LIQUID METAL JET TARGETS FOR INTENSE HIGH ENERGY BEAMS

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In the mid-80's at IHEP (Protvino), we had constructed a special stand for studying the behavior of targets irradiated by *70 GeV* proton beams with high density of energy release [1]. The proton beam was focused into target by the specially designed lithium lens (Fig.1) providing the beam focusing into a size with $\sigma < 0.5\ mm$.

The experiments scheme (Fig.2) assumed the proton beam focusing into the mercury target placed inside the aluminum cylinder and the cylindrical lead target divided into several parts. That enabled the observation of the target surface behavior in the maximum of nuclear-electromagnetic shower.

When focusing the beam into the size corresponding to the energy release density $q>1\ kJ/g$ some hydrodynamic effects have been observed:

- destruction of the aluminum container filled with mercury (Fig.3),

- "emergence" of a substance from the end of lead target in the shape of sharp formation (as a nail tip) forcing through the titanium foil.

The conclusion - this is the fundamental solution of the problem to produce the walless jet target of liquid metal. The technical solution is producing the target in the form of flat jet flowing out from the narrow and long (along the beam axis) nozzle [2].

The development of the liquid metal jet target techniques proceeded in the following stages.

1. The production of the target device with the pumping of the gallium-indium alloz ($T_m = 18℃$) for testing the operating techniques with liquid metals (pump, etc) and for the study of formation conditions for the flat jet and its behaviour depending on the pumping conditions (Fig.4, 5, 6).

The construction of the target device for the work with a beam at IHEP and a strudy of the gallium target behaviour under destruction conditions was fulfiled and shiped to IHEP.

2. Development of techniques for the work with liquid lead.

The aim is the construction of real targets of heavy metals with high melting temperature (lead, $T_m = 350℃$) and the further shift to heavier and refractive metals (gold alloys, $T_m = 600\text{-}800℃$).

The development of the liquid lead jet targer for the generation of positrons at SLAC target station (*l = 30 mm*). The development of the prototype of target device for studying the jet behaviour in the longitudinal magnetic field and under the beam (Fig.7, 8, 9).

The development of the powerful liquid lead target for the neutrino program in the kaon factory project TRIUMF. A *2 mm* wide and *25 cm* long jet directed along the beam axis. 10 litres of liquid lead circulated in the system (Fig.10, 11, 12).

In all the target devices given above with liquid metal continuous jet the conductive type electromagnetic pumps of our design have been used.

3. The development of targets made of gold and its alloys for the operation with the beam drop frequency of the order of *1 Hz*.

The aim is to reduce to minimum the volume of liquid metal and size of the target device fraction heated to high temperatures.

One version (Fig.13) is the drum with cavity filled with liquid metal rotating inside graphite chamber. With the drum rotation the liquid is elevated and flow out to the drain chamber.

At present, the prototype of another target device where the flat jet of liquid metal is formed by its forcing up (like fountain) by pulse magnetic field of a current passed through the liquid metal is now designed and manufactured (Fig.14, 15, 16).

4. One of the most vital probles for the development of designs of liquid metal targets for the operation with primary intense beams in the regime of target destruction is the study of the target substance behaviour during the explosion. Since the technology of producing flat jet targets made of gallium and lead and some specific designs of similar target devices are now quite well developed [3] and it seems reasonable to start their use namely for the study of target substance behaviour in the explosion regime.

The results of studies of the behavior of the scattered (especially along the axis of the primary beam) target substance at large energy releases can put some additional requirements to the design geometry of the real target devices for their reliable operation under complex thermal and radiation regimes.

5. Targets in the form of the stationary or pulse flat jet of liquid metal can successfuly be used both for obtaining secondary beams of quite high energy flying out from the target forward in the limited solid angle. In this case, the collecting optical system is placed at some certain distance behind the target.

In the projects of muon colliders, π-mesons (parents of muons) are planned to be collected in the maximum of their spectra at a pulse of the order of *200 MeV/c* where their angular distribution is practically isotropic in the front semispace along the beam direction. In this case, the target should be placed inside the focusing device -solenoid with strong magnetic field collecting pions [4], focusing device with the azimuthal axially symmetric magnetic field [5], or inside the multichannel collecting system for obtaining of a quasi-paraxial pion beams located aroud the target [6]. In this case, in practice, the only version of the liquid metal target is the cylinrical jet target either horizontal or vertical direction.

6. In the multichannel system of pion collection for obtaining the polarized muon beams the vertical version of cylindrical jet target is optimal.

The main problem is the formation of the open input and output surfaces of the cylindrical jet. The formation of the open input surface is necessary in order to avoid the destruction of the nozzle output and the fixed position of the pion source with respect to the collecting system. The formation of the output surface is necessary for producing the targed fixed length and for the possibility of further use of the primary beam.

Experimental results on the formation of the vertical cylindrical jet of liquid lead with the open input and output surfaces are given in pictures (Fig.17, 18, 19).

