Experiments on negative-feedback stabilization of helical plasma instability in a TO-1 tokamak

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(Submitted 9 December 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 2, 108–112 (20 January 1978)

We report here the first experiments on stabilization of helical instability of a plasma pinch in a TO-1 tokamak by the negative feedback method [A. I. Morozov and L. S. Solov'ev, Sov. Phys. Tech. Phys. **9**, 1214 (1965); V. V. Arsenin and V. A. Chuyanov, At. Énerg. **25**, 141 (1968); V. V. Arsenin, At. Énerg. **28**, 141 (1970) and **33**, 691 (1972); Yu. P. Ladikov-Roev and Yu. M. Samoĭlenko, Sov. Phys. Tech. Phys. **42**, 1644 (1973); R. Lowder and K. Thomassen, Phys. Fluids **16**, 1497 (1973); J. Hugill, Plasma Physics **16**, 1200 (1974), K. Bol *et al.*, in: Proc. Fifth Intern. Conf. of Plasma Physics and Controlled Nucl. Fusion Research, Tokyo, 1974, IAEA, Vienna, 1975, Vol. I, CN-33/A4-2; R. A. Demirkhanov, A. G. Kirov, L. F. Ruchkov, A. V. Sukachev, V. B. Maĭburov, and A. V. Nyushkov, JETP Lett. **26**, 81 (1977)].

PACS numbers: 52.35.Py, 52.55.Gb

The TO-1 tokamak has the following principal parameters. The major and minor radii of the discharge chamber, which is made of a stainless-steel sheet 1 mm thick, are 60 and 18 cm. The molybdenum diaphragm aperture radius is 12.5 cm. Inside the discharge chamber, in the shadow of the diaphragm is located a helical winding having a spatial structure $m=2$ and $n=1$.[10] The winding consists of four flat bars 5 cm wide, made of stainless steel and mounted on insulators at a distance 3.5 cm from the chamber walls. The winding does not surround the entire discharge chamber of the tokamak along the major path, and occupies one-quarter of the path between two of the four sections with the diagnostic stubs. The helical winding is fed from a vacuum-tube amplifier that can deliver to the winding a current with amplitude up to 1 kA in the frequency range from 5 to 2000 kHz. The amplifier operates in a pulsed regime with a pulse duration 12 msec. Magnetic probes for the diagnostics of the RF perturbations of the poloidal magnetic field in the shadow of the diaphragm and for use as pickups in the feedback circuit are inserted into the chamber through a stub located away from the helical winding at an angle 90° relative to the principal axis of the torus.

The experiments were performed on hydrogen at toroidal magnetic field intensities from 4 to 8 kOe. The discharge-current waveform, determined by external circuits, was close to a rectangle of 70 msec duration and amplitude $I \approx 20$ kA.

Operation with feedback was preceded by an experiment in which the vacuum tube amplifier was excited from an independent sweep generator whose frequency varied linearly for 4 msec from 50 to 5 kHz. By analyzing in this case the RF signal induced in the magnetic probe it was possible to assess the amplitude and phase characteristics of the oscillations produced in the plasma incoherence with the current in

