NEAR-WALL EFFECTS INFLUENCE ON LONGITUDINAL SYMMETRY OF A SOLID LINER COMPRESSED BY A SLOWLY INCREASING EMG CURRENT

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Introduction

Good longitudinal symmetry of magnetically driven metal cylindrical liners may be observed at a relatively short time of current rise, for example, in experiments at PEGASUS-2 facility [1]. Because of interaction of the liner with current-conducting edge walls the symmetry of compression may be much worse in experiments with a longer rise time of current delivered by explosive magnetic generators (EMG) [2].

The present paper describes the results of study of near-wall effects negative influence on longitudinal symmetry of compression of liners, close in design to experiments at PEGASUS-2 facility [1], but at an order higher duration of current supplied by helical EMG. The work was conducted within the frames of liner technology program (LT-1 experiments).

I. EXPERIMENTAL DEVICE AND DIAGNOSTICS

Experimental device consisted of helical EMG (HEMG) and liner load: two ponderomotive units (PU) connected in series with similar aluminum liners and differing in edge copper walls, delivering the current to the liner in the process of its compression.

HEMG circuit is presented in Fig. 1.

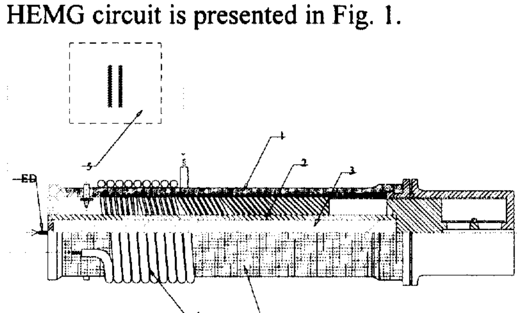

Fig. 1

The generator consists of a multisectional and multiplestart helical coil (1) and cylindrical central armature (2) with HE charge (3). Central copper armature has the inner diameter of 65 mm and wall thickness of 6.5 mm. HEMG initial inductance is ~32 μH.

For HEMG powering a coupling coil (4) was wound on the helical coil, and capacitor bank (5) was discharged to that coupling coil (EMG powering by means of magnetic flux pocketing). Such a scheme of HEMG powering allows to insulate the discharging circuit of the capacitor bank from HEMG and its recording circuits. Coupling coil consisted of 21 single-start turns with a total inductance of ~45 μF. Coupling coefficient was 0.78-0.79. The initial magnetic flux in HEMG was ~0.5 Wb (at the coupling coil current of ~17-18 kA).

Load circuit is presented in Fig. 2. Initial parameters of aluminum liners (AD1 material in Russian designation) in both PUs were the same: radius R_l=30.05 mm; height H_l=24 mm; initial thickness ΔR_l=0.95 mm in the first experiment and ΔR_l=0.97 mm in the second experiment.

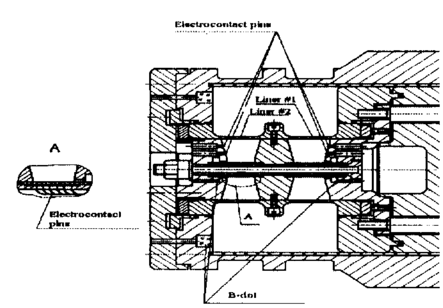

Fig. 2

In the first experiment the solid thick edge walls, delivering current to the liner, had a glide plane with the angle of inclication to the liner axis of Θ=82° in PU-1 (closer to HEMG) and Θ=88° in PU-2. Stepped ring grooves 2X4 mm^2 (ΔR_0=2 mm and ΔH=4 mm) were

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14. ABSTRACT

Good longitudinal symmetry of magnetically driven metal cylindrical liners may be observed at a relatively short time of current rise, for example, in experiments at PEGASUS-2 facility [l]. Because of interaction of the liner with current-conducting edge walls the symmetry of compression may be much worse in experiments with a longer rise time of current delivered by explosive magnetic generators (EMG) [2]. The present paper describes the results of study of nearwall effects negative influence on longitudinal symmetry of compression of liners, close in design to experiments at PEGASUS-2 facility [l], but at an order higher duration of current supplied by helical EMG. The work was conducted within the frames of liner technology program (LT- 1 experiments).

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made in the corners of the edge walls under the liner in both PUs. In the second experiment angle Θ was 82° in both PUs, the grooves in the corners of the edge walls under the liner were made only in PU-1. Current parameters of HEMG were measured by standard techniques: initial magnetic flux in HEMG was determined due to current in the coupling coil, HEMG currents were measured by inductive probes.