With free flowing of liquid metal from the volume with the given level of liquid metal surface through the round nozzle (diameter of *0.6 cm*) in optimum regime the jet has sufficiently cylindrical shape at length over *30 cm*. The optimization of flowing regime is achieved by varying the liquid level in the volume of relative nozzle output of *4-6 cm*.

- In order to form the open input surface of the cylindrical jet the flowing of liquid metal from the cone nozzle is made so that in the cone vertex the jet acquires is cylindrical cross section and the target open surface is formed for the beam entrance.

- Fixation of the target length and the formation of open surface for beam exit is achieved by "cutting" the jet by the "terminating" jet directed perpendicularly flowing from the flat nozzle.

The schematic diagram of the real target device with vertical cylindrical jet, pump, and heat exchanger is given in Fig.20, 21. The design envisages the operation with liquid metal at temperatures *600-800°C* (gold alloys).

7. In order to produce the horizontal cylindrical jet target of heavy metal it is necessary to provide quite high flowing velocity of liquid metal from the nozzle. The

most promisig seems to be the development of the techniques of electromagnetic acceleration of liquid metals. For the study of one of possible method of electromagnetic acceleration the device given in Fig.22-24 and pictures has been made. The homogeneous pressing of liquid metal (gallium-indium alloy) placed into cylidrical volume is achieved by magngnetic field of a pulse current passing directly through the metal. As a result, the liquid metal will be "forced" through the nozzle located in the upper part of the cylinder and will form the vertical jet with high velocity of liquid metal. After pulse, the liquid metal is drained into the cylidrical volume and the system returns into its initial state.

The main technical problem is unusual requirements to the parameters of a pulse current with an amplitude of few hundred kiloamperes. For the efficient press of liquid metal cylinder one should have current pulses with durations corresponding to the skin-layer in liquid metal much smaller than the cylinder radius. In this geometry, it is *100-300* microseconds. At the same time, one has to provide the flow of liquid metal during a few tens of milliseconds. Therefore, the formation of a long current puls with modulated frequency of a few kHz is required.

Available electric systems with powerful thyristor inverters enable us in the near future to start the experiments on a study of magnetic acceleration of liquid metals (Fig.25).

For the shift from vertical jet flowing up to the horizontal jet the device should be modified with the use of the pump for pumping liquid metal through the system (Fig.26,27).

References

1. A. V. Evtichyev, B. J. Kotov et al – IHEP; B. F. Bayanov, G. I. Silvestrov, T. A. Vsevolozhskaya – BINP. Thermophysical processes in targets of proton accelerators of high energy. XIII International Conference on High Energy Accelerators, Novosibirsk, 7 – 11 august 1986, v. 2, p. 290—292 .
2. G. I. Silvestrov. The problems of a secondary particles beams production. XIII International Conference on High Energy Accelerators, Novosibirsk, 7 – 11 august 1986, v. 2, p. 258—263.
3. G. I. Silvestrov. Liquid metal targets for intensive high-energy physics beams. Proceedings of the workshop on new kinds of positron sources for linear colliders. March 4 – 7, 1997, SLAC, p. 376—407.
4. R. Palmer et al. Muon collider design BNL – 62949. March 1996.
5. G. I. Silvestrov, V. A. Tayursky. Pion production system for muon collider on the base of collection devices of magnetic parabolic mirror type. Preprint BINP 98 – 4.
6. A. N. Skrinsky. Report on 3-rd International Conference Physics Potential and Development of $\mu^+\mu^-$ colliders. December 13 – 15 1995, San-Francisco.

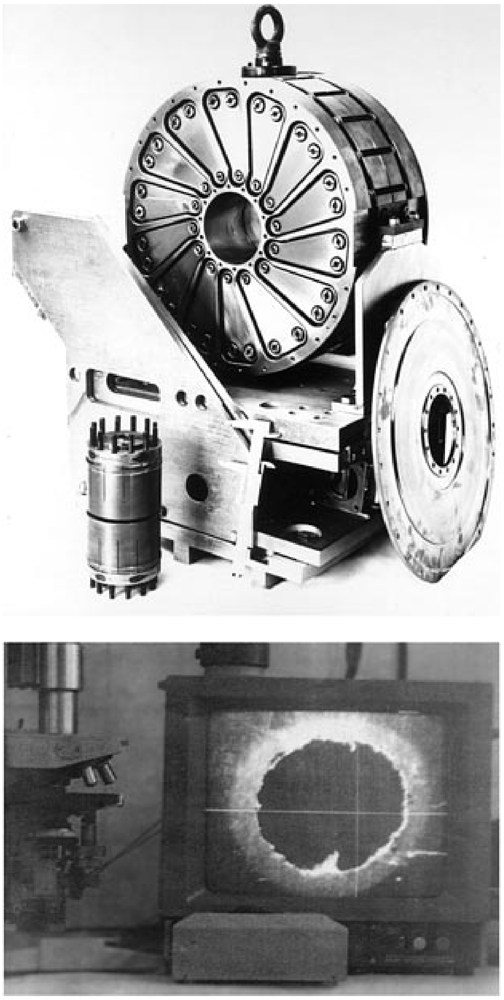


Fig.1. Lithium lens with transformer (before assembling).

