34 GHz, 45 MW PULSED MAGNICON: FIRST RESULTS*

O.A. Nezhevenko,[1] M.A. LaPointe,[1,2] V.P. Yakovlev,[1] J.L. Hirshfield [1,2]
[1]Omega-P, Inc., New Haven, CT 06511 USA
[2]Physics Department, Yale University, New Haven, CT 06520 USA

Abstract

A high efficiency, high power magnicon at 34.272 GHz has been designed and built as a microwave source to develop RF technology for future multi-TeV electron-positron linear colliders. To develop this technology, this new rf source is being perfected for necessary tests of mm-wave accelerating structures, RF pulse compressors, RF components, and to determine limits of breakdown and metal fatigue. The description of this magnicon and first experimental results are presented in this paper.

INTRODUCTION

One of the attractive candidates for the role of rf source for a new generation of particle accelerators is the magnicon, a microwave amplifier employing circular deflection of an electron beam [1]. Magnicons have shown great potential with both high efficiency and high power. A first magnicon to have demonstrated these qualities was build and tested in the 80's in Novosibirsk. A power of 2.6 MW was obtained at 915 MHz with a pulse width of 30 μsec and an electronic efficiency of 85% [2]. In experimental tests also at Budker INP [3], a second harmonic magnicon amplifier operating at 7.0 GHz achieved an output power of 55 MW in a 1.1 μsec pulse, with a gain of 72 dB and efficiency of 56%. Another frequency-doubling magnicon amplifier at the NLC frequency of 11.424 GHz has been designed and built in a collaboration between Omega-P, Inc and NRL. The tube is designed to produce ~60 MW at 60% efficiency and 59 dB gain, using a 470 kV, 220 A, 2 mm-diameter beam [4]. At present, the tube is conditioned up to power level of 25 MW for 0.2 μsec pulse widths [5].

In order to develop RF technology in the millimeter wavelength domain for a future multi-TeV electron-positron linear collider, it is necessary to test accelerating structures, RF pulse compressors, RF components, and to determine limits of breakdown and metal fatigue. A high efficiency, high power magnicon at 34.272 GHz has been designed and built as the basis for a test facility dedicated to carrying out these aims.

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, rf breakdown and pulse heating of the cavity walls. The concept of a third harmonic magnicon amplifier is introduced to overcome these limitations [6,7].

In general, a magnicon (as a klystron) consists of four major components, namely an electron gun, magnet, RF system and beam collector. The electron gun injects a 500 kV, 215 A beam with a diameter of about 1 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 [8]). The external magnetic field provides both beam focusing and coupling between the electrons and the RF fields in the cavities. The electron beam is radially deflected by the RF magnetic fields of rotating TM_{110} modes in the deflection system cavities. 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 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 $\Omega/3\omega$~0.9 [7].

The design parameters of this amplifier are given in Table 1.

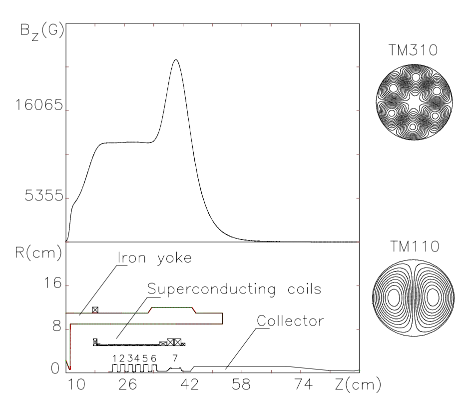

Fig. 1. Required axial magnetic field profile (top), and superconducting coil and iron yoke layout (bottom). Cavity chain and collector are also shown. Inserts at the right show RF field patterns for cavities #1-6 of deflecting system (TM_{110} mode at 11.424 GHz), and for the output cavity (TM_{310}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

* Work supported by US DoE

The gun design [9] 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. It is found in this design that 95% of the current is within a diameter of 0.8 mm [9] in the magnet.

TABLE 1. 34.3 GHz magnicon parameters.	
Operating frequency, GHz	34.272
Output 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

An engineering design drawing of the complete 34.272 GHz magnicon is presented in Fig. 2.

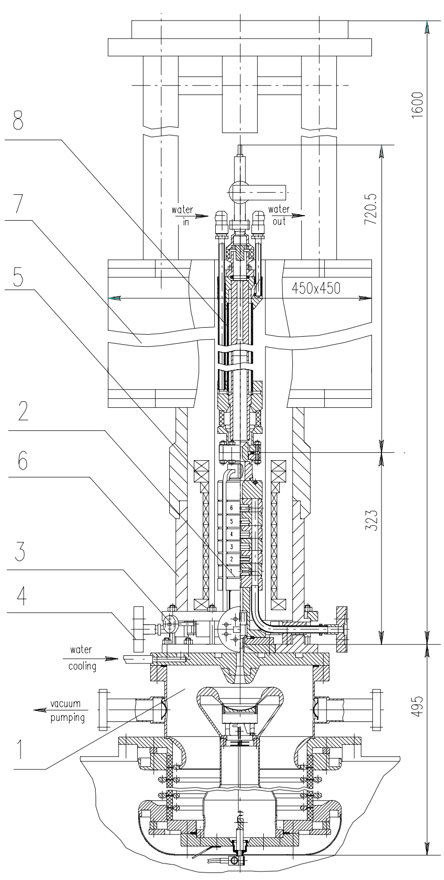

Fig. 2. 34.272 GHz magnicon amplifier tube: *1*-electron gun, *2*-RF system, *3*-output waveguide (WR28), *4*-WR90 waveguide, *5*-superconducting coils, *6*-iron yoke, *7*-cryostat, *8*-beam collector.