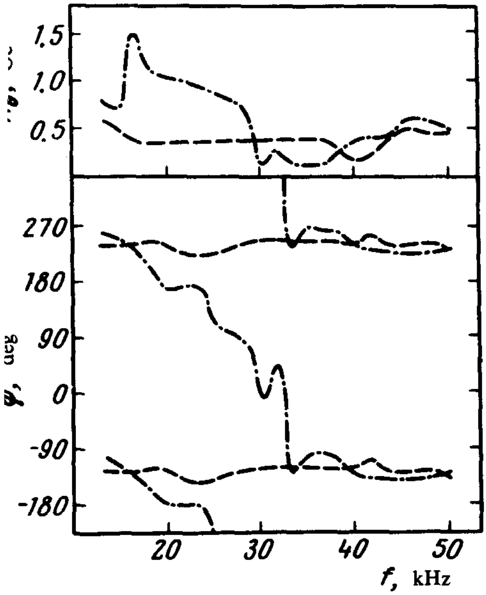


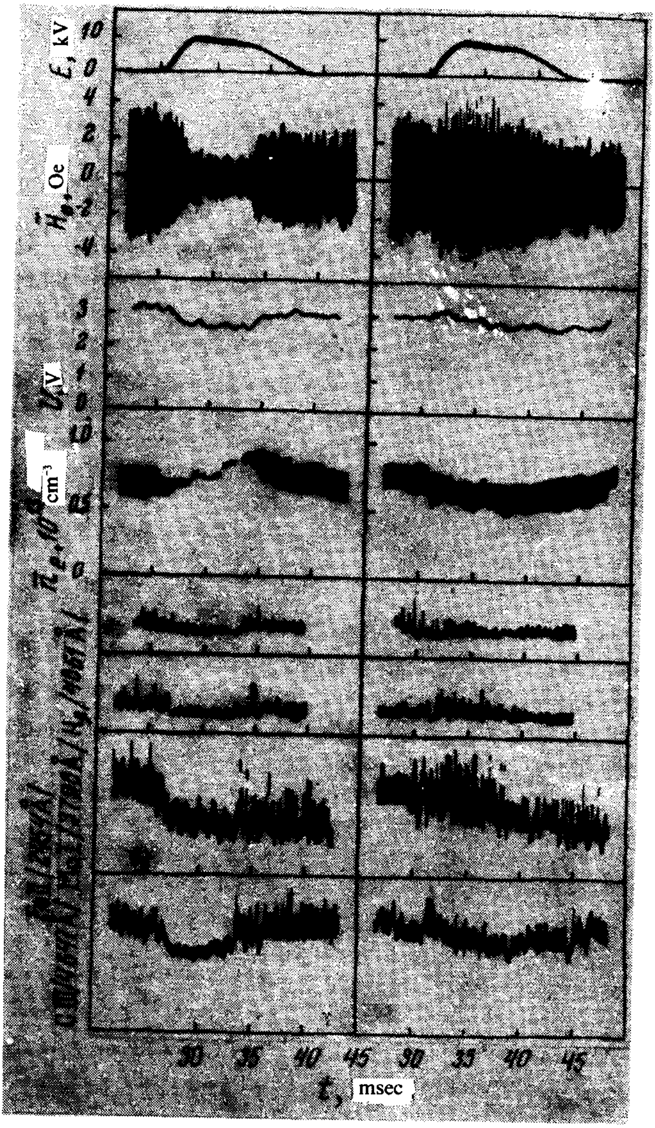
FIG. 1. Frequency dependences of the amplitude and phase (relative to the current in the helical winding) of the oscillations of the poloidal magnetic field at the chamber wall. The dashed and dash-dot curves correspond to the discharges at $H_0 = 8$ and 5.8 kOe, respectively. The current amplitude in the helical winding is 300 A.

e helical winding. There was no signal in the magnetic probe in the absence of lasma.

It turned out (see Fig. 1) that the shapes of the frequency characteristics depend n the intensity of the toroidal magnetic field H_0. In the case $H_0 = 8$ kOe, $I = 21$ kA $q = 5.0$ on the diaphragm) these characteristics have no singularities, i.e., the ampli-de and the phase of the signal from the probe depend little on the frequency of the rrent in the helical winding. The resultant RF perturbation of the poloidal magnetic eld has then the spatial structure of an $m = 2$ standing wave (see also[10]).

In weaker fields $H_0 = 5.8$ kOe, $I = 21$ kA ($q = 3.6$), as seen from Fig. 1, at frequen-es in the range from 15 to 35 kHz, resonance is observed, consisting in an increase of e amplitude of the oscillations and in the onset of a strong dependence of the phase n the frequency within the limits of this range. It should be noted that the frequencies the MHD activity, which are usually observed in the TO-1 tokamak under macro-opic unstable discharge conditions, also lie in the range from 15 to 35 kHz.

In the experiment with the feedback, the magnetic probe was connected to the put of the RF amplifier supplying the helical winding. In this case the probe was a cal multiturn coil, and therefore, in contrast to the Fourier probes described in[10], d the same coupling with all the spatial harmonics of the long-wave perturbations of e magnetic field. It was placed in the shadow of the diaphragm at the tokamak amber wall, at the point corresponding to a node of the standing wave. A frequency-dependent phase shifter and a self-tuning narrow-band filter were connected between e probe and the amplifier. The filter served to eliminate the parasitic excitations in e feedback circuit and separated from the frequency spectrum of the magnetic-probe gnal the harmonic having the largest amplitude, the filter-transmission frequency ljusted itself automatically to the changing spectral composition of the signal.



