THE NOVOSIBIRSK 7 GHz PULSED MAGNICON AMPLIFIER*

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Abstract
The report presents experimental results obtained on 7 GHz pulsed magnicon amplifier with a new version of the output cavity. It also outlines plans for the investigation steps to follow. This magnicon was developed at INP as a prototype of a microwave power source for the next generation of linear colliders. The tube operates in frequency-doubling mode of the drive signal. At present the following parameters are achieved: a maximum output power of 55 MW, an efficiency of 56%, a gain of 72 dB and a pulse width of 1.1 μs.

INTRODUCTION

The work on creation of scanning-beam microwave amplifiers is carried out at INP since 1967. This new class of devices right from the start of its development was intended for high efficient power supply of accelerators. In 1970 at INP the first device of that type called gyrocon [1,2] was created. Further development of scanning-beam microwave amplifiers has been made possible with invention and development of magnicons [3]. The first magnicon – a prototype of continuous (quasi-continuous) microwave amplifier was built and tested in the 1980s at INP [3] and showed the record electron efficiency of 85% at a frequency of 915 MHz with pulse duration of 30 μs and the power of 2.6 MW.

In the beginning of 1990s at the Institute the work was started on the development of the improved magnicon version. That magnicon was proposed as a prototype of the microwave power source for linear colliders [4]. A schematic diagram of the device is shown in Fig.1. It includes: electron gun, RF-system, magnetic system, and collector. The tube operates at 7 GHz in frequency-doubling mode, so the RF system consists of the series of deflecting cavities (the first externally driven) for beam modulation at 3.5 GHz and output cavity for conversion of beam energy into the microwave power at the second harmonic (7 GHz).

The prime object of this device investigation was to show its serviceability and ability to provide the parameters which are required from present-day microwave sources.

The design parameters are listed in Table 1.

The difficulty in achieving the desired parameters was well recognized at the beginning of our work. Thus the creation of software for simulation of electron optics, electromagnetic systems, and electron beam dynamics in both steady state and time dependent regimes was carried out simultaneously with an experimental study. Computer codes SAM, SuperLANS [5,6] as well as codes for simulation of steady-state and time-dependent magnicon operation conditions [7] have been created and refined. An electron source with unique parameters [8] has been manufactured and successfully tested. Various versions of the design of the tube and its individual components [4] have also been studied.

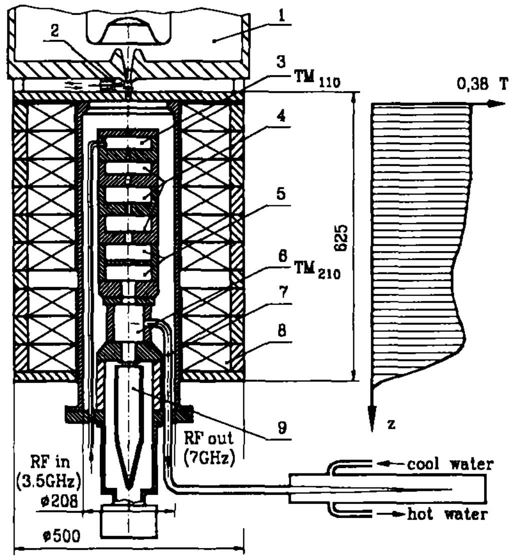

Figure 1: Schematic layout of the magnicon:
1 – electron source; 2 – vacuum valve; 3 – drive cavity; 4 – gain cavities; 5 – penultimate cavity; 6 – output cavity; 7 – waveguide (×2); 8 – solenoid; 9 – collector.

Table 1: Design parameters.

Operating frequency	7 GHz
Drive frequency	3.5 GHz
Output power	50—60 MW
Gain	55 dB
Pulse duration	1.5—2 μs
Efficiency	50—60 %
Beam voltage	420 kV
Beam current	240 A

EXPERIMENTAL STUDIES

From the simulation and experimental results it has been found that an electron beam size and matching its optics

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with the DC magnetic field are the determining factors of magnicon efficiency. In 1996, the electron source was modernized by changing the geometry of gun focusing electrode, the matching between the electron beam and tube's magnetic system was also improved. The maximum value of DC magnetic field for optimal device operating is 0.38 T. In this case scalloping of the beam transverse size in the magnetic system lies in the range from 1.9 to 2.5 mm. As a result of these improvements in 1997 an output power of 46 MW was achieved with an electron efficiency of 49% and gain of 62 dB [9].