Figure 1:

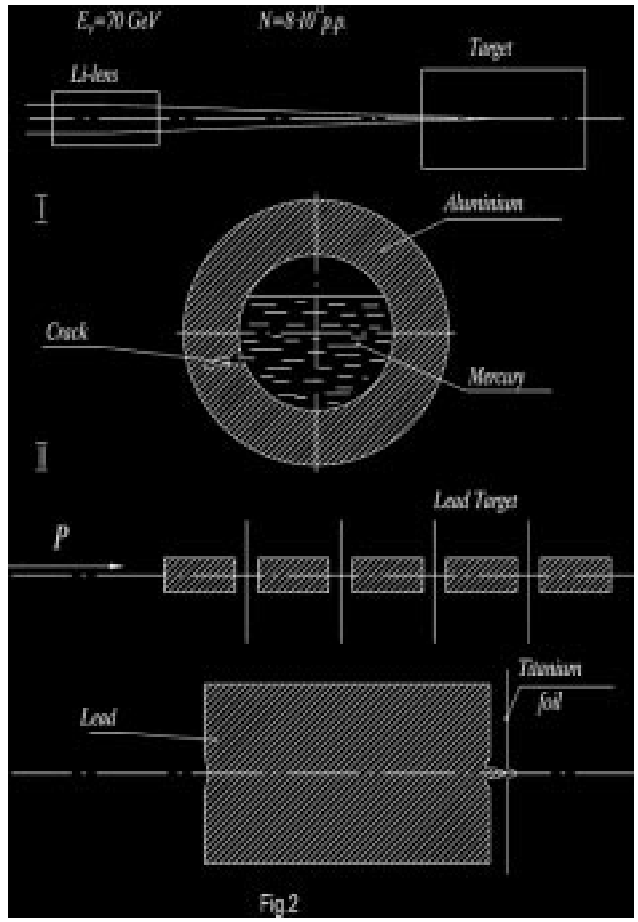


Figure 2:

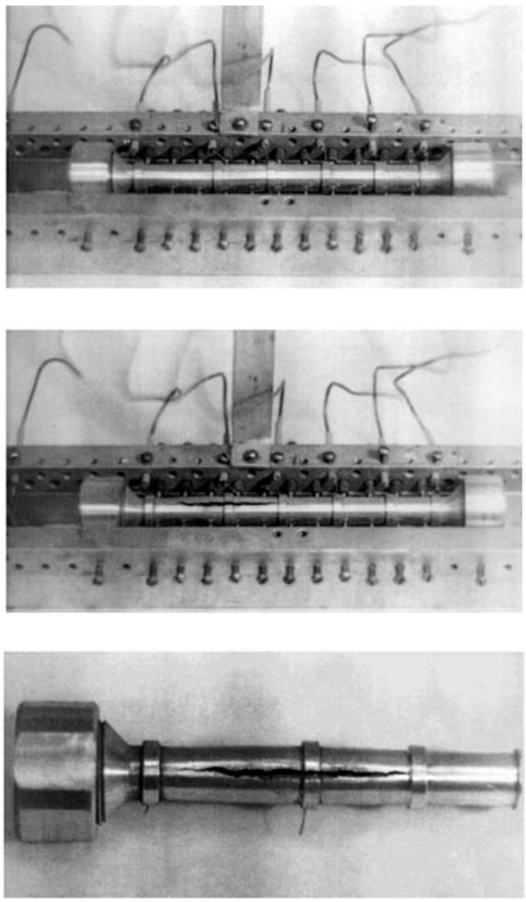
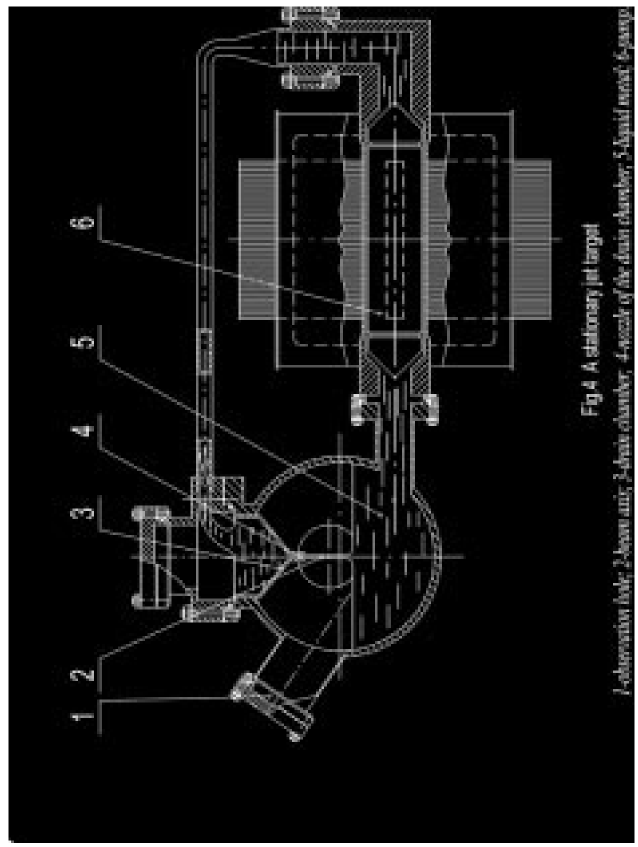


Fig.3. Photo of the aluminum cylinder before and after destruction.

