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High precision frequency stabilization of a 263 GHz continuous wave gyrotron

G.G. Denisov, A.P. Fokin, M.Yu. Glyavin, G.Yu. Golubiatnikov, L.V. Lubyako, M.V. Morozkin, B.Z. Movschevich, A.I. Tsvetkov

Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia, ap.fokin@mail.ru

Millimeter and submillimeter wave gyrotrons with medium (kW level) power got their applications as sources for dynamic nuclear polarization/nuclear magnetic resonance (DNP/NMR) spectrometry [1, 2] and various media diagnostics [3]. One of the limiting factors for gyrotrons applications is the relatively low frequency stability and wide spectrum of the output radiation. The solution of this problem can increase the sensitivity and resolution in spectroscopy and open new prospects, such as the coherent summation of radiation of multiple gyrotrons or possibilities of suppressing hydrodynamic instabilities in plasma. The known experiments on frequency stabilization of gyrotrons utilize phase lock control to one of the electrodes of the magnetron injection gun, show that the relative half width of the frequency spectrum $\Delta f / f$ and the frequency fluctuations $\delta f / f$ can be lower than $1 \cdot 10^{-9}$ and $3 \cdot 10^{-10}$ respectively [4, 5].

Experimental setup. In our experiment, we applied the phase lock loop (PLL) against the reference generator in order to control the gyrotron anode voltage. Selection of anode voltage alteration as a way of frequency control and stabilization is caused by small capacity of anode relative to other electrodes and low anode current, so there is no need in complex and expensive power supplies. The change of anode voltage does not alter the electron energy, but only its pitch-factor (ratio of its orbital to longitudinal velocity), leading to change of the active and reactive components of conductivity and, hence the change of the operating frequency of the gyrotron.

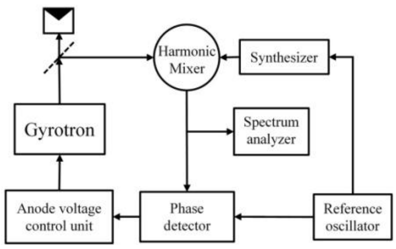


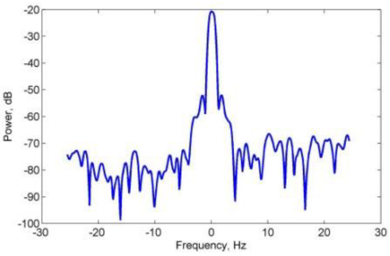
Fig. 1. Block diagram of phase lock loop stabilization system for a gyrotron frequency

The experiment was carried out on the continuous-wave (CW) gyrotron for spectroscopy and various media diagnostics with operating frequency of 263 GHz and output power up to 1 kW in Gaussian beam [6]. For the experiment, the electron beam current was limited at 200 mA and magnetic field was changed for the purpose of lowering output power to about 40 W. The accelerating voltage circuit was modified in order to reduce the high-frequency components of voltage ripple by means of low-pass LC-filter. The fast voltage control unit was installed in the anode voltage circuit and was used as an active element of phase lock control system. This unit allowed variation of anode voltage in range of anode voltage with amplitude up to 1 kV with slopes better than 1 kV/μs. The active element of the unit is the thyratron, that can be controlled by external signal.

The block scheme of the phase lock loop system is presented on the Fig. 1. The output radiation of the gyrotron with frequency 263 GHz is partially transmitted to the harmonic mixer, where it is mixed with the signal from the microwave synthesizer with frequency about 4.8 GHz. The resulting signal on the intermediate frequency of 350 MHz is then fed on the phase detector in order to frequency phase compare it with the signal from reference oscillator. The error signal from phase detector is used as the control signal for anode voltage control unit.

Results of the experiment. Our experimental setup allowed to control frequency of gyrotron radiation with modulation frequency up to 150 kHz. The sensitivity of the gyrotron was 1 MHz per volt of control signal on the anode voltage control unit. The full frequency tuning range was 7 MHz. The width of the frequency spectrum was decreased from 0.5 MHz [6] down to 1 Hz measured at intermediate frequency IF = 350 MHz, which corresponds $\Delta f / f = 3 \cdot 10^{-12}$ with measurement time of a few seconds (see Fig. 2). The low level of phase noise should be noted.

Fig. 2. Observed frequency spectrum of the gyrotron with phase lock loop at the intermediate frequency



The long-term frequency fluctuations were defined by the stability of reference oscillator ($\delta f / f \sim 10^{-9}$ for quartz clock and up to $\delta f / f \sim 10^{-12}$ for rubidium clock). Obtained spectrum width and frequency stability were previously achieved in backward-wave oscillators, utilized in spectroscopy, but with power levels of tens of milliwatts, while stabilization system with anode voltage control in gyrotrons has no apparent limiting factors in the field of gyrotron output power – as it was demonstrated with output power of 40 W.

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