fields of a rotating TM_{110} mode in the deflection system. The scanning beam rotates at the frequency of the drive signal (11.424 GHz), then enters the output cavity and emits radiation at three times the drive frequency (34.272 GHz) by interacting with the

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TM_{310} mode. Fig. 1 shows the required magnetic field profile (top) and the superconducting coil configuration and iron yoke geometry to achieve this profile (bottom). For effective deflection, the magnetic field in the deflection system should be such that $\Omega/\omega \sim 1.5$, where Ω is the cyclotron frequency and ω is the drive frequency. In the output cavity, however, for efficient extraction of energy, the magnetic field should be chosen such that $\Omega/3\omega \sim 0.9$ [9].

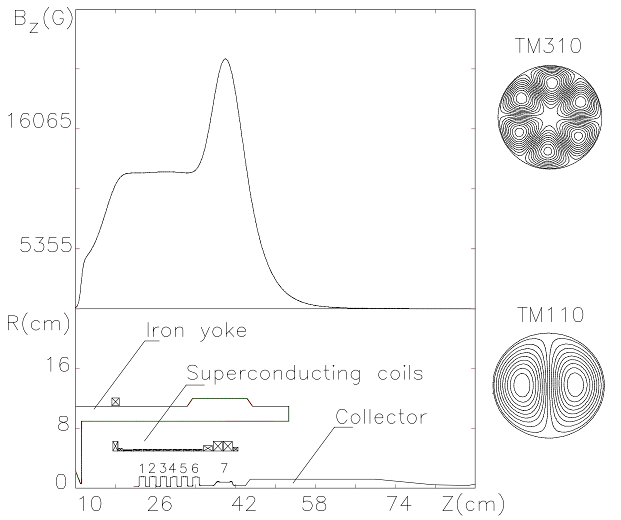

Fig. 1. Required axial magnetic field profile (top); superconducting coil and iron yoke layout (bottom). Cavity chain and collector are also shown. Inserts at the right show RF field patterns for cavities #1-6 of deflecting system (TM_{110} mode at 11.424 GHz), and for the output cavity (TM_{310} mode at 34.272 GHz).

Fig. 2 show results of steady-state computations for the axial evolution of radial orbit displacement and particle energy. The beam particles are seen to lose a substantial part of their energy in the output cavity. Beam dynamics for the finite thickness have been optimized using realistic magnetic fields and realistic cavity geometries [9]. The resulting design parameters of this amplifier are given in Table 1.

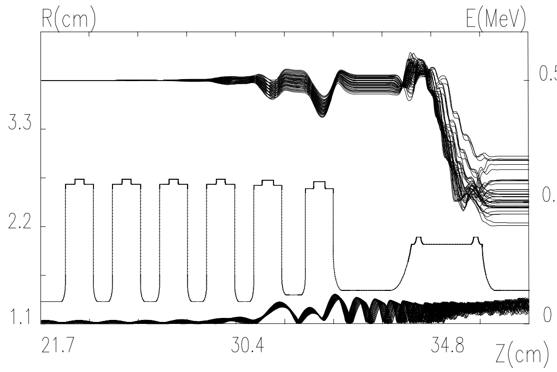

Fig. 2. Computed steady-state evolution with *z* of radial orbit displacement (bottom) and particle energies (top). Also shown are the cavity outlines.

Table 1: 34.3 GHz magnicon prameters.

Operating frequency, GHz	34.272
Power, MW	44-48
Pulse duration, μs	1.5
Repetition rate, Hz	10
Efficiency, %	41-45
Drive frequency, GHz	11.424
Drive power, W	150
Gain, dB	54
Beam voltage, kV	500
Beam current, A	215
Beam diameter, mm	0.8-1.0
Magnetic field, deflecting cavities, kG	13.0
Magnetic field, output cavity, kG	22.5

3 THE TUBE DESIGN

The complete design of 34.3 GHz magnicon is presented in Fig. 3.

1. *Electron gun.*

The gun design [9,11] calls for a cathode current density of 12 A/cm^2, and a maximum surface electric field strength of 238 kV/cm on the focus electrode. Beam compression in this gun is only partially electrostatic (500:1). Higher electrostatic compression would lead to a higher electric field at the focus electrode, and would require a magnetic field of about 13 kG at the edge of the pole piece, leading to undesirable saturation in the iron [11]. Thus a magnetic compression of about 2:1 occurs as the beam passes through the hole in the pole piece into a ~5 kG field, and a further factor of 3:1 occurs adiabatically as the magnetic field gradually rises up to 13 kG. The resulting compression ratio of 3000:1 is comparable to the 2300:1 compression ratio for the 7 GHz magnicon [7,8]. It is found in this design that 95% of the current is within a diameter of 0.8-mm [11].