Figure 3:



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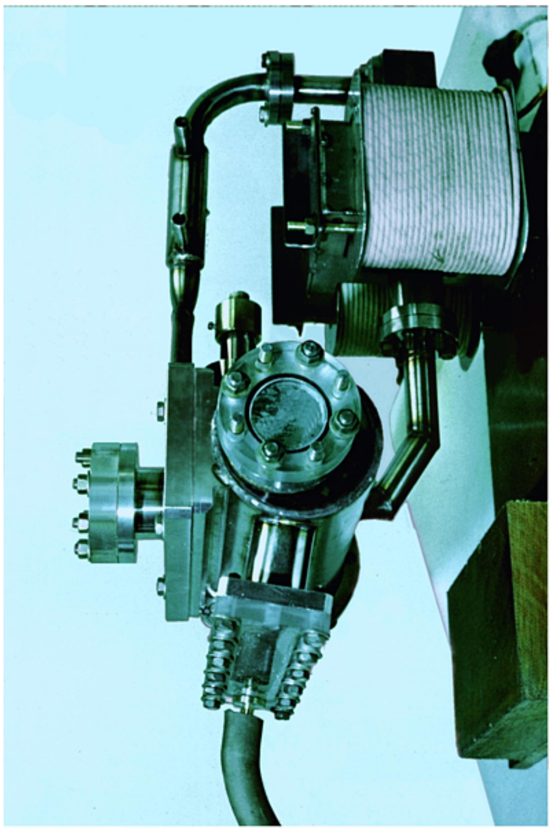


ïg.5. Photo of a target device for the investigation of liquid metal jet formation using a gallium - indium alloy.

Figure 5:

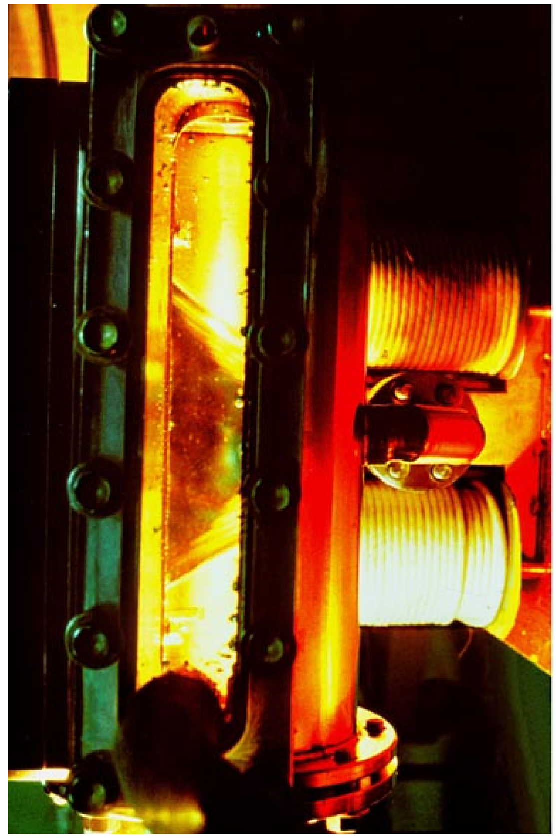


Fig.6. Photo of a liquid metal jet in vacuum.

Figure 6:

Fig.7. Photo of a liquid lead jet target device for experiments with SLAC electron beam.

Figure 7:

Fig.8. Liquid lead jet target device with a longitudinal magnetic field.

Figure 8:

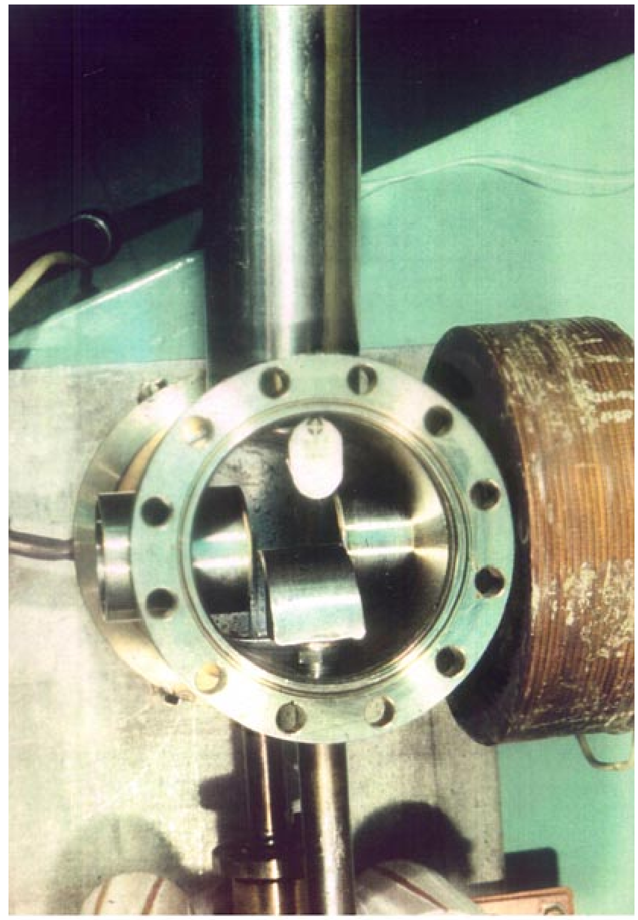


Fig.9. Top view of the target device (Fig.8) with open cover.

