MAGNICON - A NEW MICROWAVE GENERATOR
FOR ACCELERATORS

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A new VHF generator with circular deflecting of the electron beam, the extension of the gyrocon proposed by G.I. Budker in 1967, is described. The magnetic accompaniment and long interaction enable a higher power to be achieved in the decimetre and centimetre wave range, in comparison with that of the gyrocon and the klystron. The high power and efficiency, the possibility of regulating the output power of the device, as well as the high gain make it possible to effectively employ the magnicon for RF supply of accelerators and storage rings.

Operation Principle of the Magnicon

At INP (Novosibirsk), the continuous generation gyrocon of metre wave range and the pulse gyrocon of decimetre range[1,2], both possessing high power and efficiency, have been build for the VEPP-4 facility. However, the analysis shows that in an attempt to build a higher-frequency gyrocon, the difficulties arise associated mainly with electric strength and overheating of the resonators. In particular, in the gyrocon output resonator the electric field is $E \sim f$, the ohmic losses giving rise to a decrease in efficiency are $P_R \sim f^{0.5}$ and the losses per unit surface are $P_S \sim f^{2.5}$. One more (characteristic of the gyrocon) limitation is connected with the difficulty of transferring a high-power beam through narrow slits in the output resonator walls. If the slit width is assumed to be equal to $D \sim f^{-1}$, then the ultimate power of the gyrocon is $P \sim f^{-2}$.

As one of the possible solutions of the problems encountered we suggest a gyrocon with magnetic accompaniment, i. e. the magnicon[3] whose layout is schematically depicted in Fig. 1.

The electron beam from the source reaches the circular scanning device and deflects herein by the angle α_0. In the drift space the beam acquires the required radius and reaches a stationary magnetic field of the solenoid where the longitudinal velocity of the electrons converts into a transverse, rotational one, and the degree of conversion is characterized by the angle α (Fig. 1). Moving on in the uniform magnetic field along the helical trajectory, the electrons then arrive at the output resonator and excite here an azimuth-travelling wave (oscillations E_{110}) and give off their energy.

Circular scanning provides the arrival of the electrons at the output resonator in an appropriate phase of the rotating electromagnetic field. If the cyclotron frequency (Ω) is close to the operating frequency (ω), i. e. to the frequency at which the scanning has occured and the output resonator is tuned, and the direction of the cyclotron rotation coincides with that of rotation of the circular scanning, then an effective interaction can constitute many periods of high-frequency oscillations. It is natural that if multipole oscillations are used in the output resonator the device can operate in the frequency multiplication mode.

The beam energy is transferred to the electromagnetic field due to a decrease of the transverse constituent of the electron velocity at the practically constant longitudinal one; the trajectory of an electron in the resonator looks like a helix, decreasing in diameter (Fig. 1) and the electron efficiency is equal, correspondingly, to

$$\eta_e = \frac{\upsilon^2}{\upsilon_0^2} = \sin^2\alpha .$$

Conversion of the transverse electron velocity into the longitudinal velocity, which is necessary for interaction, is determined by a balance of forces caused by the action of the electric E_z and the magnetic B fields of the resonator.

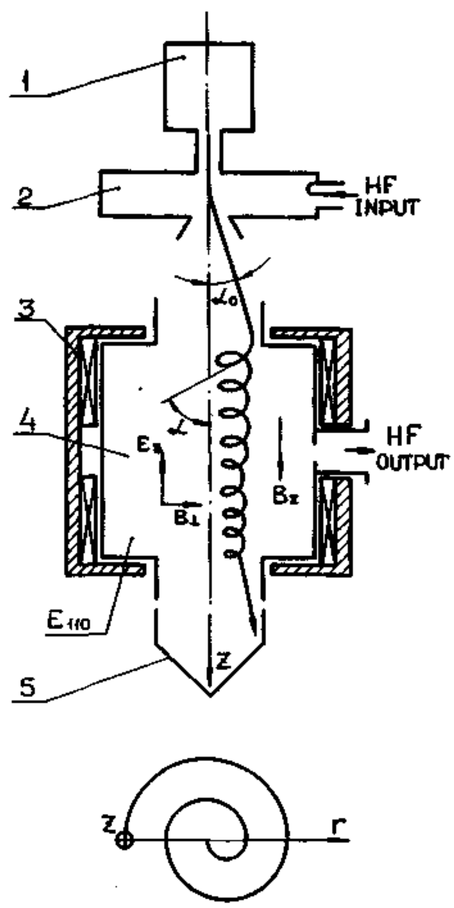


Fig. 1. 1-source of electrons, 2-scanning resonator, 3-solenoid, 4-output resonator, 5–collector.

The large length of the resonator enables one to reduce substantially ohmic losses in its walls and the specific heat release, as well as to increase electric strength by a few times.

