VNIIEF-LANL SUBCONTRACT (4756M0014-9Y)

Condensed Argon Isentropic Compression With Ultrahigh Magnetic Field Pressure: Results of the Experiment

Post-shot Report

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Table 1. Argon Experiment Shot Map

Condenser bank parameters: C=9000 μF, U=19 kV

Triggered facility	Delay	Process
Condenser bank	10	MC-1 generator powering
ВУ-19-1 (X-unit 1)	115	Protective detonator
ВУ-19-3 (X-unit 2)	60	MC-1 HE charge firing
Fiducial 1	87	Synchronization
Fiducial 2	103	Synchronization
"Release"	100+4,5	X-ray pulse triggering
БПГ (Current source)	76	Current pulse in Mn gauge

Delay μs	Osc. #	Sweeping μs	Divider	Probe	Signal
102	1...2	4	1:1	γ	X-ray pulse
1	3...6 (digital)	100	1:10	dH_{01}/dt dH_{02}/dt	Initial field H_0 and T_0 - process onset, probes 1, 2
86	7,8	25	1:1	V_{Mn1}	Manganine probe 1
100	9	8	1:4	V_{Mn1}	Manganine probe 1
100	10	8	1:1	V_{Mn1}	Manganine probe 1
86	11,12	25	1:1	V_{Mn2}	Manganine probe 2
100	13	8	1:4	V_{Mn2}	Manganine probe 2
100	14	8	1:1	V_{Mn2}	Manganine probe 2

2. Experimental Results

The first result of the experiment done is the successful operation of all devices involved in it and obtaining of all measuring probes signals. Figure 1 gives the X-ray images of the experiment. They are, primarily, the soft X-ray pictures of the compression tube - empty and filled with frozen argon. These pictures show distinctly the light and heavy parts of the compression tube: in the upper picture of an empty tube one can see a ceramic tube - the manganine probes support that are not seen in the heavy part background. In the next picture of the compression tube filled with rather dense argon, $\rho_0 = 1.63$ g/cm^3, the ceramic tube can not be seen, and any disturbances in the uniformity of the filling are not seen, so one can consider that the frozen sample is uniform - without voids and bubbles.

In the same figure, the preliminary and test images of the compression tube are placed. There, a lower copper end of the compression tube is seen, and the length of the compression tube both parts in the picture is sufficiently long to make measurements.

