Hysteresis and Frequency Tunability of Gyrotrons

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***Abstract*—We present the first devoted experimental and theoretical study of hysteresis phenomenon in relation to frequency tunability of gyrotrons.**

I. INTRODUCTION

IN gyrotrons hysteresis is the phenomenon that causes the amplitude of oscillations to lag behind the magnetic field and the voltage, so that operation regions of modes for rising and falling magnetic field and voltage are not the same. It is intimately linked to existence of the hard excitation region, where for certain parameter values of the gyrotron, stable oscillations can be induced only by kicking the oscillator with the amplitude that is larger than the stationary one. Hysteresis-like effects in gyrotron oscillators inter alia influence on mode competition have been studied in [1] and [2]. The low-power and low-mode gyrotrons are especially suitable for studying hysteresis phenomena, because they can oscillate in well-separated low-order modes that allow studying hysteresis without taking into account the radial mode competition. In recent years, great interest has developed in the applications of gyrotrons to the enhancement of NMR spectroscopy in the process known as Dynamic Nuclear Polarization [3,4]. In these applications tunable gyrotrons are needed. For this purpose at FIR, UF the 460 GHz second harmonic gyrotron (FU CW GO-II) operating in $TE_{8,5}$ mode has been developed. The expected frequency tunability >1.5 GHz.

II. RESULTS

In Fig. 1 we show an example of hysteresis in this gyrotron with respect to variation of magnetic field and accelerating voltages. The hysteresis loops are ~0.01 T and ~0.03 kV respectively..

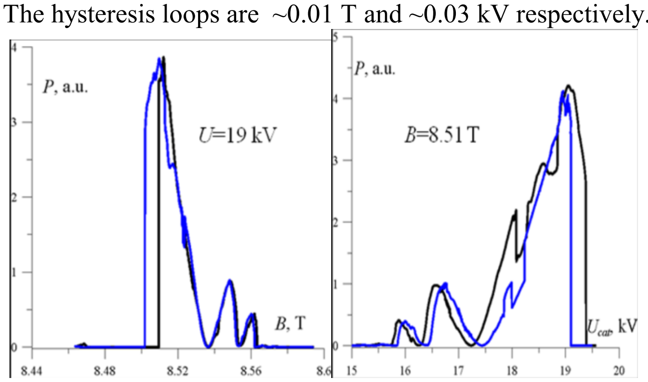

Fig. 1. Left: dependence of power on magnetic field . Acceleration voltage U, modulation voltage 8.7 kV and current 0.3 A are constant. Black and blue curves correspond to increasing and decreasing magnetic field, respectively. Right: dependence of power on cathode voltage. Magnetic field B=8.51 T, modulation voltage 8.7 kV, and current 0.3 A are constant. Black and blue curves correspond to increasing and decreasing voltage, respectively.

Theoretically hysteresis can be studied most conveniently using a time-dependent equations for the oscillation amplitude [1,2]. In Fig. 2 we show the results of theoretical calculations with the parameter values corresponding to the experimental curves in Fig. 1. Good qualitative agreement is seen. However, the theoretical hysteresis loops are significantly larger than the experimental loops. This discrepancy might be related to the fact that in this gyrotron a triode gun is employed. In such a case the pitch factor is a rather complicated function of gun parameters which complicates theoretical calculations. For this reason the comparison between experiment and theory should be regarded as qualitative.

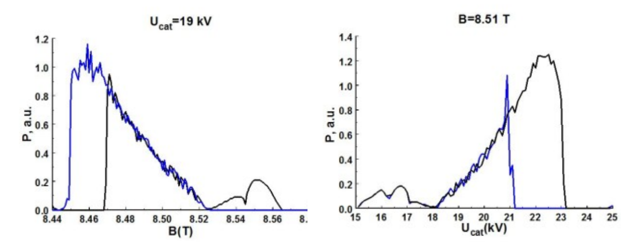

Fig. 2. Theoretical hysteresis loops.

III. SUMMARY

Clear hysteresis loops are observed both in experiment and theory. It is clear that this effect can be used for extension of frequency tunability ranges of a gyrotron by maximally $\Delta F_{mag} = 2\cdot 28\cdot \Delta B/\left(1+U/511\right)$ in the magnetic tuning, or by $\Delta F_{volt} = 2\cdot 28\cdot B/\Delta\left(1+U/511\right)$ in the voltage tuning. In reality, of course, this extension will be smaller as limited by frequency pulling. New more accurate experiments are in progress accompanied by theoretical calculations with inclusion of velocity spread and electron beam misalignment effects to quantify understanding of this interesting phenomenon.

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