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# EXPERIMENTS ON THE STABILIZATION OF FLUTE INSTABILITY WITH THE AID OF AN INTEGRATING FEEDBACK SYSTEM

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In a number of experiments aimed at the study of the influence of feedback at the m = 1 mode of flute instability in the Phoenix II installation [1], it was shown that there always exists a residual instability connected with the frequency characteristic of the feedback loop. The increment of these oscillations is proportional to the upper limiting frequency of the stabilizing system, and their occurrence limits the possibility of employing such systems for plasma stabilization. To overcome this difficulty, it was proposed [2] to decrease the increment of the residual oscillations by limiting the frequency characteristic of the feedback system from above, i.e., by using an integrating amplifier. The resultant phase shift can be compensated for by measuring not the fluctuations of the electric potential, as was done in [1] and [3], but the fluctuations of the azimuthal electric field or (for a given azimuthal oscillation mode m) as the result of the azimuthal displacement of the pickup used for the fluctuations of the potential relative to the stabilizing electrode, by an angle $\pi/2m$.

Experiments aimed at verifying the foregoing idea were made with the Phoenix II installation. We used the same stabilizing electrode as in [1], and the oscillations of the potential with azimuthal mode m = 1 were measured with an electrostatic probe displaced in azimuth by 90°. The integrating amplifier ensured a feedback-loop transfer coefficient $\delta$ in the form

$$\delta(\omega) = \frac{\alpha\beta}{\tau\omega} \quad (1)$$

up to very low frequencies $\omega \ll \omega^*$. Here $\alpha$ is the sensitivity of the pickup, $\beta$ the gain, $\tau$ the integration constant, and $\omega^*$ the frequency of the precession of the ions about the axis of the apparatus in an inhomogeneous magnetic field. The frequency of the flute oscillations in the system without feedback was $\omega^*$ [2].

Introduction of such a feedback system led to a significant change in the behavior of the plasma. The threshold of appearance of the plasma loss increased to a certain density n, which depended on $\delta$. At densities below threshold, just as in [1], we observed low-frequency oscillations, but unlike in [1], where the amplitude of the oscillations decreased when the feedback system was turned on by only a factor of 2, in this case introduction of the feedback was accompanied by a decrease of the oscillation amplitude by a factor of at least 30. When the new threshold density n was exceeded, flute oscillations again appeared and decreased the density to the natural threshold of the flute instability $n_0$. (In these experiments, carried out with injection of 8-keV atoms, the threshold density was $n_0 \simeq 1 \times 10^8$ cm$^{-3}$.)

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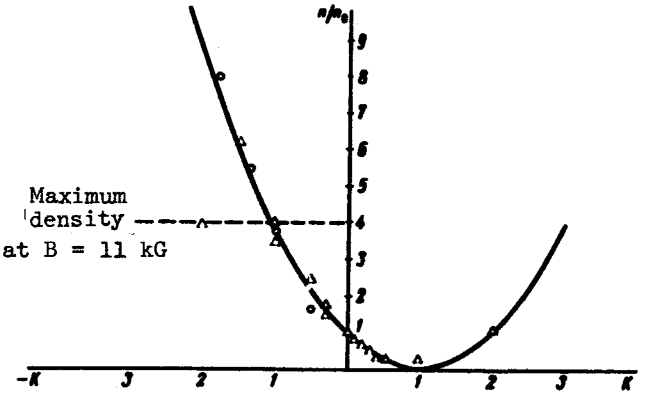


Excess of density above the threshold of flute instability, $n/n_0$, vs. the transfer coefficient of the feedback system, K.

Under the condition that the ion plasma frequency is lower than the ion cyclotron frequency, the theory [2] yields the following dependence of the threshold density of the development of flute instability, with the feedback turned on, on the transfer function of the feedback system at the ion precession frequency $\delta(\omega^*) = \alpha\beta/\tau\omega^* = K$:

$$n = n_0(1 - K)^2. \qquad (2)$$

(An inverting amplifier corresponds to $K < 0$, and a non-inverting one to $K > 0$.) The figure shows the theoretical dependence (2) (solid line) of the results of measurements at a magnetic field B = 11 kG (triangles) obtained by varying K through changes in the gain β. The experiment agrees quite well with theory when $2 \geq K \geq -1$. When $K < -1$ and $K > 2$, the feedback system became self-excited at the lower frequencies, where the transfer coefficient was very large, and stabilization was disturbed.

However, the value of K can be varied without changing the gain and without violating the self-excitation conditions, namely by changing the ion precession frequency $\omega^*$ through changing the magnetic field B. As is well known,

$$\omega^* \sim 1/B \qquad (3)$$

and consequently $K \sim B$. Thus, the value of n should vary with the magnetic field. We note that the threshold of the flute instability in the absence of feedback is independent of the magnetic field, in accord with both theory and direct measurements.

The results of the measurement of the threshold density n at different magnetic fields (from 6 to 18 kG) are represented in the figure by circles. The gain β remained unchanged in this case, and the transfer coefficient K was calculated with allowance for the variation of the field. We see that in this case, too, the agreement with (2) is good enough.

The maximum excess of density over the threshold of the flute instability $n_0$ reached 8 and was limited by the self-excitation of the feedback system and by the technically attainable magnetic field.

At such densities one can expect the appearance of higher modes of the flute instability. However, no oscillations with m = 2 were observed. Low-amplitude oscillations with m = 3 were observed at high densities.

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# E R R A T U M

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On p. 395, the fourth and fifth lines below Eq. (1) should read: "The frequency of the flute oscillations in the system withouth feedback was $\omega^*/2$" instead of ". . . was $\omega^*$ [2]."