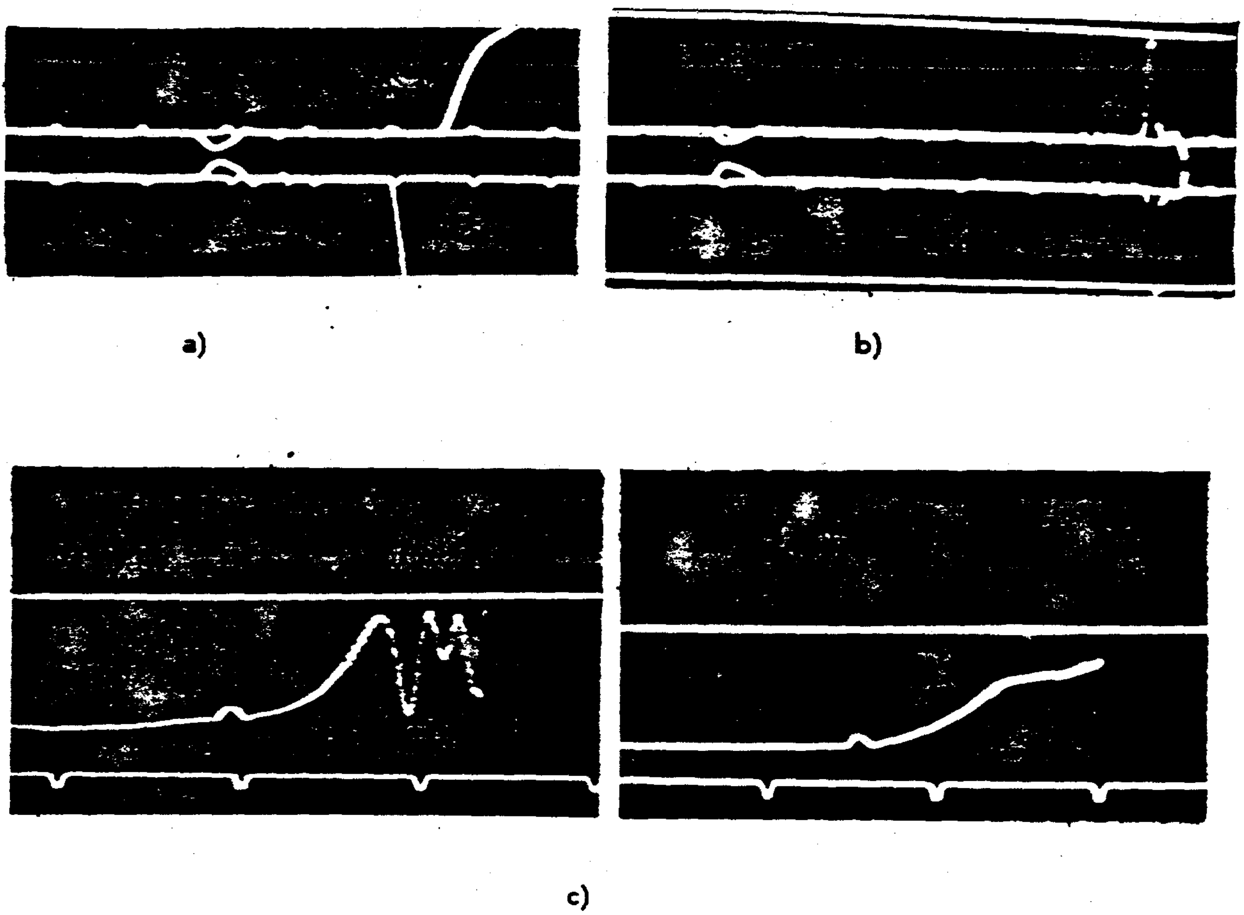

Fig. 2. Oscillograms of experiment signals.
a) calibration of the measuring cables electrical length. Time marks 0.5 μs.
b) X-ray pulse. Time marks 0.5 μs.
c) manganine probes signals. Time marks 2 μs.

Figure 3 shows the resultant processed oscillograms which depict the order and the results of calculation of time intervals - pulse delay time in the cables for each recorded signal, Δ_i, the starting moment for MC-1 liner implosion, Δ_0, and the isentropic compression process onset in the time scale of the experiment, T_0, the X-ray exposure, synchronization of the manganine probes signals with the time scale for the compression process and their amplitude scaling done with a calibration curve from Ref. [2]^2 :

$$P=356.2\frac{\Delta R}{R_0}+42.7\left(\frac{\Delta R}{R_0}\right)^2 \text{kbar},$$

where, for the simplicity sake, resistance values, R, are replaced for the respective voltages found from the oscillograms.