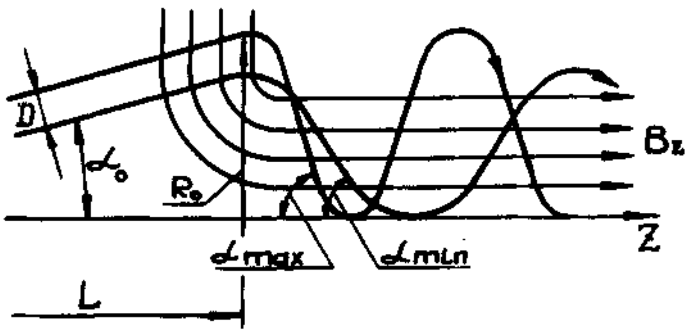
Large holes in the resonator centre (the diameter of a hole is about two Larmor diameters) coupled with magnetic accompaniment practically eliminates the problem of the pass of current flow. Naturally, the possibility arises to regulate the output power of the magnicon by changing the input signal.

The finite size of the beam cross section and the relativistic effects are the major factors determining the electron efficiency of the magnicon.

1. The finite size of the beam leads to an appearance of the spread in the pitch-angles a and to the azimuthal «smearing» of the beam (Fig. 2a). In this case, the electron efficiency may be estimated as follows:

$$\eta_e = \sin^2 \alpha_{max} \left(1 - \frac{D}{2R_0}\right)^2 \left(\frac{\sin \psi/2}{\psi/2}\right)^2,$$

where ψ is the azimuthal size of the beam. To reduce the beam diameter (D), it is naturally required to



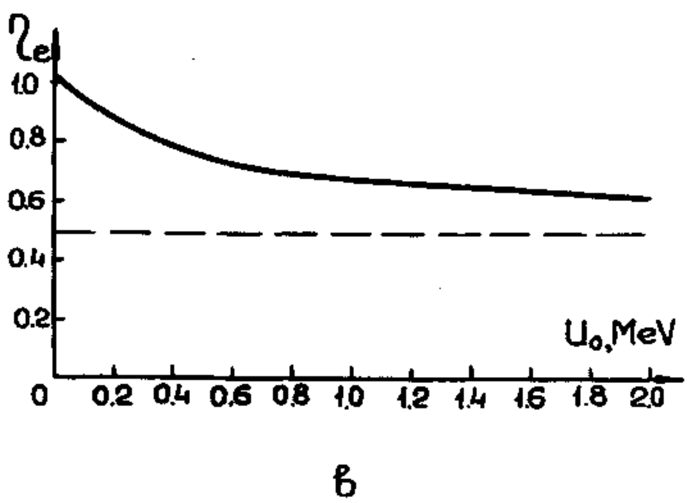


Fig. 2.

shorten the flight length (L) between the deflecting resonator and the entrance to the solenoid, i. e. to increase the deflecting angle in the circular scanning system since

$$L = \frac{\beta_0 \lambda}{\pi} \frac{\sqrt{\sin^2 \alpha_{max} - \sin^2 \alpha_0}}{\mathrm{tg}\, \alpha_0}.$$

Here λ is the wavelength of RF oscillations.

Aiming at increasing the deflecting angle without the loss in gain, we have employed the scanning resonator similar to the gyrocon resonator, but it is placed in a longitudinal stationary magnetic field, just as the output resonator of the magnicon[4]. In this case, if $\Omega/\omega = 2$ and the direction of cyclotron rotation coincides with that of the deflecting RF field of the resonator, the power consumption of the beam stops and only the losses in the resonator walls occur, thereby allowing a considerable increase of the deflecting angle[5]. In addition, a strong focusing decreases the beam size and, hence, the energy spread of electrons during the scanning, due to which the efficiency increases.

2. When using a relativistic beam to maintain the synchronism as the electrons decelerate, it is necessary to decrease the accompanying magnetic field ($\beta \sim \gamma$). This results in an additional conversion of the rotational motion into a longitudinal one and, as consequence in a reduction of the efficiency.(Fig. 2b).

To avoid this, one can sustain the synchronism «in average», i. e. create a homogeneous magnetic field inside the resonator a homogeneous magnetic field equal to

$$B = \omega \frac{m_0}{e} \left(\frac{\gamma_0 + \gamma_{min}}{2}\right),$$

where m_0 and e are the mass and charge of an electron and γ_0 and γ_{min} are its initial and finite relative energy.

Such a method makes it possible to achieve a maximum electron efficiency though its application is not desirable at energies higher than 1 MeV because of a strong shortening of the length of the output resonator.

The ultimate power of the magnicon is determined, Ist as in the gyrocon, by the electron energy and by the deflecting angle in the circular scanning system. The calculated values of the beam power (for an electron efficiency of over 80%) are listed in Table 1.

Table 1

U_0 (keV)	200	300	500	800
P_0 (MW) at $\alpha_0 = 10°$		0.1	0.5	2
P_0 (MW) at $\alpha_0 = 30°$	0.7	2	10	40
P_0 (MW) at $\alpha_0 = 70°$	15	50	200	

The estimates of the electric strength of the resonators and the heat release in them show that in the continuous mode of operation the power in the units of MW can be achieved up to $\lambda = 10 \div 30$ cm, while in the pulse one the power in hundred MW can be achieved up to $\lambda = 3 \div 10$ cm. It seems more profitable to obtain high pulse pover by doubling the frequency because the equality of the magnetic fields in the scanning and in the output resonator enables a complete magnetic accompaniment of the beam to be utilized.