VNIIEF's facility ERIDAN-3, central measuring unit (CMU) with electrocontact probes, impact and inductive pins positioned on the edge walls (see Fig. 2) were used in the experiment to study the liner-walls interaction.

Contact pins, installed on the same level (r=5.25 mm) in CMU case to measure longitudinal (axial) time difference of the liner approach to CMU, were covered by a steel screen with the outer radius of 6 mm and 0.5 mm thick. The space between the contact probes and the screen was 0.25 mm.

II. PRE-SHOT THEORETICAL-AND-COMPUTATIONAL RESEARCH

Physical circuit of experimental device and its basic parameters were chosen on the basis of analysis of results of 1-D and 2-D simulations of PU with a preset of the expected in the experiments current through the liner' evaluating curve.

1-D MHD simulations of the liners were performed using technique [3] with modification of Al_{00} conductivity of condensed states of aluminum [1]. Elasticity-plasticity of cylindrical liners was taken into account by specifying a constant yield strength Y_0=1.5 kbar and Poisson's ratio ν=0.3.

2-D simulations were performed using hydrodynamic Lagrangian technique with regard to DRAKON elasticity-plasticity [4]. Joule heating of the liners was ignored because of its small value. PU' copper wall was described in computations according to Steinberg [5]. Al-liner was described by the same elastic-plastic model with Al 1100 parameters, but with a smaller value of yield strength Y_0=0.5 kbar [1]. The copper edge walls' slope angle Θ and dimensions (ΔH and ΔR_0) of the notch in the corners of walls under the liner were varied in computations. The number of computations and the values of varied parameters are given in Table 1.

Table 1. Numbers of computations and varied parameters values.

NN computation	Θ, degrees	ΔR_0, mm	ΔH_0, mm
1	82	0	0
2	88	0	0
3	82	2	4
4	88	2	4
5	82	2	2

It turned out that the obtained in 2-D computations (R-t) and (U-t) diagrams of the liner for PU' plane of symmetry at Θ=82° and a 2X4 mm² notch (ΔR_0=2 mm and ΔH=4 mm) are practically in agreement with the results of 1-D computation. However, when the notch is absent, higher velocities occure in 2-D computations most probably because of liner linear mass decrease caused by the liner thinning near the walls.

As followed from 1-D MHD computations, by the moment of current maximum the liner is compressed more than in experiments at Pegasus-2 facility. It is compressed to a radius $R(I_{max})/R_0$=0.55. The magnetic field is ~0.5 MOe and the magnetic pressure is ~10 kbar. They grow monotonously in the process of subsequent compression, thus reaching the values of ~0.8 MOe and of ~25 kbar.

As it was expected, 2-D computations for these experiments, unlike computations for experiments at Pegasus-2 facility, predicted considerable longitudinal liner asymmetry resulting from its interaction with the walls. Fig. 3 presents maximum longitudinal asymmetry of the inner surface of the liner ΔR_{in} as a function of R_{in}.

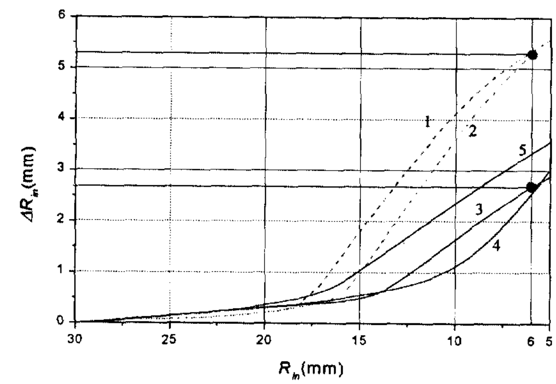

Fig. 3

Dotted lines mark the results of computations in which a near-wall cumulative jet is formed early in time. In the process of liner compression asymmetry grows slowly at first, then at R_{in}<(14-18) mm is grows faster, reaching the value of ΔR_{in}~5 mm by the end of liner compression in computation N1 (without notches at the walls corners) and two times smaller value in computation N3 (with a 2X4 mm² notch). The durations of liner collision with CMU, of 1.4 μs and 0.8 μs respectively, correspond to the above-mentioned values of ΔR_{in}. In this case the liner parts located within its symmetry plane collide with CMU ~0.5 μs earlier in computation N1 as compared with computation N3.

