# MHD ACTIVITY IN GOL-3 AT THE STAGE OF PLASMA COOLING

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*Transient MHD activity in the multiple-mirror trap GOL-3 at the stage of plasma cooling after decay of the net current was studied. Such events are diagnosed as short bursts (generally shorter than 5 cycles) of oscillations of azimuthal magnetic field with the frequency within 0.1÷1 MHz. Earlier transient events at the plasma decay stage were also observed. At that time an existence of long-lived internal current structures in the GOL-3 plasma was supposed.*

*The paper presents new results from the magnetic diagnostics. Azimuthal and longitudinal mode localization agrees with the assumption that the magnetic field is generated by filaments with the current in the range of 1÷50 A in nearly uniform azimuthal distribution. Statistical analysis shows that the main oscillation frequencies are grouped near the inversed time of the Alfven wave propagation along the trap. Power dependence of the pulse probability on its amplitude with the index α = –1.87 was found. Relationships of MHD activity on the regime of plasma heating and on a degree of the beam stabilization at the exit receiver are discussed.*

## I. INTRODUCTION

Multimirror approach to plasma confinement for fusion is studied at the GOL-3 facility in Novosibirsk.[1] The plasma of $10^{20}÷10^{22}$ $m^{-3}$ density is confined in a 12-meter-long solenoid, which produces axially periodical (corrugated) magnetic field. In the basic operation regime the solenoid consists of 55 magnetic cells (22 cm long each one) with $B_{\max}/B_{\min}$ = 4.8/3.2 T (mirror ratio $R$ = 1.5). The plasma is heated by a high power relativistic electron beam (~0.8 MeV, ~30 kA, ~12 µs, ~120 kJ). The beam current is compensated by the return plasma current flowing in the opposite direction. Due to the 1000-fold suppression of the plasma conductivity in the volume of the REB this current flows mainly in the thin layer of the hot plasma outside of the beam.[2] Typical net current of the preliminary discharge at the moment of the beam injection is ~ – 5 kA. (Detailed time sequence of the experiment is described e.g. in Ref. 1 and 2)

Further we will discuss the stage of plasma cooling which lasts ~1 ms after the end of the beam injection (See Ref. 2). The net plasma current is below 100 A during this period. Despite of this signs of a transient MHD activity were found as short bursts (generally shorter than 5 cycles) of oscillations of the azimuthal magnetic field with the frequency within 0.1÷1 MHz (Fig. 1). Earlier transient events at the plasma decay stage were also observed by other diagnostics.[2]

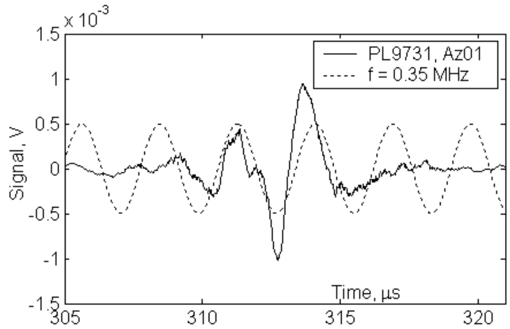

Fig. 1. Waveform of a typical pulse. Sine wave of 350 kHz frequency is shown for clarity.

Analysis of ~8000 events in ~1200 shots was conducted. Pulses were detected by the 3-fold excess of the noise level. The main frequency was defined as thepoint of maximum in the Fourier spectrum of the oscillation.

The current in each event could be estimated as

$$\delta I \sim \frac{r_0}{\omega_0}\frac{c^2}{2\tilde{S}}U_0,$$

where $r_0$ stands for characteristic distance from the measuring coil to the center of current, $\omega_0$ is the main frequency, $\tilde{S}$ corresponds to the surface of the measuring coil and $U_0$ is measured signal.

