# STATUS OF 34 GHZ, 45 MW PULSED MAGNICON*

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*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 a future multi-TeV electron-positron linear collider. To develop this technology, this new RF source is being perfected for necessary tests of accelerating structures, RF pulse compressors, RF components, and to determine limits of breakdown and metal fatigue. To date the magnicon has produced a peak output power of 17 MW with a gain of 47 dB at a repetition rate of up to 5 Hz.

## INTRODUCTION

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 in realistic regimes accelerating structures, RF pulse compressors, RF components, and to determine limits of breakdown and metal fatigue. A key element of a test facility required for such experiments is a high-power (tens of MW), 0.5-1 μsec pulsed microwave amplifier. The most attractive candidate for this role 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 built 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 Naval Research Laboratory (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].

In scaling magnicon amplifiers from cm to mm wavelengths (consequently, to smaller physical dimensions), several design issues arise at high power due to the limitations imposed by cathode loading, breakdown field, and pulsed heating of the cavity walls. A third harmonic magnicon amplifier described in this paper is introduced to overcome these limitations [5,6,7].

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## THIRD HARMONIC MAGNICON AMPLIFIER

In general, a magnicon consists of four major components, namely an electron gun, magnet, RF system and beam collector (see e.g. [7]). For the tube described here, the electron gun injects a 500 kV, 215 A beam with a diameter of about 1 mm into a chain of cavities that constitute the RF system. The deflection system consists of a drive cavity, three gain cavities and two "penultimate" 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.

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

Table 1: Magnicon Design Farameters

| | |
|---|---|
| Operating frequency, GHz | 34.272 |
| RF power $P_{RF}$, MW | 44-48 |
| Electronic efficiency $\eta_e$, % | 41-45 |
| Output power $P_{out}$, MW | 36-39 |
| Pulse duration, μsec | 1 |
| Repetition rate, Hz | 10 |
| Drive frequency, GHz | 11.424 |
| Drive power, W | 150 |
| Gain, dB | 54 |
| Beam voltage $V$, kV | 500 |
| Beam current $I$, A | 215 |
| Beam diameter, mm | 0.8-1.0 |
| Magnetic field, deflecting cavities, kG | 13.0 |
| Magnetic field, output cavity, kG | 22.5 |

In this table the RF power is equal to $P_{RF} = VI\eta_e$. Output power is equal to $P_{out} \approx 0.82P_{RF}$ due to Ohmic losses in the output cavity and output waveguides. Maximum efficiency corresponds to a beam diameter of 0.8 mm.

The magnetic field is determined by interaction conditions. For effective deflection, the magnetic field in the deflection system should be such that $\Omega/\omega \sim 1.5$, where $\Omega$ is the cyclotron frequency and $\omega$ is the drive frequency. In the output cavity for efficient extraction of energy, the magnetic field should be chosen such that $\Omega/3\omega \sim 0.9$ [6].

The complete engineering design of 34.272 GHz magnicon is presented in Fig. 1.

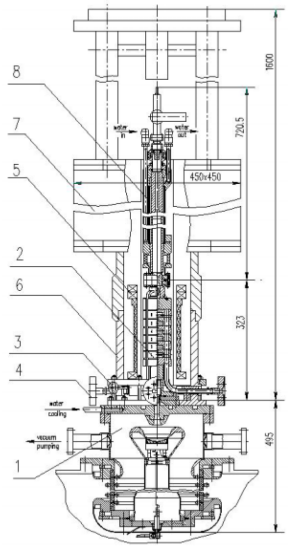


Fig. 1: 34.272 GHz magnicon amplifier tube: *1*-electron gun, *2*-RF system, *3*-output waveguide (WR28), *4*-WR90 waveguide, *5*-superconducting coils, *6*-iron yoke, *7*-cryostat, *8*-beam collector.

The diode gun design 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. During tests of the gun with collector parameters close to the design were achieved [8].

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 harmonic frequency modes [6]. 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 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 [5,6]. The diameter of the output cavity is about 1.75 cm. Power is extracted by a set of four WR28 waveguides with an azimuthal separation $\Delta\theta = \pi/2$ that couple to both field polarizations [5]. One of the output waveguides is shown in Fig. 1. The RF system is constructed as a brazed monoblock.

A general view of the fully assembled tube is shown in Fig.2.

Fig. 2: A general view of the fully assembled tube.

## EXPERIMENT

Preliminary tests of the tube began in May, 2003. After about $2\times10^5$ pulses at a repetition rate of about 1 Hz, the process of conditioning progressed to the point where a maximum output power of 10.5 MW in 0.25 μs pulses was achieved, as measured by a calibrated crystal detector [7]. Experiments at Yale University were suspended in June 2003 by administrative fiat.

The cycle of tube conditioning resumed in early 2005 and continued for about 2.5 months, mostly at a repetition rate of 1-2 Hz. During this cycle, the modulator pulse was shortened, as shown in Fig. 3, in order to reduce the risk of the gun arcing during conditioning. The conditioning process has proven to be protracted, and at this writing is not yet completed. The magnicon peak output power reaches about 17 MW for the beam voltage of 455 kV and a beam current of 187 A. Output power calibration was carried out by calorimetric measurements of average RF power in the loads. The output signal was frequency-analyzed with a shorted, slotted line; no parasitic oscillations appeared at the operating conditions.