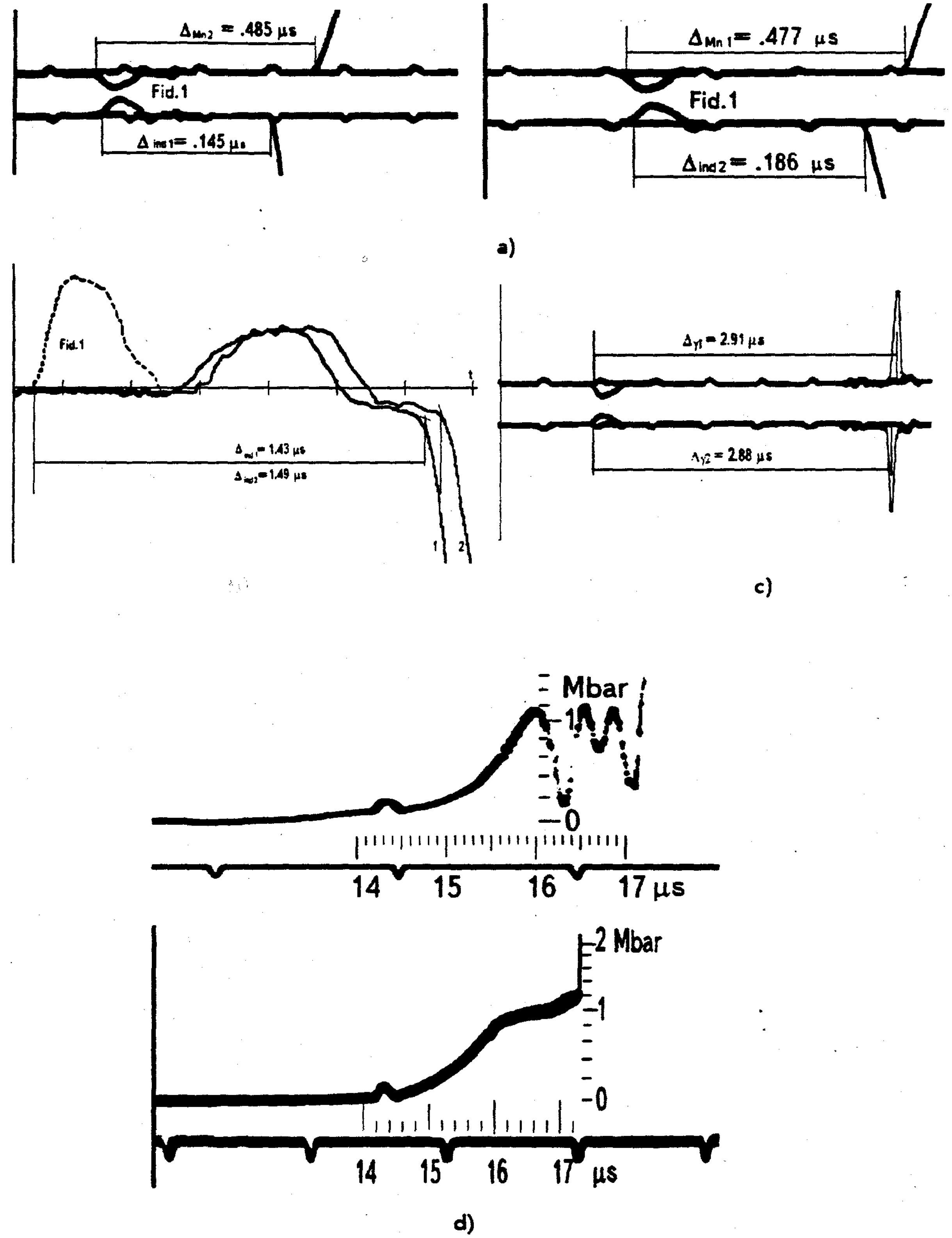

Fig. 3. Processed Oscillograms of Induction, Manganine, and X-ray Probes Signals.

a) cable length calibration: b) compression onset; c)X-ray exposure; d) piesoresistive technique signals

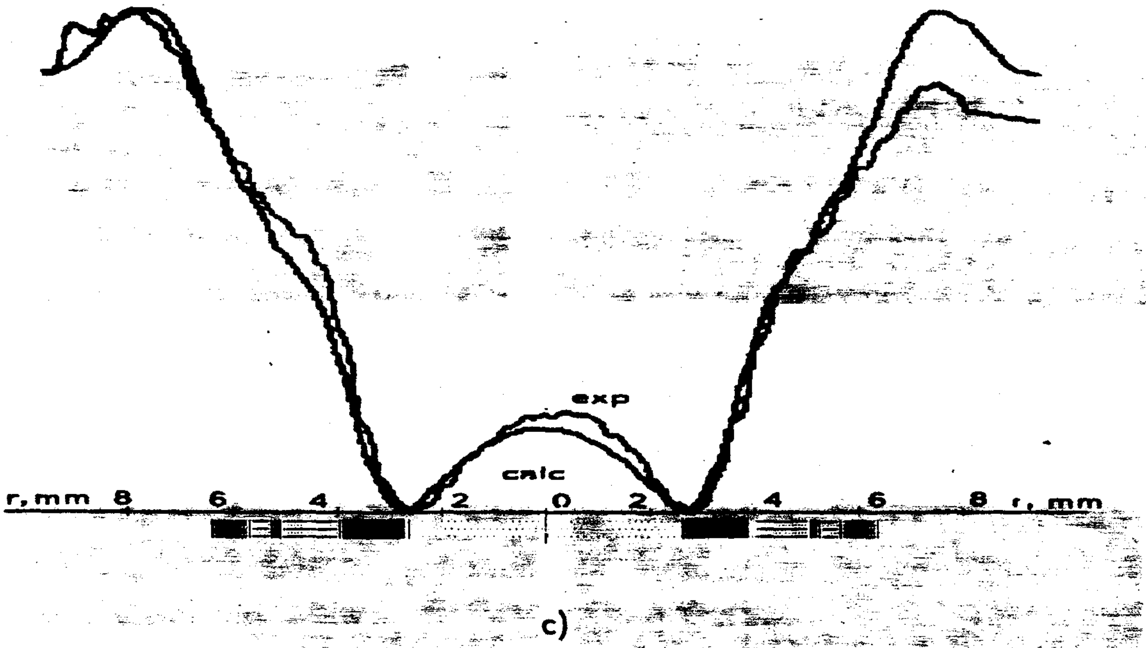

Fig. 4 (continued).