Figure 9:

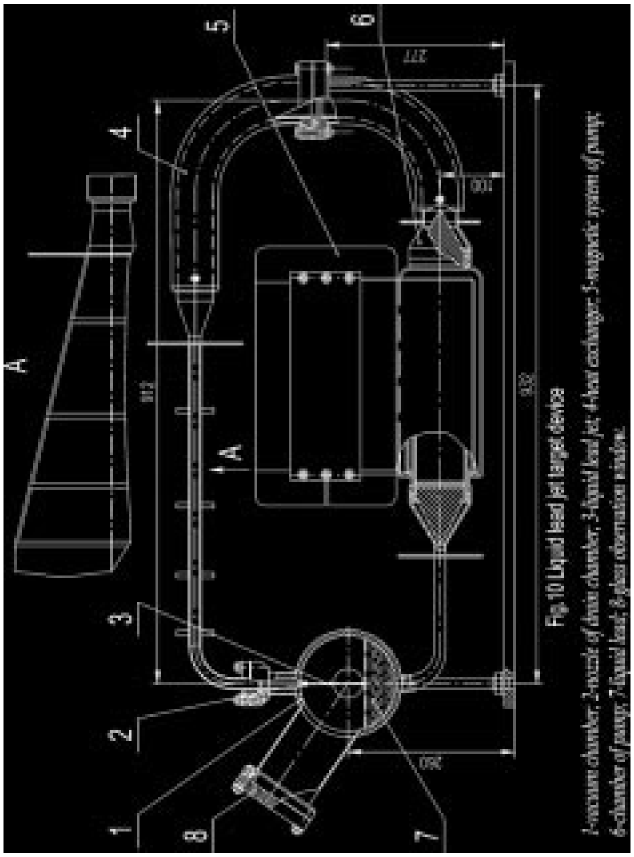


Fig.10 Liquid lead jet target device

1-vacuum chamber, 2-nozzle of drain chamber, 3-liquid lead jet; 4-heat exchanger; 5-magnetic system of pump; 6-chamber of pump; 7-liquid lead; 8-glass observation window.

Figure 10:

Fig.11. Photo of a target device for pumping 10 liters liquid lead in process of assembling.

Figure 11:

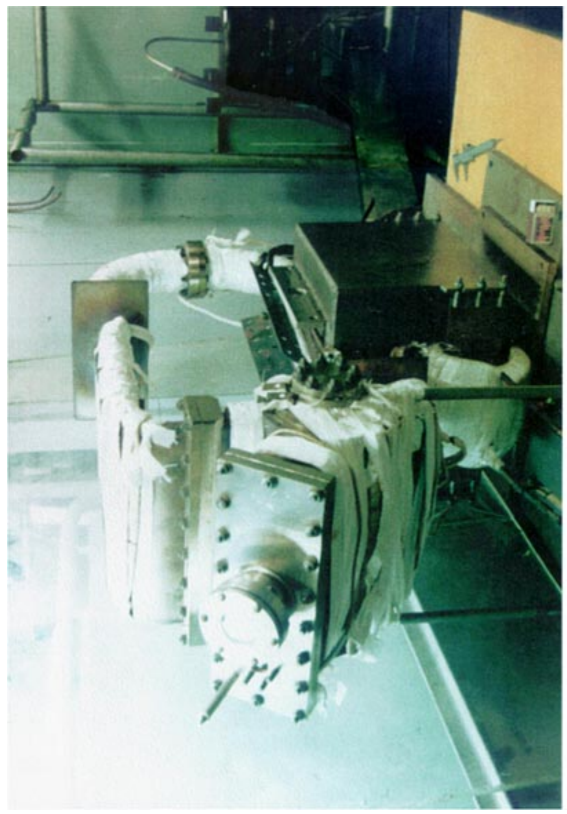


Fig.12. Photo of the target device during experiment.

