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MAGO-3 RESULTS OF THE EXPERIMENT

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MASTER

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ABSTRACT

In the report the results of joint LANL-VNIIEF experiment MAGO-3 are given. The experiment was aimed to investigate the of magnetized plasma parameters when it overflows trough Laval nozzle. The details of the experiment are described, data obtained by VNIIEF experts are given.

MAGO-III experiment
(short comment for VNIIEF data)

MAGO-III experiment has been conducted in VNIIEF on September 13, 1995. Its statement was near one for MAGO-I and MAGO-II experiments.

The main purpose of experiment was the using of extending diagnostic tools and methods in MAGO chamber with usual current and pressure conditions.

Experimental arrangement is shown on figure from p.1., where the B-dot position is shown too. As previous experiments the experimental unit consisted of helical EMG, opening and closing switches and MAGO chamber.

The scheme of the experiment is Shown on figure on p.2.

The main results of the experiment are:

final EMG current	- 14,8 MA
preliminary chamber current	- 2,3 MA
main chamber current derivative	- $4 \cdot 10^{12}$ A/S
main chamber current	- 5,2 MA
DT gas pressure in chamber	- 10 mm Hg
neutron yield	- 10^{13} n/shot
neutron pulse duration	- 600 ns

The VNIIEF results for probes where information was obtained are shown on figure on p.p. 3...11.

One of the peculiarity of the experiment was the considerable azimuthal current asymmetry for data from B-dot probes of rings IV,V,VI,while the current asymmetry on chamber input (ring III) is small.

VNIIEF team thinks that MAGO-III experiment was successfull enough.

INTRODUCTION

The report gives the results of MAGO-3 experiment conducted in VNIIEF on September, 13, 1995 under the subcontract N0002P0004-95(task order N021).

The experiment was prepared and conducted jointly by Russian (VNIIEF) and American (LANL) experts. The main goal of MAGO-III experiment was to get the data on plasma temperature and density. These measurements were made by US experts. . MAGO-III chamber in almost did not differ from MAGO-I, II, IIP chambers and was described in details in reports /1,2,3/.

This report presents the data, obtained by VNEEF on operation conditions of the explosive magnetic energy source, plasma chamber and measurements of neutron radiation parameters.

1. POWERING CONDITIONS OF A PLASMA CHAMBER

Experiment MAGO-3 has been conducted according to the configuration of Fig 1.1.

The calculated and experimental diagrams of experimental system operation conditions and times practically did not differ. The time diagram shows the times of IMG, opening and closing switches initiations, times of EMG contour and opening switch closing and the time of EMG contour break. It also presents the values of current derivatives, obtained in the experiments at the characteristic moments of the power source operation with the closing switch closed; the maximum derivative of the helical EMG, the maximum current derivative in the load - MAGO chamber. The time of the beginning of neutron generation in a chamber is shown as well. The diagram is shown in Fig.1.2.

Operation conditions of a power source are checked by recording current derivatives using inductive probes (B-dot rings I, II), located at the output of the helical generator, opening current switch and at the input of a MAGO chamber, correspondingly /2/ (Fig.1.1.).

Azimuthal location of inductive probes is given in Fig.1.4. The stars indicate the probes, which signals were recorded by LANL.

The initial powering current of a helical generator was recorded by an integrating Rogovsky coil, located at the capacitor bank output. The capacitor bank of 240 f was charged up to the voltage of 19 kv. Fig.1.5. shows the curve of a capacitor bank discharged current. The discharge time into the EMG helical coil was 132 s, initial powering current was 20 kA. The sharp increase of a discharge current rate rise corresponds to the closing of the EMG expanding central armature and the helix and to the end of generator initial powering.

The current for initial powering of a plasma chamber was recorded by inductive probes, located in the rings I and II. Before the closing switch is closed the signals from these probes match, after the switch is closed the helical EMG contour is closed by the opening switch conductor, as a result the probes in the ring I record the further current rise in a generator, the probes in the ring II record practically constant current for initial powering of a MAGO chamber (Fig.1.6., 1.7.). The insignificant rise of the current for initial powering of the chamber results from the magnetic field diffusion through the opening switch conductor. The current for initial powering of a plasma chamber at the moment of the switch operation was 2,3 MA with its rise rate $5 \cdot 10^{10}$ A/s, Fig.1.8.

Fig.1.9 presents EMG current derivatives after the closing switch is closed. The current derivative with the switch contour compressed is shown in Fig. 1. 10

The maximum current derivative of helical EMG was $1,0 \cdot 10^{12}$ A/c, the current at the end of the generator operation was 14,8MA

In MAGO-III experiment the main HE charge of the opening switch was initiated by the explosive delay line (EDL). The calculated time for operation of the opening switch was 349 s from the beginning of a capacitor bank discharge (106 sec from the time, when the opening switch came into action).