Table 2. Numerical Parameters of Isentropic Compression Device

Initial magnetic field B_0	175^{+5}_{-5} kG
Compression process onset T_0	$88.30^{+.02}_{-.02}$ μs
Exposure moment Tγ	$17.59^{+.02}_{-.02}$ μs
Reference aluminum cylinder	Compression $2.21^{+.1}_{-.1}$ Pressure* $3^{+.4}_{-.4}$ Mbar
Reference aluminum layer in the light part of the tube	Compression $2.2^{+.3}_{-.3}$ Pressure* $3^{+.6}_{-.6}$ Mbar
Reference aluminum in the heavy part of the tube	Compression $2.24^{+.4}_{-.4}$ Pressure* $3.1^{+1.4}_{-1.4}$ Mbar
Argon in the light part of the tube	Compression $5.3^{+.15}_{-.15}$ Pressure** $6.4^{+.7}_{-.5}$ Mbar
Argon in the heavy part of the tube	Compression $5.2^{+.2}_{-.2}$ Presure** $6.1^{+.8}_{-.8}$ Mbar

*) The aluminum pressure ([Mbar]) was calculated with the formula[3] :

$$P_{cold}(\rho) = 0.3505y^2\{\exp[8.5876(1-y^{-1})]-y^2\} - \\ 6.3613\cdot 10^{-3}y^5(0.4525+y^{-4.3575})\exp[1.0143(1-y^{-4.3575})]$$

gauges. From the cited manganine probes signals it is seen that the pressure in the vicinity of the probe location grows to ~ 1 Mbar, then approximately for a microsecond - till the maximum pressure - in the argon (or in the manganine, it is also new and interesting enough) something is happening. It seems as if the argon pressure remains constant or wave-like varying about this magnitude, then grows by jump as the oscillograms of the divided signals show, to >6 Mbar, but the probe indications after a probe resistance jump are highly doubtful.

It seems that one must consider to be a reliably stated fact of argon state change near 1 Mbar pressure (the similar piezoresistive probe signals were obtained in the previous shot also). And the expected probe closure due to argon transition in conducting state is not seen on the oscillograms. It seems that this change in argon state (or manganine, we repeat) at 1 Mbar does not allow to use manganine in detecting the change in the argon conductivity. So one must use other techniques, ex., used in the solid hydrogen properties investigation the method of direct registration of conductivity arising in compressed materials[5] . To be more convinced in the revealed change of the argon properties at 1 Mbar one must also get a manganine gauge signal in the region of light part of the tube, i.e. conduct the shot with the light and heavy parts of the compression tube changed in location.

Speaking of the future experiments we propose one more change in the compression tube design, namely to prolong the tube sections of different mass. By the estimates, the sound velocity in the solid argon at megabar pressures is 10 km/s and higher, i.e. the velocity of pressure equalization (or substance flow from the high pressure area in the heavy tube section into the light one) is rather high. The pressure pulse (see the signals of the manganine gauges) lasts nearly 3 μs, consequently, the picture sections where the sample compression is measured, must be ≥ 60 mm apart. This also means that it will be, probably, necessary not to use the cylinder of the reference substance, leaving the reference substance only in the compression tube layer, and leaving the possibility of the reduction of the experimental program by 2 times employing the compression tube made of two parts of different masses. And at last, speaking of the future experiments we would like to remind of the necessity of developing of isentropic device X-ray image continuous recording for, at least, a microsecond.

CONCLUSION

The experiment on solid argon isentropic compression with MC-1 generator ultrahigh magnetic field pressure which was scheduled in VNIIEF-LANL subcontract, has initiated the condensed argon study at megabar pressures. The experiment has recorded the predicted argon compression by more than 5 times that, by the existing concepts, corresponds to 6 Mbar pressure. Thus, the main goals of the experiment were achieved: demonstration of the method's possibilities and statement of the subsequent study. The isentropic compression device capabilities were shown, the basic characteristics of the isentropic compression and an initial parameters of the experimental facilities and techniques were defined, new information on the changed argon properties at 1 Mbar was obtained.

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