Figure 12:

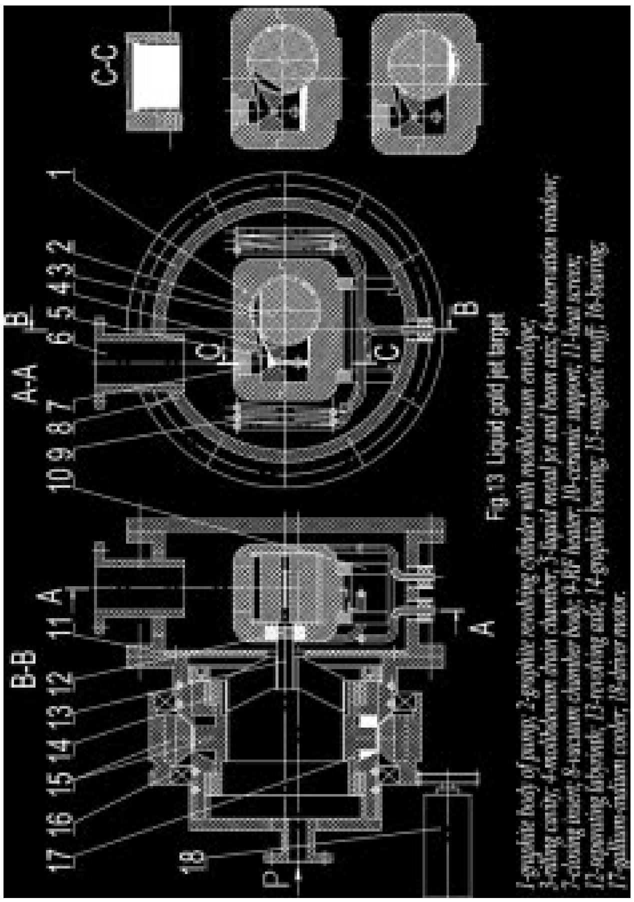


Figure 13:

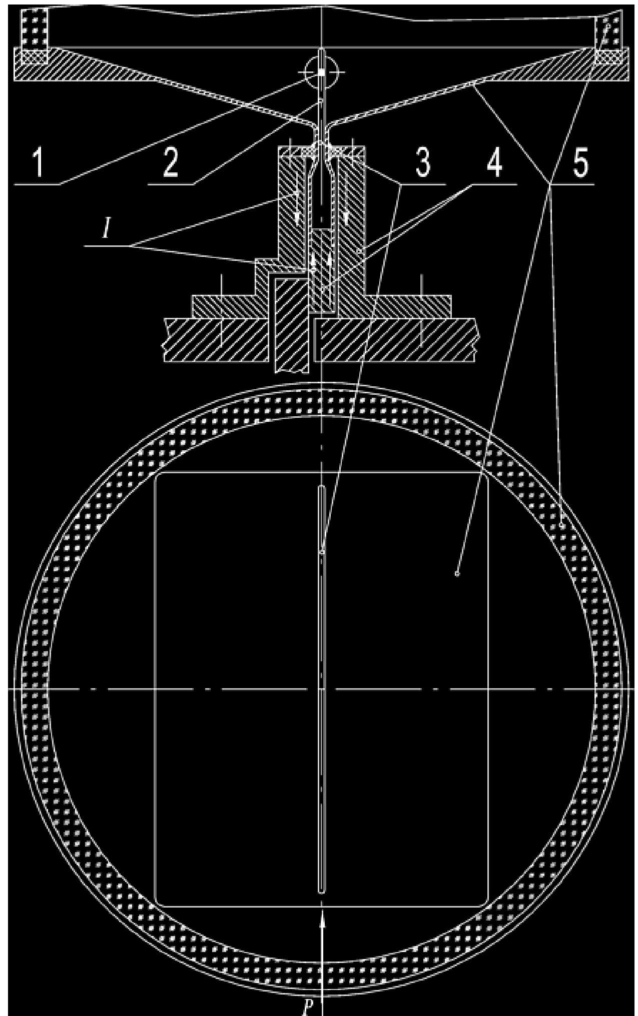


Fig.14 Flat liquid metal jet "fountain" type

1-beam axis; 2-liquid metal flat jet; 3-flatnozzle; 4-flat current input; 5-vacuum chamber.

Figure 14:

Fig.15. Photo of a target device prototype for vertical flat jet formation.

Figure 15:

Fig.16. Top view of the target device (Fig.15).

Figure 16:

Fig.17. Photo of the vertical cylindrical liquid lead jet.

Figure 17:

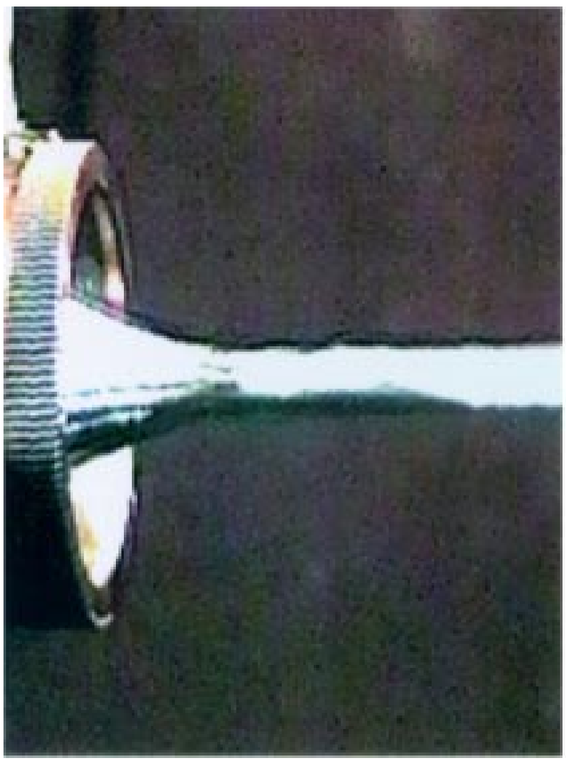


Fig.18. Photo of a conic part of the liquid lead jet.