At present, the gun is delivered. After manufacturing it was tested up to 100 kV, and test shows that the perveance is very close to design value. Modulator and pulse transformer were tested up to 500 kV. The beam collector is under construction. Now the gun is in preparation for full voltage tests.

2. *RF system.*

The RF system consists of seven cavities: one drive (#1) and three gain cavities (#2-4), two “penultimate” cavities (#5-6), and one output cavity (#7). The shapes and dimensions of the cavities are chosen to avoid monotron self-excitation of axisymmetric modes, and harmonic frequency modes [9]. All cavities of the deflection system are about 1.25 cm long and their diameters are about 3.0 cm. There are four WR90 waveguides built in the body of deflecting system. One of them is for drive cavity, and the rest are for measurements in the cavities #3, 5 and 6. These waveguides will also be used for pumping. The length of the output cavity (3.15 cm) and its shape were optimized to achieve maximum efficiency, absence of parasitic oscillations, and acceptable surface electric fields [9]. The diameter of the output cavity is about 1.75 cm. Power will be extracted by a set of four WR28 waveguides with an azimuthal separation $\Delta\theta = \pi/2$ that couple to both field polarizations [9]. One of them is shown in Fig. 3. The RF system is made as a brazed monoblock that allows backing up to 400° C.

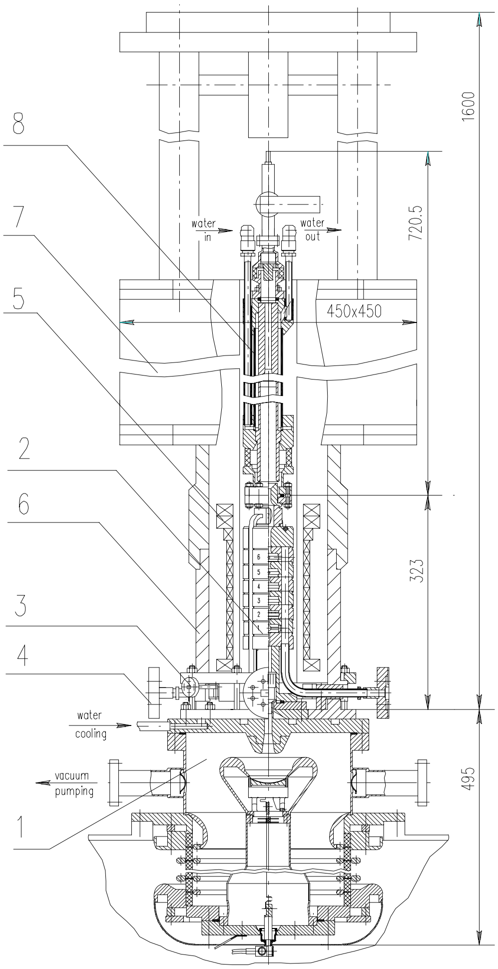

Fig. 3. 34.3 GHz magnicon amplifier tube: 1-electron gun, 2-RF system, 3-output waveguide (WR28), 4-WR90 waveguide, 5-superconducting coils, 6-iron yoke, 7-cryostat, 8-beam collector.

At present, cold tests are completed, and manufacturing has begun. The RF system is expected to be ready to the end of 2000.

3. Magnet

A superconducting solenoid (see Fig.3) provides a magnetic field of 13 kG in the deflection system and 23 kG in the output cavity. The magnet coils consist of three independently driven sections for adjustment of the magnetic field profile. Each section has a permanent superconducting switch. The coils are placed in a liquid helium cryostat with a vertical room temperature bore of 80 mm in diameter. The cryostat holds about 25 l of liquid helium. In order to decrease the liquid helium evaporation rate, radiation shields in the cryostat are cooled down to 30° K by an cryo refrigerator. The storage time of liquid helium is about 30 days.

The magnet is scheduled for delivery in July 2000.

4 CONCLUSION

It is expected that the most critical parts will be ready to the end of 2000. Tube tests lane scheduled to begin in early 2001.

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