Assuming $\omega_0$ = 400 kHz and $r_0$ = 5 cm for the coil with $\tilde{S} = 32\times16\ mm^2$

$$\delta I[A] \sim U_0[mV]$$

## II. CHARACTERISTICS OF THE PULSES

### II.A. Azimuthal spectrum

Amplitude of the first azimuthal mode in all pulses was higher than of other modes (Fig. 2). Amplitude of the zero mode is determined mainly by the nonideality of the measuring system.

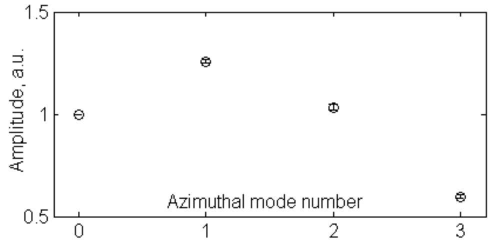

Fig. 2. Azimuthal spectrum of the perturbation.

Amplitudes of higher modes monotonously decrease with the mode number. For the modes located on the characteristic transversal scale $a$ these amplitudes could be estimated as

$$A_n \sim \int_{-a}^{a} cos^n x dx \sim 2a\left(1-n\frac{a^2}{6}\right).$$

For the given spectrum the parameter is $a <\sim 1$.

This spectrum can be explained by the existence of thin current filaments in the plasma. Note that the plasma column rotates with the frequency $\omega \sim 10\,\mathrm{kHz}$ in the crossed magnetic field and radial electric field caused by the plasma potential. Therefore the net azimuthal spectrum of the current can have no significant amplitudes (more than $100\ \mathrm{A}\!\left/n\right.$, where $n$ is the mode number) of lower modes because in this case periodical oscillations of the magnetic flux through the measuring coils will present, that is not the case.

Such structure could be the result of the late evolution of a tearing mode (calculated e.g. in Ref. 3) if any mechanism of splitting of current filaments exists.

### II.B. Longitudinal correlation

Pulsed nature of bursts corresponds to fast evolution from one quasistationary state to another. According to the assumption of linear evolution of the improper waves[4] (in particular case the dispersion equation with variable density has no eigen Alfven waves) the restructuring of the magnetic field and the current pattern propagate along the magnetic field with the local Alfven velocity and decays in

$$\tau > 1\mu s \times (kl)^{2/3},$$

where $l = 11$ cm is the characteristic length of the Alfven velocity change and $k$ corresponds to the width of the wavefront. This time stands in agreement with the decay of the observed pulses in assumptions of their short wavelength (comparable with the length of one cell of the corrugated field).

The process of propagation was observed directly by the system of the local azimuthal probes set in several points along the trap (Fig. 3). The average speed of the wavefront is $(1 \div 5) \cdot 10^8$ cm/s; it corresponds to the mean magnetic field of 4 T and the plasma density of $10^{20} \div 10^{21}$ m$^{-3}$. The wave propagates through the entire plasma column from one of its ends. If we improve near-the-wall conductivity in one of the ends, then the probability of the burst starting in it decreases. Such correlation makes possible an assumption about the dependence of the event probability on the rate of the magnetic dissipation. As the characteristic time of the burst is much less than the time of magnetic diffusion through the entire plasma cross-section (which is ~1 ms), the effect should be caused by a faster process. For example, it can be reconnection of the magnetic field lines which seems appropriate for the configuration with radius-dependent direction of the current[5].

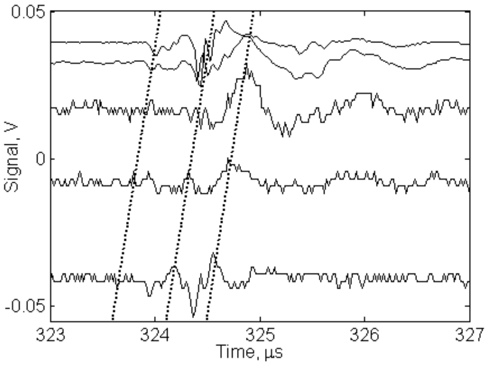

Fig. 3. Longitudal correlation of the bursts. Zero lines are shifted proportionally to the coordinate of the probe (from bottom to top: 167, 288, 398, 464 and 492 cm), pinch of dotted lines corresponds to the mean Alfven velocity.