Figure 18:

Fig.19. Photo of the liquid lead jet with terminating jet.

Figure 1:

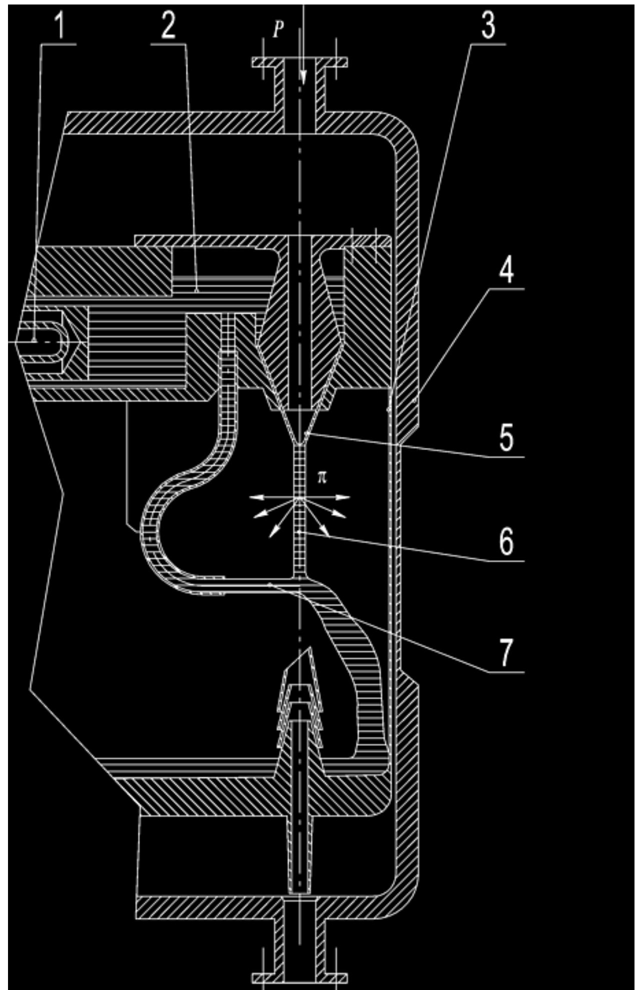
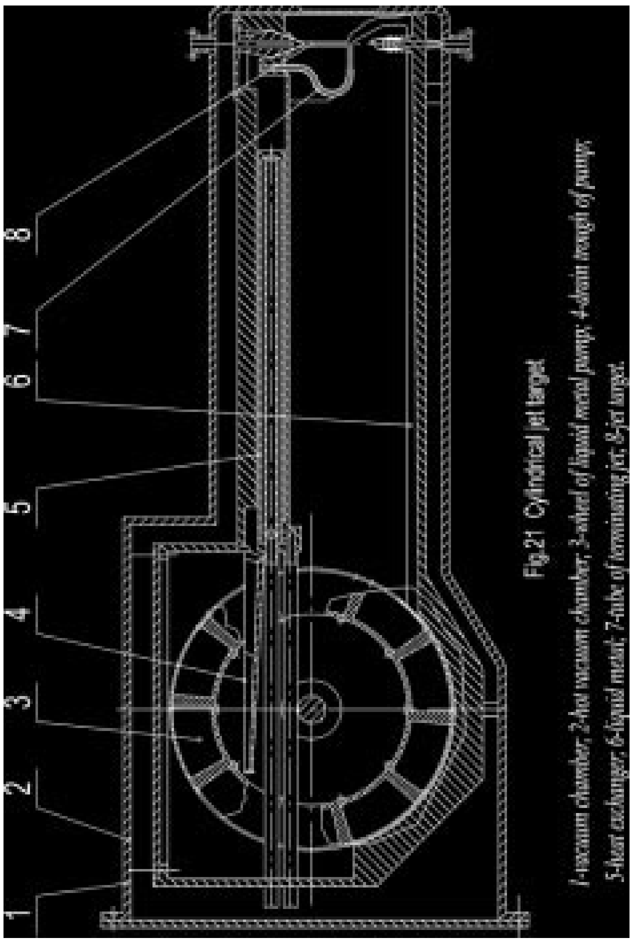


Fig.20 Cylindrical jet target

1-heat exchanger; 2-liquid metal; 3-hot vacuum chamber; 4-vacuum chamber; 5-conic liquid metal jet; 6-cylindrical liquid metal jet; 7-terminating jet.

