PERFORMANCE OF X-BAND PULSED MAGNICON AMPLIFIER*

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Abstract

A frequency-doubling magnicon amplifier at 11.4 GHz has been developed and built as the prototype of an alternative microwave source for the Next Linear Collider, and to test high power RF components and accelerating structures. The tube is designed to produce ~60 MW, in ~1.2 µsec pulses at 58% efficiency and 59 dB gain, using a 470 kV, 220 A, 2 mm-diameter beam. Recent results of the tube performance are presented in this paper. Operation of this magnicon has established a research facility located at NRL as only the second laboratory in the USA, after SLAC, where high-power microwave development at the NLC X-band frequency can take place.

INTRODUCTION

This paper describes the current experimental status of the 11.424 GHz Omega-P/NRL magnicon amplifier [1], that is under development as an alternative RF source for a future electron-positron linear collider. The magnicon [2] is microwave amplifier tube that combines the scanning beam synchronism of the gyrocon [3] with a cyclotron resonant interaction in the output cavity. This synchronism makes possible high efficiencies and, with larger cavities than in klystrons, allows higher powers at high frequencies than comparable klystrons [2,4].

A schematic layout of the Omega-P/NRL magnicon is shown in Fig. 1. The tube consists of an electron gun, ~6.5 kG solenoid, RF circuit and collector insulated from ground. The 500 kV diode gun provides the required 100 MW of power, and a 2 mm diameter beam in the solenoid which corresponds to a beam area compression of 1400:1 [5]. The RF circuit has six 5.712 GHz TM_{110} deflection cavities (a drive cavity, three gain cavities and two penultimate cavities), followed by an 11.424 GHz TM_{210} output cavity. In contrast to the magnicon described in ref. [4], the two penultimate cavities are not coupled and operate in the angle summing mode, in order to suppress an instability that limits the pulse width [6]. To extract RF power there are two output apertures at the downstream end of the output cavity, separated by 135°, that couple to WR-90 waveguides.

The magnicon design parameters for the measured 2-mm beam diameter [5] are summarized in Table 1 and general view of the tube is shown in Fig.2.
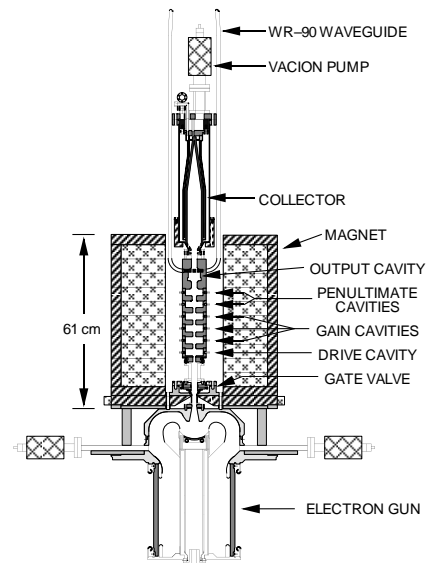

Figure 1. The magnicon schematic.

Table 1. Design parameters of the X-band magnicon.

Frequency, GHz	11.424
Power, MW	60
Efficiency, %	58
Pulse duration, µsec	1
Maximum repetition rate, Hz	10
Gain, dB	59
Drive frequency, GHz	5.712
Beam voltage, kV	470
Beam current, A	220
Perveance, A-$V^{-3/2} \times 10^{-6}$	0.68
Beam diameter in magnet, mm	2

EXPERIMENTAL RESULTS

1. Operation of the Omega-P/NRL magnicon has established an 11.424 GHz high power accelerator test facility at NRL. During 2001-2002, the facility was used to carry out two separate collaborative experimental programs, namely study of high-power active microwave
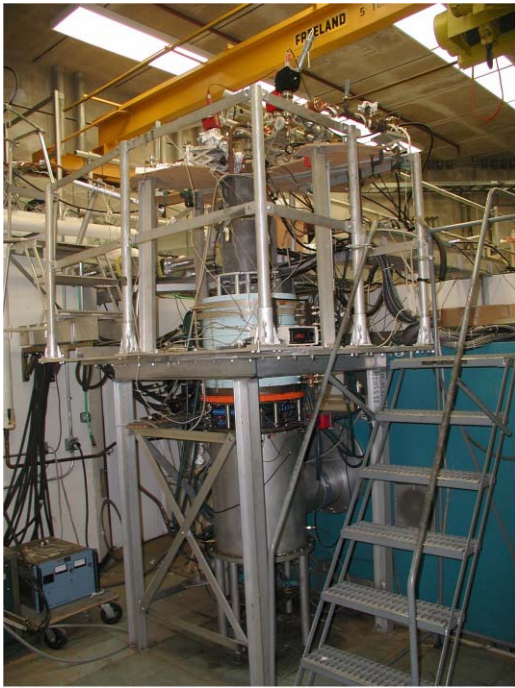
Fig. 2. General view of 11.424 GHz magnicon.

pulse compressors and high-gradient dielectric-loaded accelerating structures [7]. In 2002 high-power ceramic windows were installed at the magnicon output waveguides. These windows, built by Calabazas Creek Research, Inc. [8], allow one to change the test experimental configuration without breaking vacuum in the tube. Starting in February 2003, the magnicon underwent an extensive three-month cycle of rf conditioning.

2. After this cycle of conditioning, the output power remained limited to a level of 26 MW in a 200 ns pulse. Oscillograms are shown in Fig. 3.

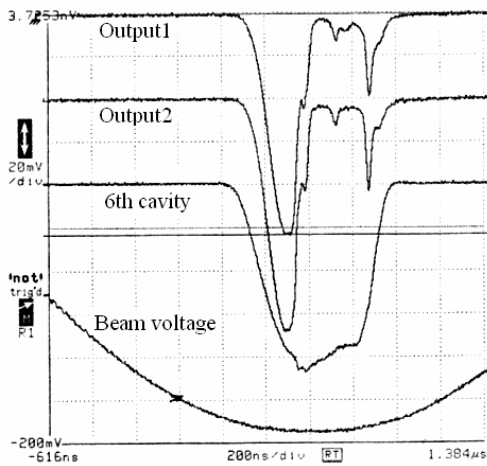Fig. 3. Oscillograms of both output signals, and signal from the penultimate (6th) cavity. Beam voltage pulse is shown also..The output power is about 13 MW in each output, the beam voltage is 490 kV and surface rf field in cavity 6 is about 600 kV/cm.

One can see that both output signals look similar, and that the output pulse width is limited by effects in the output cavity but not in the deflection system. Pulses from both penultimate cavities have the full width (signal from cavity 6 is shown in Fig.3) compared to the shortened output pulses. The output power was measured calorimetrically in both output waveguides. The measurements show that the output powers in the waveguides are equal to within a few percent over a wide range of output power.

3. The dependences of signals from the last three deflection cavities, as well as output power *vs.* input power, are shown in Fig. 4.
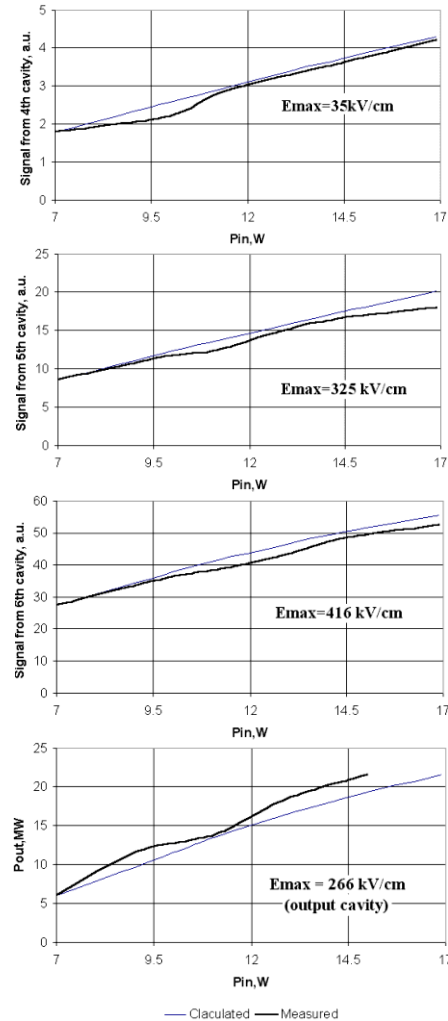

Fig. 4. Signals from the last three deflection cavities and the output power *vs.* the input power.

One can see that behavior of the measured curves is in good agreement with the simulation results. The maximum surface electric fields are given in Fig. 4 as well. One can see that these fields are well below the breakdown limit. Note, that the maximum achieved surface electric field in cavity 6 (Fig. 3) is about 600 kV/cm, which is higher than the value required for magnicon operation at a full power of 60 MW. The

curves in Fig. 4 are plotted against the measured input power, which is higher than the calculated value, mostly due to a shift in the first cavity frequency, which leads to strong reflections from the input port.