### II.C. Frequency spectrum

Magnetic nature of the events causes also the independence of the main frequency of the burst on the temperature. The frequency corresponding to the doubled time of the propagation of the Alfven wave through the entire plasma column for the ion density $4{\cdot}10^{20}$ m$^{-3}$ can be estimated as

$$f_L = \left\langle \frac{2\sqrt{\pi n_i m_i}}{B} \right\rangle L \approx 0.35 \text{ MHz}.$$

Statistical analysis has shown three well separated peaks with the frequencies of ~0.38, ~0.86 and ~1.4 MHz

(Fig. 4). The smallest of them agrees well with the estimate above.

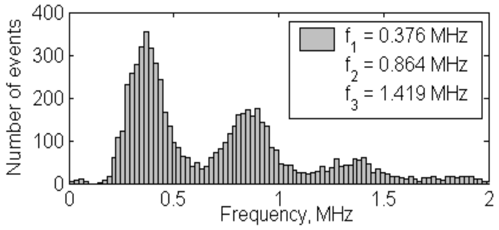

Fig. 4. Frequency distribution of the pulses.

### II.D. Radiation emission

Transient activity was also found in several experiments in the neutron or gamma emission from the plasma (note that the scintillation detectors used for this diagnostic does not distinguish one type of radiation from another). These events are highly correlated with the described magnetic activity (Fig. 5).

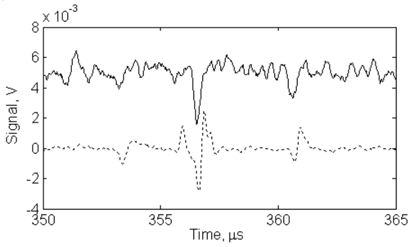

Fig. 5. Correlation with the radiation emission. Solid: neutron/gamma emission, dotted: magnetic signal.

In assumption of magnetic reconnection such emission could be explained by hard-accelerated particles or by neutron generation on their collision with the wall.

Statistical analysis of the emission can not be provided because of the lack of the detector sensitivity.

### II.E. Amplitude distribution

The probability density of the pulse amplitudes in the diagnosed range fits well in the power distribution with the power index $\alpha = -1.87$ (Fig. 6). Constant probability of the pulses with the amplitude below 1 mV can be caused by loss of events due to noise and by superposition of the pulses.

Assuming that the energy dissipation takes place on the viscous scale of the magnetic field which is much less than the initial scale of the current

$$l_{dis} = \frac{c^2}{\omega_{pe}^2 \tau_e V_a} \sim 10^{-4}\ cm \ll R$$

one should draw a conclusion about the existence of the mechanism of the energy transportation from the large scale to the smaller which is a subject for latter research.

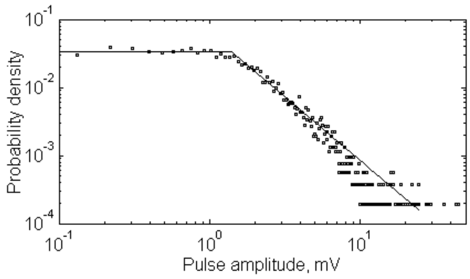

Fig. 6. Amplitude distribution of the pulses.

## III. CONCLUSION

Transient MHD activity in the multiple-mirror trap GOL-3 at the stage of plasma cooling was studied. The speed of the wave front corresponds to evolution of the improper magnetic perturbation. Azimuthal and longitudinal mode localization agrees with the assumption that the magnetic field is generated by decompensated filaments with the current in the range of 1÷50 A. Magnetic activity is correlated with the emission of hard radiation.

This effect can be explained by the magnetic reconnections in the closed strongly filamented current structure generated during the injection of the high-power relativistic electron beam in the plasma.

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