Some Concepts of Relativistic Gyroamplifiers for Particle Acceleration

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I. INTRODUCTION

Gyroamplifiers are very promising sources of coherent, phase-controlled, powerful electromagnetic radiation for driving future particle accelerators. At a given wavelength the interaction space in gyroamplifiers is much larger than that for klystrons. Therefore, gyroamplifiers usually operate at short wavelengths ($\lesssim$ 3 cm) where the problem of miniaturization of the interaction space is, for conventional klystrons, extremely severe.

Two years ago the operation of relativistic gyroklystrons in a 10 GHz frequency range was successfully demonstrated [1]. The next step in the gyroamplifier development is directed towards improvement of electronic efficiency, enhancement of radiated power and an increase in operating frequency. Some concepts of relativistic gyroamplifiers aimed at improving these output parameters are considered below.

II. GYROKLYSTRON WITH ZERO TRANSIT ANGLE IN A DRIFT REGION

Electron velocity spread is one of the most important factors reducing the efficiency of gyroklystrons as well as other microwave tubes. Since in gyroklystrons the first, modulating cavities are separated from the output cavity with a rather long drift region it is desirable to minimize the effect of electron velocity spread on electron transit through the drift space. We will show that this can be done by minimizing the electron transit angle through the drift space,

$$\Theta_{dr} = \int_0^{L_{dr}} [(\omega - \Omega)/v_z]\, dz.$$

Here ω and Ω are the operating frequency and electron cyclotron frequency, respectively, v_z is electron axial velocity, and L_{dr} is the length of the drift region.

For a two-cavity gyroklystron the electron gyrophase relative to the electromagnetic (EM) field phase at the entrance to the output cavity may be written as $\Theta_{ent} = \theta_0 - q\sin\theta_0 - \Theta_{dr}$. Here θ_0 is the initial gyrophase at the entrance to the first cavity and q is the bunching parameter proportional to the field amplitude in the first cavity and the drift space length, L_{dr}. Both q and Θ_{dr} depend on electron velocity spread.

We studied the effect of pitch angle spread ($\alpha = v_\perp/v_z$ is the pitch angle, i.e. the ratio of orbital to axial electron velocity components) in a monoenergetic electron beam on the efficiency of relativistic gyroklystrons. The equations of motion of relativistic electrons averaged over fast electron gyration were used. The axial structure of the output resonator field was described by $\sin(\pi z/L)$. The orbital velocity spread was described by a triangular distribution with the width corresponding to a 6% RMS spread. The operating voltage was taken close to 500 kV and both the bunching parameter and the pitch-ratio for the central fraction of the electron beam were equal to one.

First we found the dependence of the electron efficiency, optimized with respect to the phase of the EM field and the cyclotron resonance mismatch in the output cavity, on the field amplitude and the length of this cavity for the ideal electron beam (no velocity spread). Then we considered the effect of spread for two cases: a) magnetic field constant along the drift region and output cavity, b) magnetic field in the drift region tapered so that the transit angle, Θ_{dr}, is close to zero for all electrons. It was found that for parameters predicting 44% efficiency of operation with the ideal beam the velocity spread in the first case reduces the achievable efficiency to 29%. At the same velocity spread the corresponding tapering of magnetic field in a drift region permits one to realize 36% efficiency. So, it becomes possible to mitigate the spoiling effect of velocity spread on the gyroklystron efficiency about 2 times by corresponding tapering of the magnetic field in the drift space.

III. CONCEPTS OF GYROAMPLIFIERS FOR WAVELENGTH SHORTENING

In general, for gyrodevices operating at the cyclotron resonance condition, to provide the operating frequency increase one has to increase the external magnetic field. That makes the microwave system (including magnets) more expensive. However, there are two possibilities for increasing the operating frequency at a fixed value of the magnetic field. Both of them follow from the cyclotron resonance condition

$$\omega - k_z v_z \simeq s\Omega$$

where k_z is the axial wavenumber and s is the resonant cyclotron harmonic number. These are operation at high cyclotron harmonics ($s > 1$) and operation with a large Doppler frequency upshift. The latter gyroamplifiers are known, in the case of moderate frequency upshift, as gyrotwistrons.

Theoretical studies of the cyclotron harmonic and Doppler upshifted operation of gyroamplifiers with the same operating frequency and magnetic field, the same electron beam, the same prebunching cavity and drift space, were started in [2]. It was shown that in the case of an ideal electron beam the Doppler upshifted operation is more efficient (46% versus 26% for the second harmonic gyroamplifier). Then, electron velocity spread causes the degradation in efficiency which, in principle, for the frequency upshifted operation, is more pronounced than for the harmonic one. The latest studies show that, nevertheless, the optimized efficiency of gyrotwistron operation becomes equal the efficiency of ideal second harmonic operation (26%) only when the RMS value of the pitch-angle spread is about 22% (at this velocity spread the maximum second harmonic efficiency is only 16%). So for a wide range of electron velocity spreads the frequency upshifted operation of the gyrotwistron may be more efficient than that of the second harmonic. This is because in the case of operation with large axial wavenumbers (like in gyrotwistrons) the energy may be extracted from both the rotational and axial electron motion. Note that successful second harmonic operation of the relativistic gyroklystrons has been recently demonstrated [3] and experiments with relativistic gyrotwistrons are planned.

The authors are thankful to O. Dumbrajs for his valuable help in numerical simulations.

This work was supported by the U.S. Department of Energy.

IV. REFERENCES

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