IG. 2. Sets of oscillograms of the amplifier anode-supply voltage, of the signal from the magnetic probe, of e discharge voltage, of the plasma concentration averaged over the diaphragm diameter, and of the tensities of the spectral lines of the hydrogen and of the impurities for two phase shifts, separated by 180°, the feedback circuit.

For the experiment with the feedback we chose a tokamak discharge with $_0=5.1$ kOe, $I=19$ kA ($q=3.5$), with supply of neutral gas into the chamber during e discharge pulse. This regime is characterized by an advanced MHD activity of the $=2$ mode, whose amplitude varied little with time.

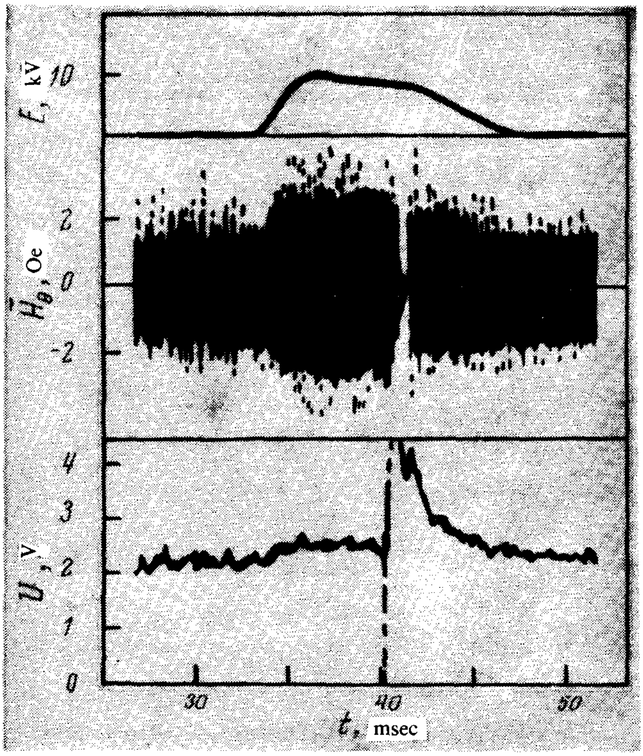


FIG. 3. Excitation of tearing instability under the influences of feedback.

Figure 2 shows sets of typical oscillograms of signals from the magnetic probe and of a number of plasma characteristics for two phase shifts, that differ by 180°, in the feedback circuit. It is seen from the figure that, depending on the phase, the amplitude of the signal from the magnetic probe increases or decreases. The decrease of the amplitude is accompanied by a decrease in the discharge voltage, by an increase of the plasma density, and by a change of the intensities of the radiation of a number of spectral lines. The observed behavior of the plasma characteristics attests to an improvement in its containment and to a weakening of the interaction with the diaphragm and with the wall of the discharge chamber.

At another phase, buildup of the signal leads to opposite changes of the plasma characteristics. Moreover, at sufficiently high gain in the feedback circuit, the growth of the MHD activity is accompanied by the appearance of negative-voltage discharge peaks that are typical of pairing instability (see Fig. 3). The last result is one more argument favoring the assumption that a causal connection exists between the helical instability and the pairing instability, and gives grounds for hoping to be able to use feedback to combat these two instabilities simultaneously.

Summarizing, we can state that helical instability is sensitive to the action of a feedback system of relatively simple form. To stabilize the $m=2$ mode it suffices to use a single-channel system with a local pickup and with a helical winding that surrounds only a small fraction of the plasma pinch along the major path of the torus. The perfection of the stabilization system and further study of its influence on the plasma stability and its parameters will be the subject of our forthcoming work.

The authors thank Academicians B.B. Kadomtsev, I.N. Golovin, V.V. Arsenin, V.A. Chuyanov, S.V. Mirnov, and A.G. Kirov for interest in the work and for useful discussions, and also L.I. Molotkov and A.N. Silaev for help with the optical measurements.

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