It also has been found that the magnicon electron efficiency significantly drops due to the longitudinal inhomogeneity and azimuthal asymmetry of RF fields in the output cavity, which are caused by the coupling holes with waveguide power outputs [10]. These built-in outputs are located on the cylindrical surface and spaced 135 degrees apart by azimuth and produce both azimuthal asymmetry and longitudinal inhomogeneity of RF field. These problems were solved with the special design of the output cavity (see Ref. [10]).

With all of these improvements the present experimental results as shown in Table 2 are very close to the design goals.

Table 2: Achieved parameters.

Operating frequency	7.005 GHz
Drive frequency	3.5025 GHz
Output power	55 MW
Gain	72 dB
Pulse duration	1.1 μs
Efficiency	56 %
Beam voltage	427 kV
Beam current	230 A

Oscillograms of the pulses, experimental and calculated curves are shown in Fig. 2–3. Parameters obtained at the device optimal operating regime are marked by • symbol. The output power calibration was carried out by calorimetric measurements of an average level of RF signal passed through the waveguide vacuum loads (there are no waveguide windows).

An output cavity with a loaded Q-factor Q_l=230, which is somewhat higher than the optimal value Q_l=180, was used in experiments (seen from the calculated curve in Fig. 4a), that decreases the device efficiency by 2 %. The increased Q-factor has been chosen in order to shift from the region of possible instability causing a sharp efficiency drop.

A small difference between the frequency characteristic curve and simulation results (Fig. 4b, curve 2) is due to non-optimal tuning of drive cavity input circuits.

Simulation results show that increasing in efficiency can be achieved by decreasing DC magnetic field (Fig. 4c). Therewith a gain drops but still remains high enough. In the given series of experiments we were

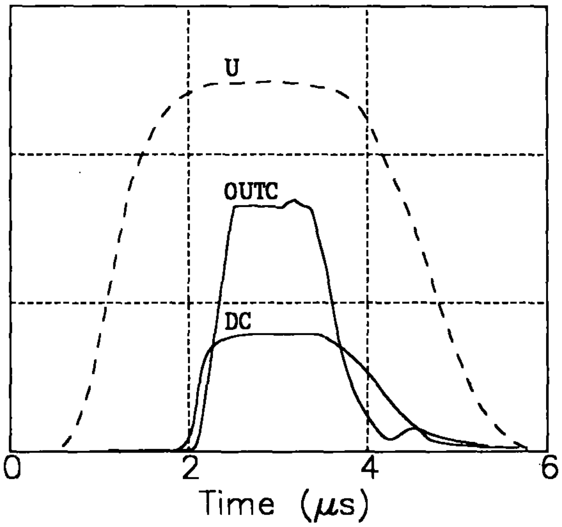

Figure 2: Oscillograms:
U – beam voltage; DC – drive cavity signal; OUTC – output cavity signal.

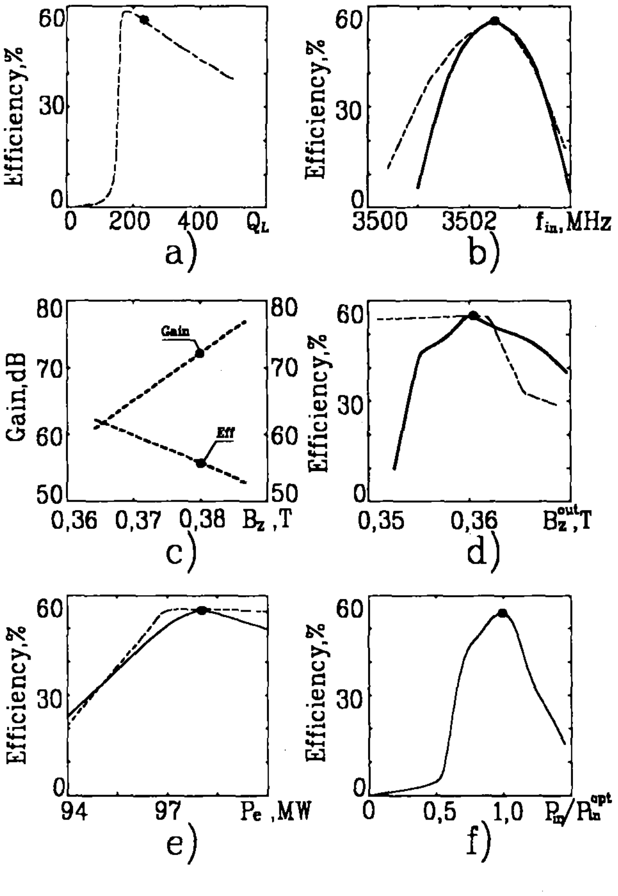

Figure 3: Experimental and calculated curves:
a) loading dependence; b) input frequency dependence; c) DC magnetic field dependence of gain and efficiency; d) output cavity DC magnetic field dependence of efficiency; e) beam power dependence of efficiency; f) efficiency versus drive power. Continuous lines correspond to experimental data, dashed – to simulation results.

unable to decrease DC magnetic field significantly, for a beam quality is impaired because of mismatching. However, since the magnetic system solenoid consists of two sections powered by individual sources, dependence between an efficiency and magnetic field value in the output cavity area has been studied (Fig. 4d). It can be seen that experimental data are in good agreement with simulation results at operation regime and at minor variations of that field when change of the beam optics in the deflecting system may be ignored.

We did not achieve the designed output pulse length yet. One of the reasons is associated with a strong dependence between the efficiency and beam power. Figure 4e) shows calculated and experimental curves obtained at fixed values of DC field and drive signal. Difference between them within non-optimal areas may be explaned by the fact that the calculations were carried out for a fixed beam optics. That optics corresponds to the optimal operating regime.

The pulse length may be roughly estimated from the time dependence of the beam voltage (Fig. 3) and beam power dependence of efficiency (Figure 4e). The real pulse length will be always shorter due to effects not taken into account.

Simulation of the signal shape at the given beam power dependence of efficiency shows, that for the voltage pulse of given shape the output signal length is limited by 1.5 μs. This problem can be overcome by improving the voltage pulse shape on the gun.

Another possible reason is related to excitation of 0-type oscillation in a penultimate cavity. The penultimate cavity consists of two cavities coupled through the central hole (coupling coefficient is 0.7%). The operating mode for this cavity is π-mode. However, simulation results show, that in spite of a high value of Q-factor, 0-mode limits a pulse length of the output signal at a level of 0.8–1.2 μs. This effect was detected in the course of 11.424 GHz magnicon development at Omega-P [11].

Figure 5 shows a typical outlook of instability growth in the penultimate cavity at 0-mode exciting, obtained by simulation. It should be noted that instability growth time is critically sensitive to the DC magnetic field value. So the change in the output pulse length may range up to 40 % at the DC magnetic field change of 0.6%.

At present time we design a new penultimate cavity, which will allow us to remove this restriction.

SUMMARY

In the latest series of experiments on 7 GHz magnicon almost all design parameters have been achieved. Experimental data are in an excellent agreement with simulation results. Achieved results allow to consider a magnicon as an alternative power source for linear colliders applications interchangeably with the best modern klystrons even at present time.

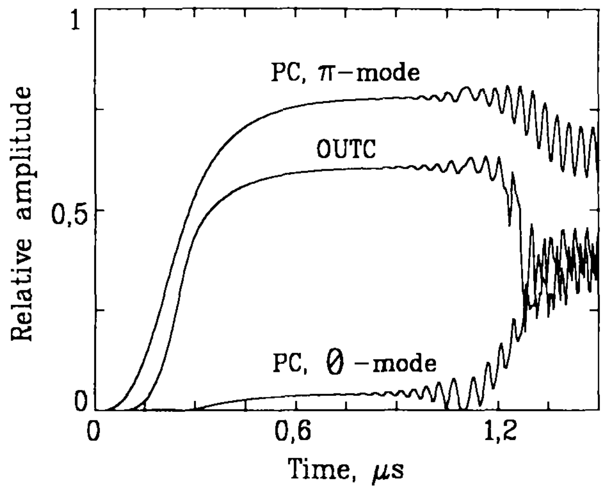

Figure 4: Transient process in the magnicon when both 0- and π- modes are excited in the penultimate cavity; PC corresponds to penultimate cavity, OUTC – to output cavity.

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