Experimental device

To test the service capability of the device and to optimize the technical solutions, the pulse magnicon has been built at the INP at a frequency of 915 MHz and a pulse duration of about 50 μs. The device is schematically shown in Fig. 3.

A diode gun (2) with a LaB_6 emitter serves as the source of electrons. The gun is supplied from a step-up transformer (1), the latter is in its turn supplied by a hard-tube modulator. Having left the gun, the beam passes through an electron-optical channel (3) and reaches a circular-scanning unit (4). This unit consists of two resonators placed in a magnetic field. The first, active resonator is excited from a source of input signal through inputs (5) and serves for an initial small-angle scanning of the beam. The second, passive resonator is excited by the beam and a basic deflection of the beam here occurs ($\alpha_0 = 25°$). To reduce the losses in the deflecting angle during the extraction, the beam leaves the magnetic field near the device axis through a small hole in the magnetic screen[5]. Having passed through the drift space the beam gets into an output resonator (6) (distribution of the magnetic field is demonstrated

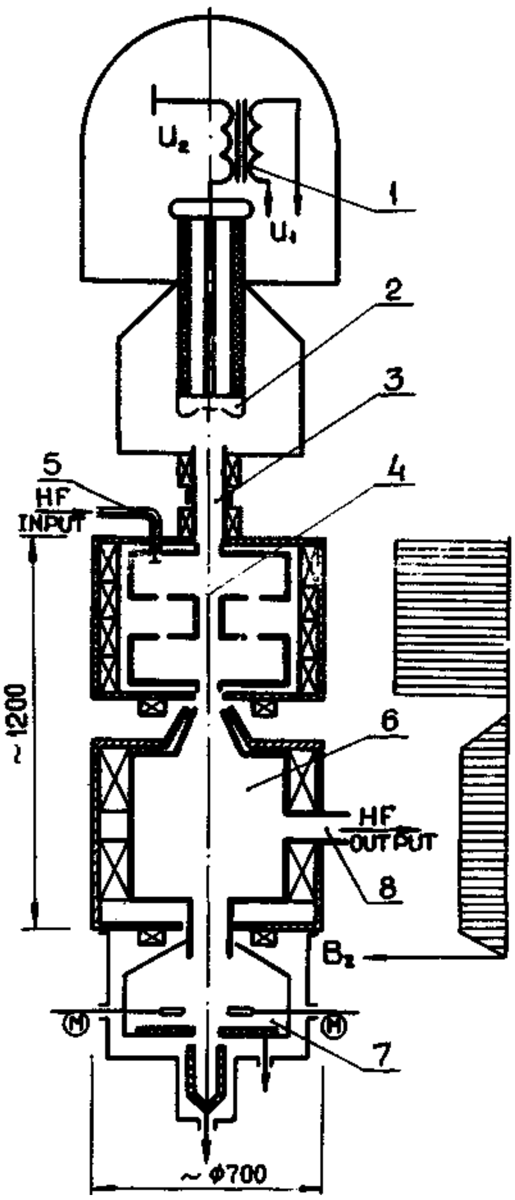


Fig. 3.

in Fig. 3) and then into a collector section (7). The high-frequency power is extracted from the magnicon through two waveguides (8) and is then supplied to coaxial absorbing loads through wave-coaxial joints.

Just as with the gyrocon, the adjustment of the device starts from an obtaining of the circular scanning of required quality. To do this, it is required to train carefully the scanning resonators (by a charge in a magnetic field) and to obtain a minimal transverse size of the beam at the entrance to the output resonator. To adjust the collector scanning, section 7 is screwed directly to the scanning system, and the beam characteristics are measured using the probes shifted by stepping motors (on Fig. 3). The further adjustment consists in choosing the coupling between the output resonator and the load, as well as in choosing the magnitude of the accompanying magnetic field. The device is computer-controlled and the measurement of the basic parameters is automatized.

Table 2 presents the basic parameters of the operating magnicon.

Table 2

Electron energy (keV)	280
Beam current (A)	9.4
Beam power (MW)	2.6
Pulse duration of the beam (μs)	50
Repetition frequency (pps)	1 ÷ 2
Output power (MW)	1.7
Efficiency (%)	65
Losses in the output resonator (kW)	50
Losses in the passive resonator (kW)	180
Electron efficiency (%)	74
Duration of the RF power pulse (μs)	30*
Gain (dB)	26

*It is determined by the oscillations build-up time in the passive resonator.

No parasitic oscillations on the frequencies including the third harmonic of the operating frequency (3 GHz) have been observed.

The calculations prove the possibility of creating an effective magnicon with a continuous power of 5-10 MW and a pulse power of 300-800 MW for power supply of the accelerators. The results obtained in the first tests of the magnicon confirm the correctness of our ideas and allow one to hope for the creation of devices with the parameters close to those indicated above.

References

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