The RF system consists of seven cavities: one drive (#1) three gain (#2-4), two "penultimate" (#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 of harmonic frequency modes [7]. 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 the deflecting system. One is for the drive cavity, and the rest are for diagnostic measurements in cavities #3, 5 and 6. These waveguides are also 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 [7]. The diameter of the output cavity is about 1.75 cm. Power is extracted through four WR28 waveguides having an azimuthal separation $\Delta\theta = \pi/2$ that couple to both field polarizations [7]. Only one of the four is shown in Fig. 2. The RF system is built as a brazed monoblock that allows baking up to 400° C.

EXPERIMENT

Before assembling the full magnicon, the gun and beam collector were assembled and tested up to the design power of 100 MW in μsec pulses [9]. Initial conditioning up to ~515 kV was carried out without beam current. To achieve this, a matched load was connected to the primary of the pulse transformer. After cold conditioning, the gun was conditioned and tested hot up to ~480 kV and ~200 A. The measured beam current is in excellent agreement with the design value, with a measured error no greater than ±2%.

The magnicon was then assembled, cold tested and baked out in 2002. The cryomagnet was installed only later, after making modifications necessary to achieve the required axial symmetry of the magnetic field.

The general view of the fully assembled tube is shown in Fig. 3.

Preliminary tests of the tube were conducted for only a few days prior to PAC2003. Oscillograms of the measured input and output signals are shown in Fig. 4. The beam voltage for this experiment was 450 kV, beam current was 185 A, and drive frequency was 11.428 GHz. After a few days of conditioning at a repetition rate of 1 Hz, the output signal had not yet stabilized, and in the process of conditioning a rise of pressure is observed. Preliminary calibration shows about 1 MW of output power in one output and consequently, about 4 MW in total.

CONCLUSION

The 34 GHz magnicon amplifier is assembled and first tests have been conducted. To date the measured output power is about 4 MW.

The program of future experimental work on the 34 GHz magnicon test facility includes:

a) Experimentation on metal fatigue caused by pulse heating, and consequently determination of accelerating structure longevity.
b) Development high-power components, including output windows, mode converters, phase shifters, power splitters and power combiners, low-loss transmission lines, etc.

Fig. 3. The general view of the fully assembled tube.

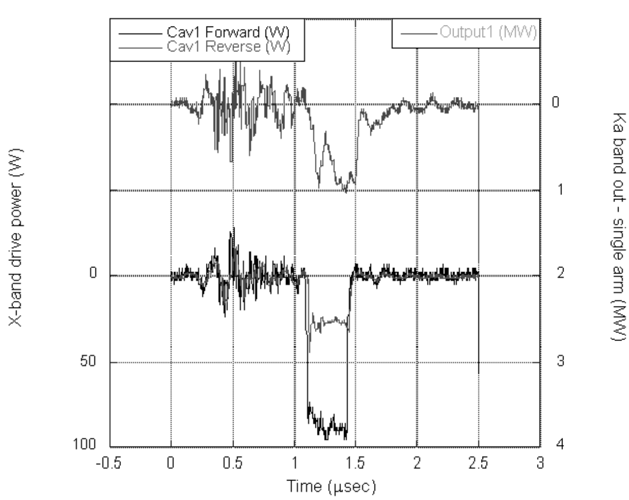

Fig.4. The oscillograms of the measured input and output signals. The upper curve represents output power and the lower curve is incident input signal.

REFERENCES

[1] O. A. Nezhevenko, *IEEE Trans. Plasma Sci.*, **22**, 1994, pp. 756-772.
[2] M.M. Karliner, *et. al.*, Instrum. Methods Phys. Res. A **269**, p. 459 (1988)..
[3] E.V. Kozyrev, *et. al.*, EPAC98, Stockholm, 1998, p.1897.
[4] O.A. Nezhevenko, *et al.*, *IEEE Trans. Plasma Sci.*, **30**, 2002, pp. 1220-1230.
[5] O.A. Nezhevenko, *et al.*, Present Conference, TPAE022.
[6] O.A. Nezhevenko, *et al.*, PAC97, Vancouver, 1997, p. 3156.
[7] O.A. Nezhevenko, *et al.*, AAC2000, AIP **569**, p. 786.
[8] O.A. Nezhevenko, and V.P. Yakovlev, *IEEE Trans. Plasma Sci*,, **28**, 2000, pp 542-549.
[9] V.P. Yakovlev, *et al.*, PAC2001, Chicago 2001, p. 1041.