In Fig. 4 one can see the plots of the calculating mesh

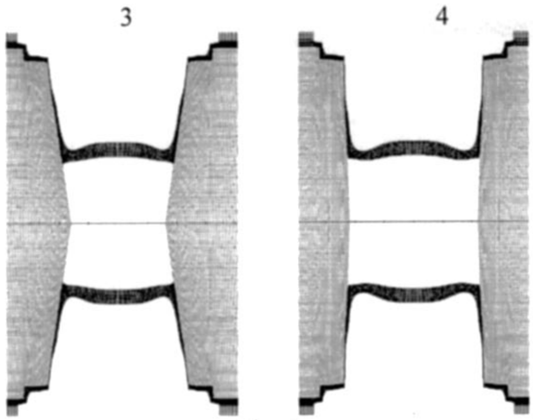

Fig. 4

for PU' compressed liners in the first experiment by the moment of their approach to CMU. Higher cylindricity of the liner and less near-wall thinning of it can be observed at Θ=82° (computation N3) in comparison with the liner at Θ=88° (computation N4). Fig. 5 presents the analogous plots for the second experiment liners (for both liners Θ=82°). When there is no circular step at the corner of the edge wall, one may observe significant near-wall advance

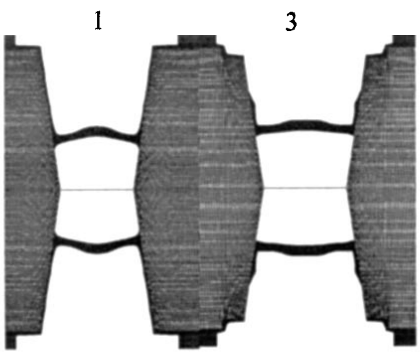

Fig. 5

and less cylindricity of the liner (computation N1) as compared with a case with such a step (computation N3). The plots in Fig. 5 are built up for the current curve obtained in the second experiment (see Section III) at t=115 µs.

III. RESULTS OF EXPERIMENTAL STUDY

The results of current measurements in PU in the first experiment are given in Fig. 6: I_{max}(t≈117.2-117.3 µs)≈4.4-5.0 MA (t=0 corresponds to the moment of electrodetonator initiation in HEMG, see Fig. 1). Fig. 7 represents the radiographic images of initial position of the liners and their location at t=116.6. µs when the liner has moved a little more than a half of its initial radius.

Computer processing of the radiographs was carried out studying the density of x-ray film' blackening. This was done with the aid of special algorithms and 16-bit precision programs. D is proportional to the optical thickness of the recorded object: $D=\lg(I_0/I_{tm})$, where I_0 and I_{tm} are the intensities of radiation falling to the film

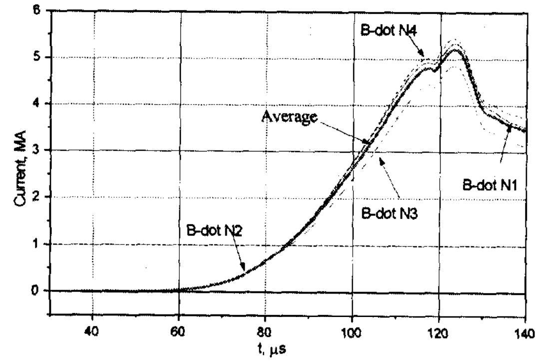

Fig. 6

and of that penetrating through it. Fig. 8 and 9 show the results of the liner boundaries' determination. The boundaries were determined as a maximum of image gradient modules. This maximum was obtained after

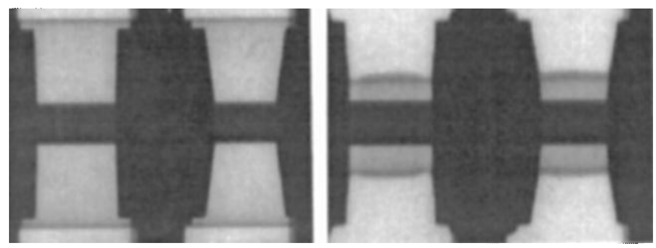

Fig. 7

elimination of all the noise (differentiation operator is unstable given the noise). Static images were used to work out the boundary criterion. The images of liner boundaries represent the laying-out of extended profiles according to gradient maximum.

As well as in 2-D computations, bigger cylindricity of the liner may be seen at Θ=82° (see Fig. 8) and smaller near-walls thinning, as compared with the angle Θ=88° (see Fig. 9). In the latter case a twofold near-wall thinning of the liner may be observed together with near-wall ejections of substance in front of the liner.