Operation of the opening switch was recorded by two groups of the inductive probes, located at the output of the opening switch (probe ring II) and at the input of

FIRE SCHEME

Fig. 1.1

FIRING SCHEME

Electrical scheme

TIME DIAGRAM

1e12 A/s

Derivative of initial current
EMG

Current derivative of EMG

Fig. 1.2

Experimental arrangement

Fig. 1.3

Azimuthal B-dot location for the rings III, IV, V, VI

Fig. 1.4

MACO III, 13 sep 95

Fig. 1.5

MAGO III, 13 sep 95

g. 1.6

Fig. 1.7

MAGO III, 13 sep 95

MAGO III, 13 sep 95

Fig. 1.9

MAGO III, 13 sep 95

1.10

a plasma chamber (probe ring III). Fig.1.11, 1.12 give the dependencies of derivatives and currents according to the measurements of probe ring II. The maximum value of the current derivative, recorded by this group of probes was $(3,8-4,0)10^{12}$ A/sec, the average current was 5,4MA.

Fig. 1.13, 1.14 show the results of measurements by probe ring III. The maximum value of the current derivative are in the range of $(3,8-3,9) 10^{12}$ A/sec, the average current is 5,2 MA.

Before the experiment the plasma chamber was subjected to a standard process of degassing and discharge cleaning in high-current pulse discharges in a deuterium medium.

In the experiment the MAGO chamber was filled by equimolar DT mixture up to the pressure 100 mm Hg.

Fig.1.15 shows the current derivatives, recorded by inductive probes of the first plasma chamber(probe ring IV).The maximum derivative was 2.610^{+13} A/sec.

Current derivatives, obtained from inductive probes of the rings IV,V are presented in Fig. 1.16, 1.17 and 1.18. The probes of that group are located at the radii 30mm and 94mm.

The behavior of inductive probe signals both from the first and second MAGO chambers is close to that, observed in the earlier experiments: MAGO-I, II and II-P. This gives the foundation to conclude that the experimental system operates in a normal way. Though it should be noted that there is a significant asymmetry of the current derivatives in the experiment both in the first and second MAGO chambers (rings IV, V, VI), while the current symmetry at the chamber input(ring III) is good. This phenomenon can not be explained by inaccuracy of the measurements, but most likely is associated with the specific features of plasma discharge flow in the chamber.

2.NEUTRON MEASUREMENTS

Originally there was a plan to conduct MAGO-3 experiment with DD chamber filling. The one of the principal reason was the possibility to measure the neutron spectrums in two perpendicular directions by the detector sets, where detectors were maintained in different distances. Formerly we had information about some interesting effects connected with neutron spectrums at the beginning of the neutron pulse but it was necessary to confirm these data. In MAGO-3 experiment the data about such effects with DT chamber filling was obtained (see post-shot report MAGO-1). In MAGO-3 experiment we hope to receive new information due to US oscilloscopes with high time resolution. Just for these purposes we asked US experts about possibility to record the signals from VNIIEP detectors by LANL devices.

The using of DT chamber filling (the decision about it was made near before the experiment) made the neutron spectrum measurements noninteresting, moreover the point of explosion was changed due to short length of optical cables and the chamber was removed from collimation system centre. Because of the sensitivity of the detectors was changed directly before the experiment and we had not enough time for complete detector test we have some failure and did not received information from detectors at distances 130m and 180m.

Fig. 1.12

Current derivative of chamber (Ring 3)

Fig. 1.14

Fig. 1.16

Fig. 1.18

From the other side, DT allows us to use the Cu- activation methodic for integral neutron measurements.

Received neutron yield $2.4 \cdot 10^{13}$ neutrons per shot.

The form of neutron pulse from detector mounted at 1m is shown on fig. 2.1

3. DISCUSSION OF THE EXPERIMENTAL DATA

The final conclusion on MAGO-III experiment will be made after discussion of all data, obtained by both Russian and American sides, and it will serve as a material for joint publication. This part of the report includes the results of MAGO-III experiment discussion among VNIIEF experts.

According to measurement data the experimental facility operated in a mode close to the expected one. A helical EMG provided the required main and preliminary currents. The magnetic energy in the EMG contour was higher, than 5MJ. The opening switch shaped the current pulse with the required parameters. The current derivative at the opening switch output was more, than 4TA/sec.

The processes at the MAGO chamber input were symmetrically enough, though the inductive probes recorded asymmetry of discharge development in the first and second chamber. Upon the whole the process in the chamber were standard, the character of signals from inductive probes of the first and second chambers is close to the data obtained in the previous experiments. The general character of the process in the plasma chamber corresponds to the conceptions based on MHD calculations.

4. THE RESULTS OF MHD CALCULATIONS AND THEIR COMPARISON WITH EXPERIMENTAL DATA

For the condition of the conducted experiment one-dimensional MHD calculations have been done. They have been done in the setting, specified in /1/. The chamber in calculations was presented as a channel, the radius and width of which, depending on the path along the channel, are the same as in /3/ (Fig.4.1). The current source was modeled using an electrotechnical circuit (Fig.1.1) /2/. In calculations L inductance was accepted to be 23nH. Dependence of resistance on time was described by the equation:

$$R(t) = 5t + 4t^2 \quad [m\Omega], \quad (4.1)$$

(t in mks).