Figure 2:



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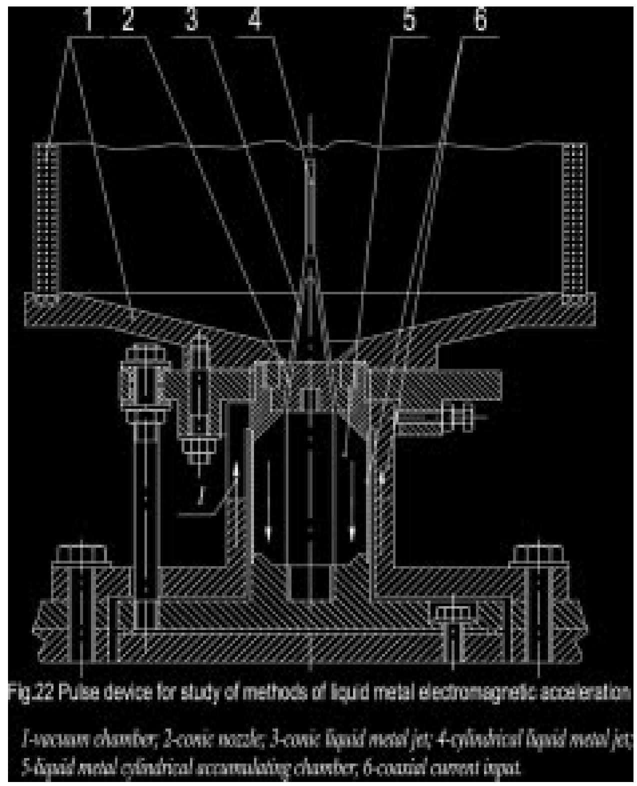


Figure 4:

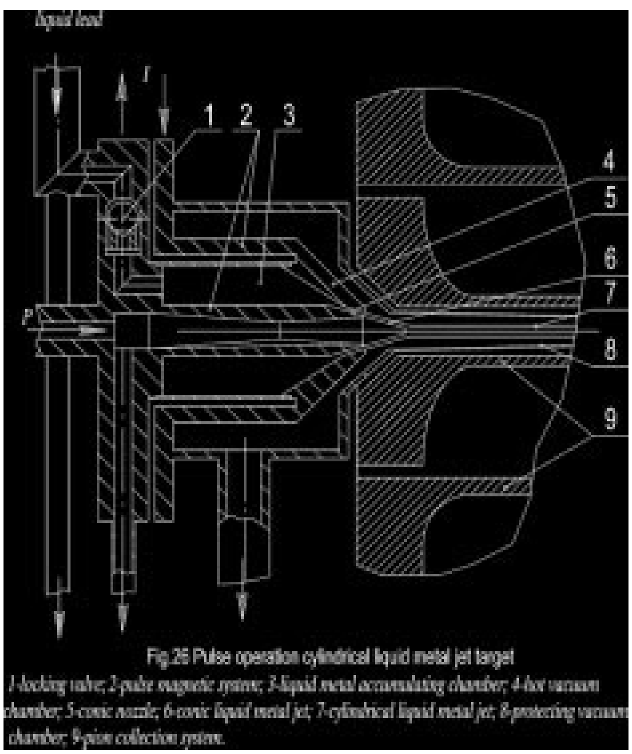
Fig.23. Photo of a device for investigation of a electromagnetic methods of liquid metal acceleration.

Figure 5:

Fig.24. Top view of the device (Fig.23).

Figure 6:

Figure 7:



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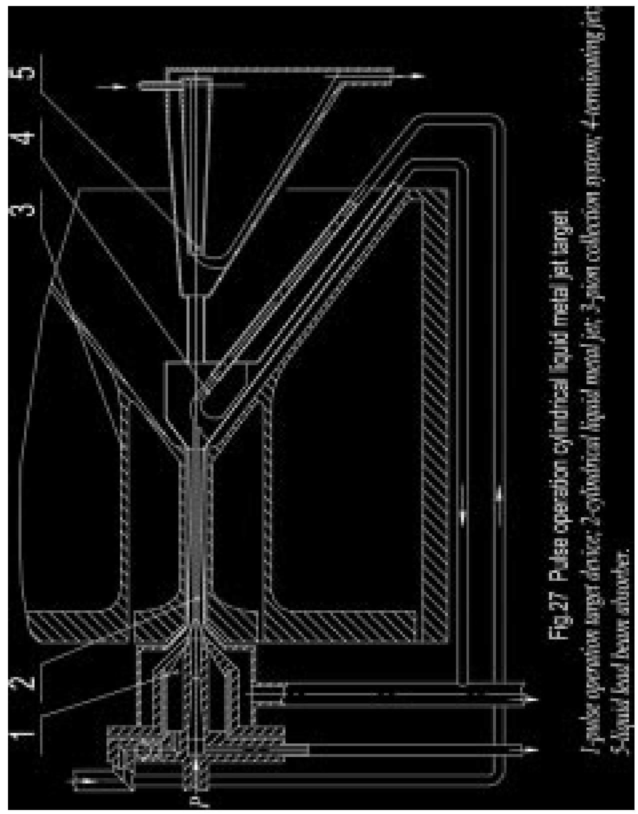

Figure 9: