THE LATEST EXPERIENCE WITH 7 GHz PULSED MAGNICON AMPLIFIER*

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Abstract

This paper presents a progress in the program of developing and researching of the high power pulsed 7 GHz magnicon – an amplifier operating in frequency-doubled mode. The tube design chosen by the numerical simulation and previous device versions investigation, the problems faced and overcome during testing as well as the latest experimental results in which a power of 30 MW, efficiency of 35 % and pulse width of 0.7 μs have been obtained at operating frequency of 7 GHz are described in the paper.

INTRODUCTION

The magnicon [1, 2, 3, 4] belongs to a new class of microwave amplifiers – deflection-modulated devices. The first magnicon was built and tested in the 1980's in INP [2]. During the first tests the magnicon showed efficiency exceeding that of klystrons achieved in the course of over 50 years of its development.

This paper presents the results of testing the advanced version of magnicon, which was described in detail at previous International Workshop (RF94) [5] and developed in INP as a prototype of the microwave power source for linear colliders.

A schematic diagram of the device is shown in Fig.1. The magnicon consists of the following basic units: an electron source, RF system, magnetic system and a collector. RF system consists of two parts: the deflecting system for

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beam modulation and the output cavity for conversion of the beam energy into the RF energy. A magnetic system provides a long-term interaction between beam electrons and RF fields in the cavities as well as beam focusing.

The tube is an amplifier operating at frequency of 7 GHz in frequency-doubling mode .

On all the deflection system cavities the circularly-polarized TM_{110} mode (Fig.1) oscillations are excited. The drive cavity 3 is excited by the drive generator. The passive (gain) cavities 4 and 5 are excited by a deflected beam. The penultimate cavity 5 consists of two coupled cavities in which the beam excites the opposite-phase (π-mode) oscillations, thereby enabling the realization of the deflection angle "summing" mode of operation [1]. This enables one to attain a deflection angle $\alpha > 50^\circ$ (which is necessary for reaching high efficiency) at a cavity surface RF field E≈250 kV/cm. In the output cavity 6 the modulated beam excites the TM_{210} mode (Fig.1) with a frequency two times larger than the drive frequency. All the cavities are located inside the solenoid 8, which produces a longitudinal magnetic field. For an effective beam deflection and interaction in the output cavity it is necessary for the cyclotron frequency of electron rotation in the solenoid field to be 1.5–2 times higher than the drive frequency [2, 4, 7]. The output cavity is more than 8 *cm* long that provides $E \approx 250\ kV/cm$.

The design parameters of this magnicon version are listed below:

Operating frequency	7 GHz	Drive frequency	3.5 GHz
Output power	55 MW	Gain	53 dB
Pulse duration	1.5 μs	Beam voltage	420 kV
Repetition rate	5 pps	Beam current	240 A
Efficiency	56 %		

The results of the beam behavior simulations in the process of deflection and deceleration are shown in Fig.2.

The design is based on the detailed preliminary numerical simulations [8]. The physical model considers a beam of finite transverse size, real space distribution of DC magnetic field and real RF fields of the cavities. Those fields were calculated by SAM and SuperLANS2 codes [9, 10]. We do not take into account space charge effects and finite beam emittance. The numerical model is based on macro particle methods. We have created the codes for both steady state and time dependent simulations. A self-consistent solution during the steady state simulation is obtained by choice of the cavity RF field amplitudes and phases to achieve an overall power balance. Steady state simulations were used for magnicon optimizing and stability analysis. Time dependent code has been applied for transient process investigations.

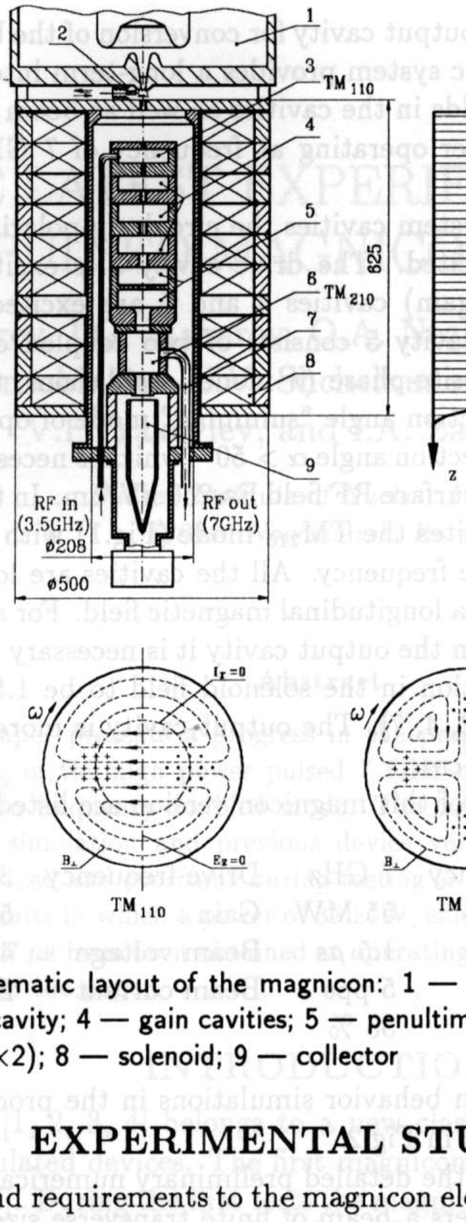


FIGURE 1. Schematic layout of the magnicon: 1 — electron source; 2 — vacuum valve; 3 — drive cavity; 4 — gain cavities; 5 — penultimate cavity; 6 — output cavity; 7 — waveguide (×2); 8 — solenoid; 9 — collector

EXPERIMENTAL STUDIES

The problems and requirements to the magnicon elements revealed and formed during the previous magnicon versions investigation [4, 5, 6, 11, 12] were took into account in present design.

1. At the present time, the initial tests of the latest magnicon version (Fig.1) have been carried out. The parameters obtained are listed below:

Frequency	7.006 GHz	Drive frequency	3.503 GHz
Power	30 MW	Gain	55 dB
Pulse width	0.7 μs	Beam voltage	401 kV
Repetition rate	3 pps	Beam current	210 A
Efficiency	35 %		

The oscillograms presented in Fig.3 are: beam voltage (U), signal from

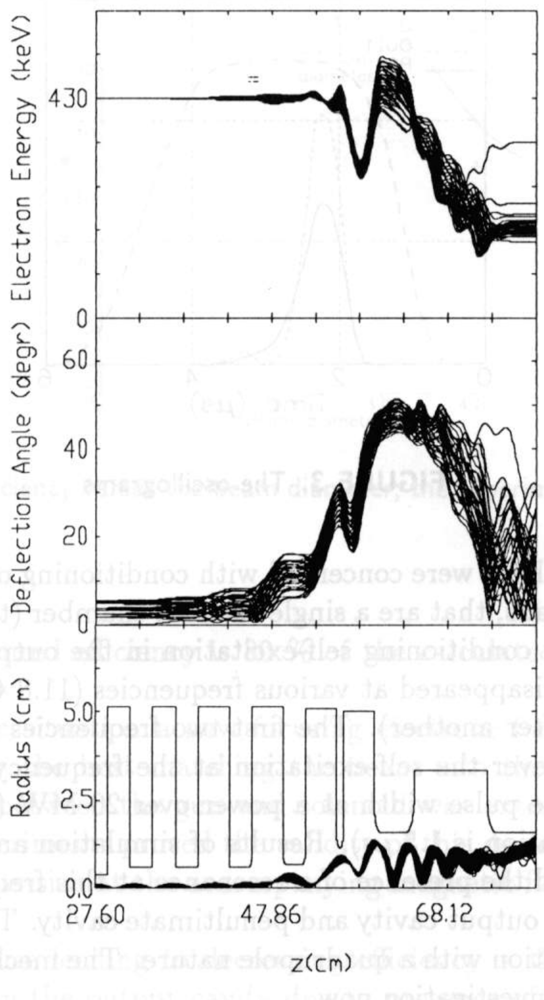


FIGURE 2. Simulation of the magnicon for a 3 mm diameter beam

the penultimate cavity (PC4) and output signal (OUT1). The output signal (peak power) calibration was carried out by the calorimetric measurements of average RF power.

The magnicon cavities consist of separated copper parts connected with one another by indium seals. This design allows to replace the RF system parts operatively but does not allow to bake-out the cavities up to high temperatures. This leads to long RF condition times for the cavities.

In the described experimental studies during the deflecting cavities conditioning the self-excitation was observed at different frequencies. After dismantling of the tube autographs of electric discharges were found almost in all the cavities. The discharges autographs indicate the self-excitation of various modes (symmetric and non-symmetric). However, these self-excitations disappeared during conditioning and were not observed at the operating range of drive signals.

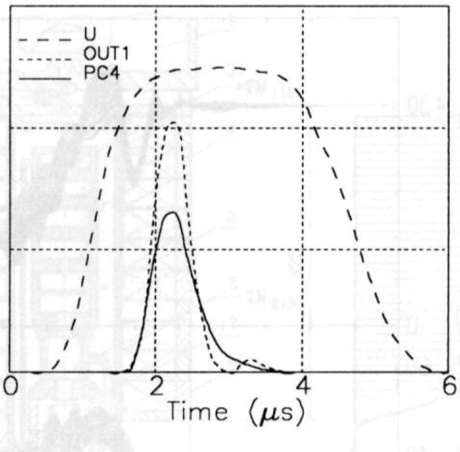


FIGURE 3. The oscillograms

The main problems were concerned with conditioning of the output cavity, waveguides and loads, that are a single vacuum chamber (there are no ceramic windows). During conditioning self-excitation in the output cavity appeared and after a time disappeared at various frequencies (11.8 GHz, 5.92 GHz and 12.04 GHz, one after another). The first two frequencies disappeared during conditioning, however the self-excitation at the frequency 12.04 GHz is still here and limits the pulse width at a power over 20 MW (at lower power the output signal duration is 1.5 μs). Results of simulation and measurements at atmosphere proved the presence of a resonance at this frequency. Oscillations present also in the output cavity and penultimate cavity. The oscillation mode has a field distribution with a quadrupole nature. The mechanism of this mode exciting is under investigation now.

2. The main causes of decreasing efficiency with respect to the designed value are a thicker beam (than the calculated one) and the non-optimal loaded Q-factor.

In the course of work on the 7 GHz magnicon we examined 7 cathodes. Depending on the cathode quality and gun assembling the beam diameter varies somewhat, however the average d_{max}=2.8 mm. However, in the present magnicon version the magnetic field of solenoid (8, Fig.1) is 0.37 T rather than 0.45 T, which is the projected value for operating gun [6].

This magnetic field decreasing by 20 % leads to the beam diameter increasing up to d_{max}=4 mm. The calculated efficiency value versus beam diameter d_{max} is shown in Fig.4. It is clear from Fig.4, that at d_{max}=4 mm efficiency cannot exceed 42 % and for the projected value of 56 % it is necessary to have the beam with d_{max} ≈3 mm. Moreover, the coupling between the output cavity and load was equal to 200 and was have been chosen optimal for the efficiency of 56 %. In the case of the beam with a large cross-size the efficiency decreases and it takes a higher loaded Q-factor value to obtain a maximal

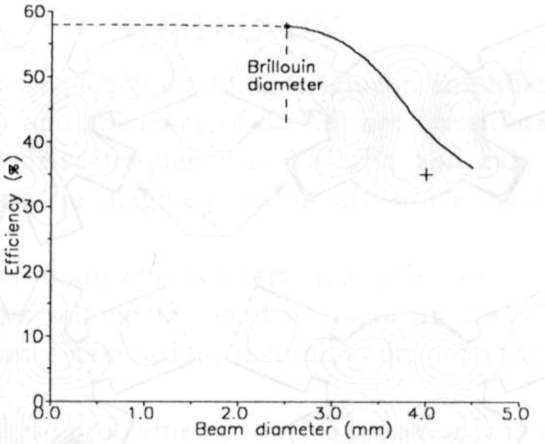


FIGURE 4. The efficiency versus the beam diameter; the experimental point is marked with +

output power.

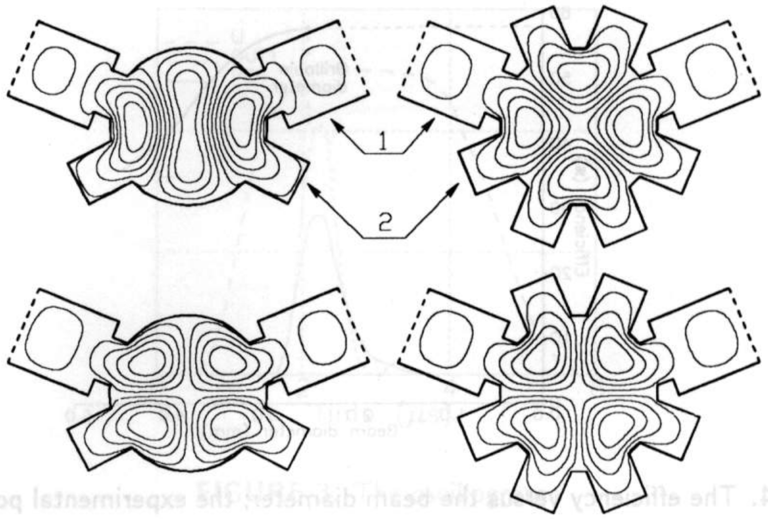
Thus the measured efficiency is 80 % of the calculated value for the real beam available now.

To improve the situation a new focusing electrode for the gun has been developed, and for the best matching the beam into the solenoid magnetic field the distance between the gun and solenoid was extended. This work is done now and experiments proved the validity of this decision. The measured maximal beam cross-size at the accompanying magnetic field of 0.37 T is less than 3 mm.

3. Another cause leading to decreasing efficiency is the RF fields distribution distortion in the output cavity due to presence of coupling apertures with waveguides. The field maps (2D simulation [10]) for orthogonal TM$_{210}$ modes, superposition of which defines the RF fields distribution in output cavity, are presented in Fig.5. For compensation of the coupling apertures with the waveguides 1 effect there are two protrusions 2 in the present design output cavity, however, their effect is inadequate. One can see that field distribution of these two modes differs sufficiently. The loaded Q-factors of these modes also somewhat differ (180 and 220). As a result the interaction with the beam is found to be irregular along the azimuth that leads to the decreasing efficiency.

This problem can be solved by increasing the number of protrusions. The improved cavity version is being developed now. We also think that improved cavity design can better the situation with the parasitic modes self-excitation firstly through decreasing the coupling between the beam and non-symmetric parasitic modes.

4. The measured dependence between the output power and drive signal (Fig.6) is in quite good agreement with the simulation results.



Present design Improved version

FIGURE 5. Field maps in the output cavity: 1 — waveguides, 2 — protrusions

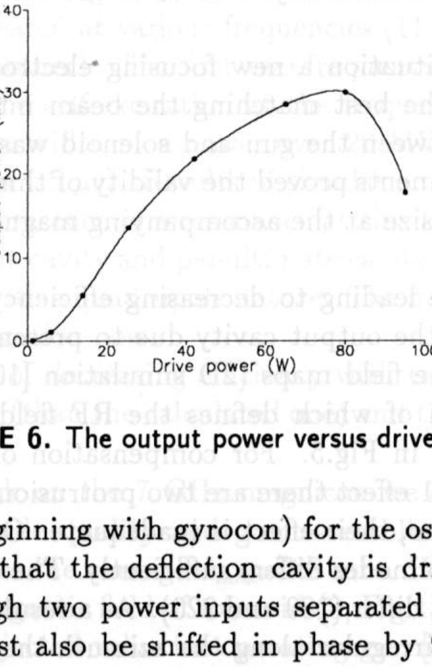


FIGURE 6. The output power versus drive signal

It is traditional (beginning with gyrocon) for the oscillations with circular polarization obtaining that the deflection cavity is driven by two signals of equal amplitude through two power inputs separated in azimuth by 90° [1, 13]. These signals must also be shifted in phase by 90°. In magnicon the beam is magnetized and its gyrotropic properties lead to the circular deflection "self-stabilization" effect, i.e. if oscillations with an elliptical polarization are excited in the cavity, the ellipticity is reduced in the presence of the beam [1, 2]. The experimental tests have verified that in the present magnicon version this wholesome effect shows itself so strongly that one can drive the deflection cavity by one signal (like a klystron) without a loss in output power and efficiency.

SUMMARY

In the course of 7 GHz frequency-doubling magnicon amplifier investigation a peak power of 30 MW and efficiency of 35 % have been obtained in a pulse of 0.7 μs width. The drive frequency is 3.5 GHz and gain is 55 dB. This performance establishes the magnicon as an attractive candidate for linear collider applications.

During investigations many effects interfering with normal device operating were revealed. They are: self-excitation of the penultimate cavity (TM_{010} and TM_{110} modes), harmonics generation, instability in penultimate and output cavities [5, 11, 12].

After eliminating these problems the device behavior is in good agreement with theoretical predictions and simulation results. The main causes of the difference between obtained efficiency and design value of 56 % are the relatively thick beam (diameter is 4 mm instead of 3 mm) and RF fields non-symmetry in the output cavity. We are going to eliminate these drawbacks and obtain parameters approaching the designed ones in the nearest future.

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