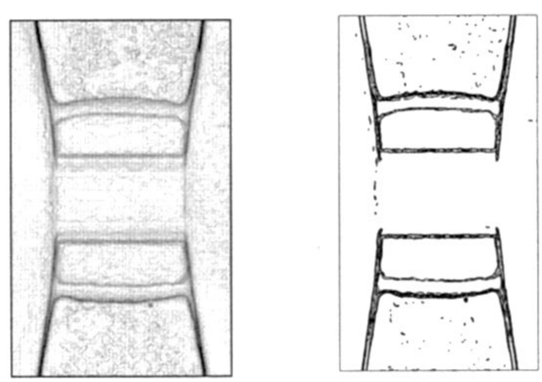

Fig. 8

The maximum current in the second experiment was I_{max}(t≈118 µs)≈4.6-4.8 MA. Because of untimely triggering of x-ray facilities, the radiographs were made prior to the near-wall effects' evolution. However, the electrocontact probes made it possible to record in PU-1 and PU-2 the points of R-t diagram of the near-wall parts of the liner on the radii R=15 mm and 22 mm (see Fig. 10) and the longitudinal time difference of the liner approach to the radius of CMU (see Fig. 11) (in both PUs $\Theta=82°$). Fig. 10 shows that in accordance with 2-D hydrodynamic computations the speed of the near-wall

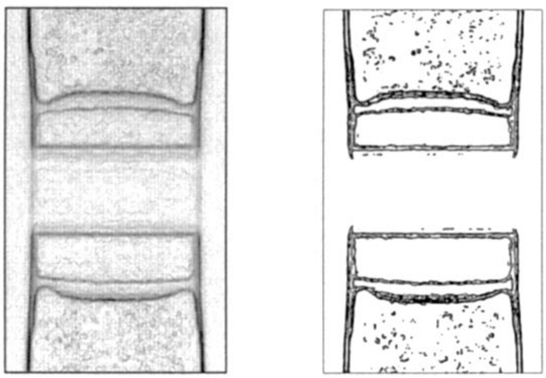

Fig. 9

parts in PU-2 (in which there were no circular notches at the corners of the edge walls) was higher than in PU-1. As is shown in Fig. 11, the near-wall zones in PU-2 approached CMU ~0.8 μs earlier, than the near-wall zones in PU-1. Deviation from cylindricity is bigger in PU-2 than in PU-1. Total time difference in PU-1 was 0.4 μs, while in PU-2 it was 0.8 μs, i.e. 2 times bigger. Experimental time difference is somewhat less than that in 2-D computations. Probably, it is connected with the fact that the real dynamic strength of copper is a little bit lower, than it is according to Steinberg [5].

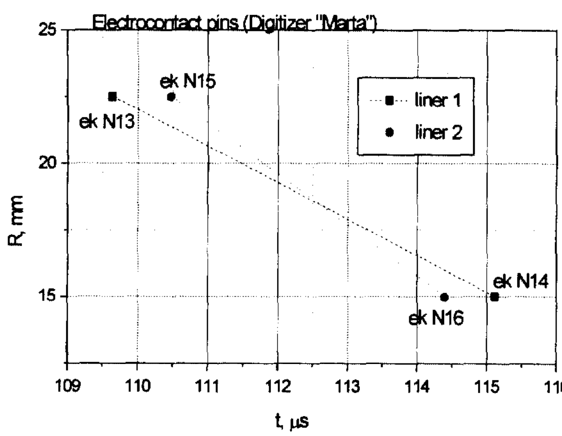

Fig. 10

It should be mentioned as well that no significant penetration of magnetic field under the liners in the

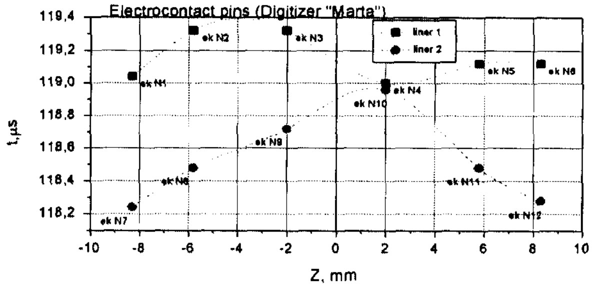

Fig. 11

process of their compression was recorded in any of the experiments. That's what predicted the computations.

IV. CONCLUSION

Two experiments of LT-1 series showed that 2-D computations due to hydrodynamic Lagrangian technique with regard for DRAKON elasticity-plasticity describe satisfactorily the near-wall effects during the compression of solid aluminum liners by a slowly increasing magnetic field of EMG. Besides that, the experimentally recorded longitudinal symmetry of the compressed liner is higher than it follows from the computations. This may be connected with a lower dynamic strength of copper edge current-conducting walls, as compared to Steinberg's elastic-plastic model [5].

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