At the initial moment the current flowing along L0 inductance was IEMG = 15MA, initial powering current flowing along L inductance was I0 = 2.1MA this current was increased by 10 per cent in calculations.

MAGO-3 neutron pulse

Fig. 2.1

The initial pressure of DT gas filling the chamber was 10Torr (Pressure was slightly decreased (by 10per cent) in calculations to account for 2-D effects) .

Figs.4.1 and 4.2 give dependencies of calculated and experimental current derivatives and currents on time in a load. It is seen from comparison of the current derivatives in the load $\dot{I}_3$ (cf. Fig. 4.1) (probes in Ring 3) that they are in good agreement with each other. The maximal value of the calculated current derivative $\dot{I}_3$ equal to 3.9 MA/ms is close to 3.2 MA/ms registered in experiment. The computational curve falls to zero at time 2.5 ms, the experimental curve falls below zero at time 2.3 ms. Good accord of these curves (in average) is reinstated by the shape of currents (cf. Fig 4.2). Nevertheless the computed current derivative $\dot{I}_3$ has substantially more small scale oscillating features than experimental one.

Figs 4.3 gives the time dependence of current derivatives in the first compartment of the chamber $\dot{I}_4$ (for $S = 7$ cm coordinate). Comparison of dependencies of currents I_4 (cf. Fig.4.2) and their derivatives $\dot{I}_4$ in the first compartment of the chamber shows good agreement by order of magnitude in periods and amplitude of oscillations. These oscillations in calculation are caused by magnetic sound. Substantial azimuth asymmetry in the experimental curves of $\dot{I}_4$ is well expressed (cf. Fig.4.2). Readings of the two probes concord in time, but differs in main part of the time interval in factor of ~ 2 . It is seen that in the interval from $t=0$ to $t=1.2$ ms before computational high frequency oscillation calculated curve lays approximately between the experimental. Fig.4.4 represents dependencies of current in the second chamber compartment (for $S = 21$ cm). It is seen from comparison the current derivatives $\dot{I}_5$ (probes in Ring 5) that oscillations in calculation begin somewhat later (approximately after ~ 0.6 ms) than in experiment. These oscillations begin at time ~ 2.1 ms in calculation and at time ~ 1.5 ms in experiment. Maximal and minimal values of $\dot{I}_5$ approximately the same in computation and experiment. The period of oscillation in computation is ~ 7 times less than measured in experiment. At time $t=3$ ms the calculated curve oscillates ~ 5 times and in experiment only a single oscillation was detected.

Calculated and experimental curves of neutron generation rate are presented in Fig.4.5 and Fig.. The total neutron yield (5.9 10¹²) is approximately ~ 4 times less than in experiment (2.63 10¹³). The calculated neutron yield generation curve has shape with two humps the experimental curve shape is triangular. It should be mentioned, though, that the shape of a neutron pulse is significantly influenced by magnetosonic oscillations and it is difficult to predict their phase in the calculations, that is why the shape of a neutron pulse in the calculations and in the experiment may differ substantially. In calculation the neutron generation begin at time ~ 2.5 ms in experiment at time ~ 1.9 ms.

A number of differences between the calculated and experimental curves, for instance later appearance of currents and beginning of neutron generation, could be

Fig. 4.1 Computational and experimental current derivatives measured by probes in ring 3

Fig. 4.2 Computational and experimental currents measured by probes in rings 3,4

Fig. 4.3 Computational and experimental current derivatives measured by probes in ring 4

Fig. 4.4 Computational and experimental current derivatives measured by probes in ring 5

Fig. 4.5 The calculated neutron pulse

connected with one-dimensionality of calculation. Moreover, substantial discrepancies could be caused by azimuth asymmetry of currents. This asymmetry approximately 20 per cent for I_3 (cf. Figs. 4.1) and ~2 for I_4 , I_5 , I_6 (cf. Figs. 4.2-4.4). There is a well expressed trend of divergence increase with increase in the number of the measurement ring. The azimuth asymmetry taken place could increase the neutron pulse duration and smooth to a certain extent pulsation in the neutron generation rate curve. This consideration, at least partially, could explain the differences in duration and shape of the calculated and experimental neutron pulses. As a whole the degree of concordance as well as differences between calculations and experiment for MAGO-3 are at the same level as in the previous analogous experiments.

CONCLUSION .

The report gives the results of the joint Russian-American MAGO-III experiment. The experimental facility, including a helical explosive generator, closing and opening switches and a plasma chamber operated in the given conditions:

- preliminary powering current -2,3MA
- EMG current before the contour rupture-14,8MA
- current in the plasma chamber- 5,2 MA
- integral neutron yield- $2,4 \cdot 10^{13}$ n/shot.

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