4. The shape of the shortened output signals and relatively low surface electric field in the magnicon cavities (Fig. 4) strongly suggest that the reason for the pulse shortening is not breakdown, but multipactoring. It was also found that pulse shortening is accompanied by a pressure increase in the tube collector. In an attempt to understand the possible cause of the observed problems, measurements of microwave signals from the collector have been made. The results of these microwave measurements are shown in Fig. 5 and Fig. 6. The oscillograms in Fig. 5 are taken in the regime of relatively low power, when there is no pulse shortening. The collector signal measurement was made with shorted slotted line, and the shape of the signal is very similar to that from cavity 6. The frequency measurements were made with both the slotted line and a heterodyne method. The measured frequency is exactly equal to the magnicon drive signal (~5712 MHz). Up to the certain level of power the amplitude of the collector signal scales smoothly with the magnicon input signal. When the input power is increased, pulse shortening in the collector signal is observed, and this begins at a power level that is lower than the level when output pulse shortening begins. These observations suggest excitation of a resonant mode in the collector, with efficient
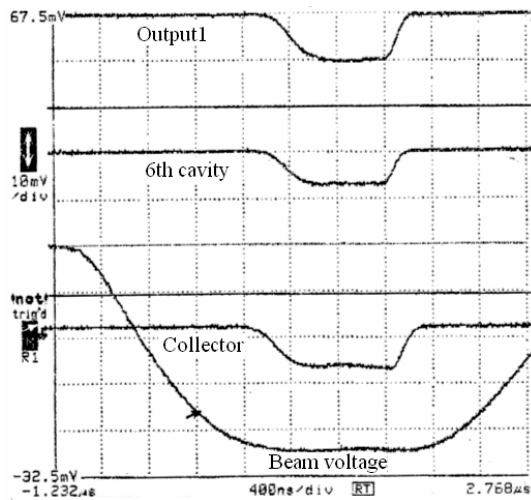

Fig.5. Magnicon signals for low power.

interaction of the gyrocon/magnicon type [2,3]. At the maximum power level, the collector signal drops to low amplitude, and one can see a peak in the midst of the collector signal (Fig. 6). The frequency of the signal in the peak is about 6.7 GHz. This signal is not synchronous with the magnicon drive or output frequencies and most probably is the result of self-excitation.

Thus, one is led to conclude that effects leading to output pulse shortening originate in the collector. The collector plasma cannot play a significant role in the interaction between the collector and the output cavity,

because the plasma drift time would be too long and the time difference between these two effects is too small. Most probably, electrons from multipactoring in the collector drift along the magnetic field into the output cavity, thereby triggering multipactoring therein.
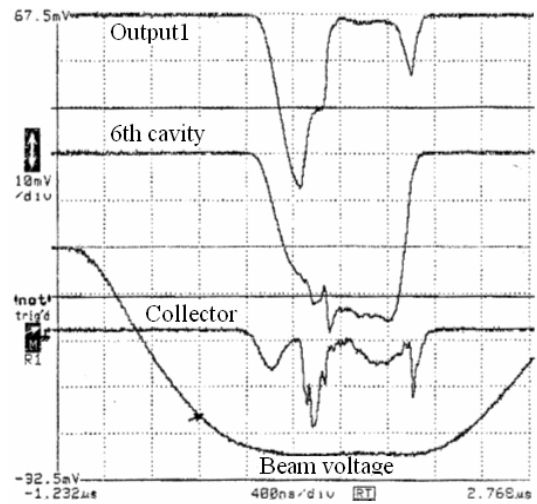

Fig.6. Magnicon signals for high power.

CONCLUSION

Future plans include design and fabrication of a new collector, based on the design of the collector built for the 34 GHz Omega-P magnicon [9]. This latter collector does not incorporate a large internal chamber that could support a spurious resonant mode, but also allows external damping to be inserted around the collector insulator in case oscillations do arise. It is anticipated that use of a re-designed collector will allow the 11.424 GHz magnicon to reach its design output power in a full-width pulse.

REFERENCES

[1] O.A. Nezhevenko, et al., PAC2001, Chicago 2001, p.1023.
[2] O.A. Nezhevenko, *IEEE Trans. On Plasma Sci.,*, vol. 22, p. 765, 1994.
[3] G.I. Budker, et. al., *Part. Accel*., vol. 10, p.41, 1979.
[4] E.V. Kozyrev, et. al., RF98 Workshop, AIP **474**, p.187.
[5] O.A. Nezhevenko, et al., *IEEE Trans. On Plasma Sci*., vol. 30 , p. 1220, 2002.
[6] O.A. Nezhevenko and V.P. Yakovlev, *IEEE Trans. On Plasma Sci.*, vol. 28, p. 542, 2000.
[7] S.H. Gold, et al., AAC2002, AIP **647**, p.439.
[8] http://calcreek.com
[9] O.A. Nezhevenko, et al., AAC2000, AIP **569**, p. 786.