The drive signal and signals from penultimate cavities (#5 and #6) are shown in Fig. 4. Output signals at maximum power level are shown in Fig. 5. At lower power the pulse shape is more rectangular.

The measured drive curve and the measured bandwidth are shown in Figs. 6 and 7. The drive curve is seen to be monotonic, and stable at zero drive; while the 3-dB bandwidth is seen to be about 30 MHz (10 MHz×3).

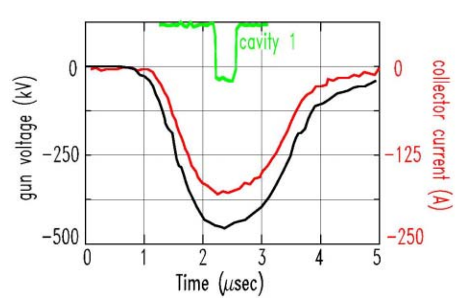


Fig. 3: Beam voltage (lower curve) and beam current (upper curve). Drive signal is also shown.

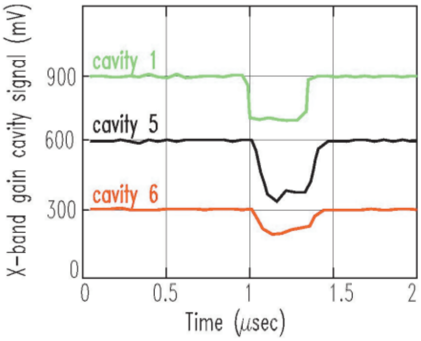


Fig. 4: Drive signal and signals from the cavities #5 and #6.

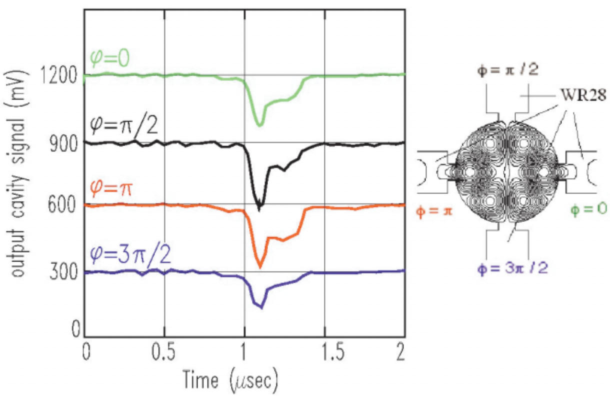


Fig. 5: Output signals from the four WR-28 output waveguides, and field pattern in output cavity.

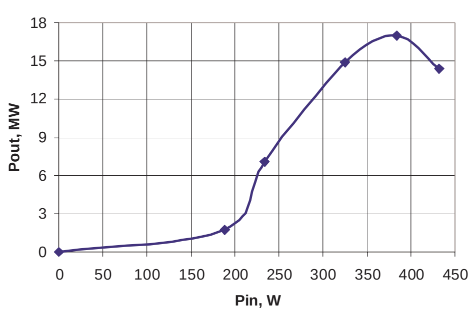


Fig. 6: Output power *vs*. input power. Solid line connects data points.

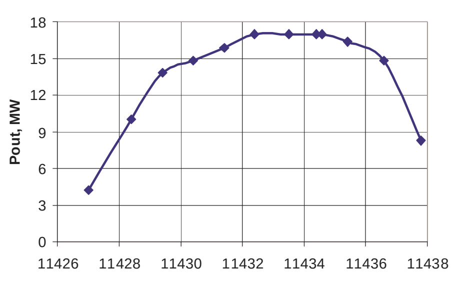


Fig. 7: Output power *vs*. drive frequency. Output frequency is three times higher. Solid line connects data points.

The results of the tests are summarized in Table 2.

Table 2: Magnicon Test Results

| | |
|---|---|
| Output power $P_{out}$, MW | 17 |
| RF power $P_{RF}$, MW | ~21 |
| Electronic efficiency $\eta_e$, % | ~24 |
| Repetition rate, Hz | up to 5 |
| Gain, dB | 47 |
| Beam voltage $V$, kV | 455 |
| Beam current $I$, A | 187 |

Electronic efficiency is calculated as $\eta_e = P_{RF} /(VI)$, where $P_{RF} = P_{out}/0.82$.

## CONCLUSIONS

The 34.272 GHz magnicon amplifier is assembled and operating tests have been conducted. To date the peak value of measured output power is 17 MW.

Conditioning progresses, the shapes of output signals and signals from deflection cavities are not yet stable, and pressure rises are observed. The tube demonstrates single frequency operation as a third harmonic amplifier with a gain of about 47 dB. Shorted slotted line measurements confirmed that the output signals are monochromatic to within a margin of about 30 dB.

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