Pilot Target Supply System Based on the FST Technologies: Main Building Blocks, Layout Algorithms and Results of the Testing Experiments*)

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In this report, we discuss the main building blocks and interface units of the FST supply system, layout algorithm and new results of the testing experiments. In this area, we firstly give a presentation of the FST approach to design and construction of the target supply system for HiPER project; describe possible ways of integration of our latest developments into engineering applications (e.g. FST-layering module with a double-spiral layering channel), and discuss the cost estimations of the FST supply system in the case of HIPER-scale targets.

Keywords: free-standing target, cryogenic layering, cryogenic target injection, rep-rate mode, burst mode

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1. Introduction

In this report we focus on work that addresses the issues related to the development of a pilot target supply system based on the free-standing target (FST) technologies [1–5]. The work has been performed through coordination of a number of Russian Research Groups, namely: P.N. Lebedev Physical Institute of RAS (LPI) as the leading organization, Prokhorov General Physics Institute of RAS, A.A. Dorodnitsin Computing Center of RAS, Red Star State Unitary Enterprise, M.V. Lomonosov Moscow State University, State Polytechnical University (SPU) of St.Petersburg, TUAP, Ltd and CryoTrade, Ltd.

In this report, we discuss the main building blocks and interface units of the FST supply system, layout algorithm and new results of the testing experiments. In this area, we firstly present basic requirements to the target supply system for HiPER project, based on the FST approach and describe possible ways of integration of our latest developments into engineering applications. There were manufactured and treated the mockups of all basic and interface units of the target supply system that showed the capability of the system operation. In particular we firstly present the comparative analyses of the experimental results on targets movement inside single spiral layering channel and double-spiral one, which shows the promissory of the double-spiral channel application for reactor-scale targets. We firstly present the results of mockups testing on free-standing target delivery to target collector as well as on operation of target-&-sabot assembly unit at 77 K. We also present results of experiments on ferromagnetic sabot acceleration by electromagnetic coil at cryogenic temperature (77 K). Finally, we discuss the cost estimations of the FST supply system in the case of HIPER-scale targets.

2. Pilot Target Supply System Based on the FST Technologies (FSTSS)

Basic requirements to the FSTSS are as follows:

- Cryogenic target fabrication and injection at a rate of 1-to-10 Hz
- Survivability of a fuel core via formation of ultrafine fuel layers with inherent survival features (the grain size of the solid fuel should be scaled back into the nanometer range)
- Using multiple target protection methods including nano-coatings/materials for specific applications
- Time and space minimization for all production steps, i.e., tritium inventory minimization
- Cost is within the range of commercial feasibility.

The FSTSS consists from 3 main building blocks and 3 interface units, namely:

1) Block#1 – FST layering module (LM) based on using moving free-standing spherical capsules. Figure 1 shows the FST-LM schematics (a) and the different layering channels (b, c). The operational scenario of the LM is:

- FST layering module works with a target batch
- Targets remain un-mounted in each production step
- Transport process is target injection between the basic units: shell container – layering channel – test chamber.
- Targets move along the layering channel in a rapid succession - one after another, which keeps up a repeatable target injection into the test chamber (target collector).

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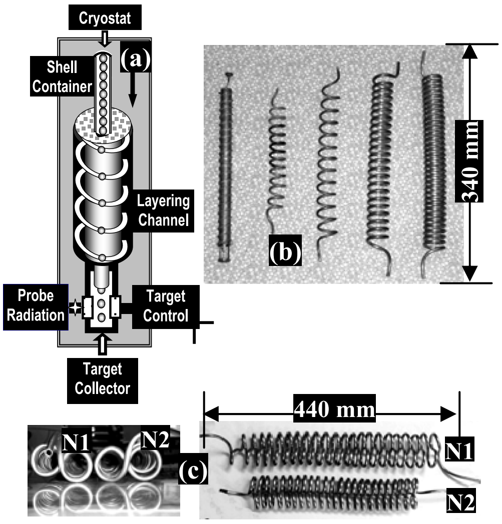

Fig. 1 The FST-layering module: (a) schematics, (b) a set of single layering channels, (c) the double-spiral layering channels (mock ups N2 and N3).

During FST layering, the following processes maintain a uniform layer formation:

- Target rotation results in a liquid layer symmetrization under its rolling along the layering channel (single- or double spiral).
- Fuel freezing is due to the heat conduction through a small contact area between the shell and the wall of the layering channel (metal tube cooled outside).

Mockups testing show considerable increase of the target residence time in the LM with a double - spiral layering channel (Fig. 1, c). This fact can be used for the LM upgrade for IFE targets.

2) Block#2 – device for target-and-sabot assembly in a rep-rate mode.

3) Block#3 – system intended for target acceleration and rep-rate injection ($\nu > 1$ Hz) into a reaction chamber.

4) Shell container (SC) as an interface unit between the fill system and the Block #1; SC is intended for arrangement and transportation of a batch of free-standing targets from the filling system to the LM, and for loading the free-standing targets in a rep-rate mode from the SC to the layering channel (under gravity). Testing of the SC designed for 10 shells has shown the possibility of rep-rate operation of the SC at cryogenic temperatures; 0.1 Hz operation was demonstrated [3, 4]. We designed the SC for loading 200 HiPER targets to the LM with 1-6 Hz.

5) Target collector (TC) as an interface unit between Block #1 and Block #2; TC is intended for cryogenic targets loading (under gravity) in a rep-rate mode from the TC to the assembly device (Fig. 2).

6) Electro-magnetic coil as an interface unit between Block #2 and Block #3; the coil intended for target-&-sabot pre-acceleration and delivery at a start position of an injector.

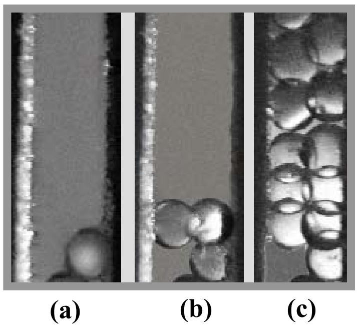

Fig. 2 Free-standing target delivery to target collector: (a) 1st target injection, (b) 3rd target injection, (c) collector with 12 injected targets. Target is CH shell of ~ 1 mm diam.

The FSTSS based on layering within the moving free-standing spherical capsules (FST layering method) and satisfying the integration scheme stated above can operate with different target designs and includes concepts for IFE reactor fueling (similarity principle).

At first, a prototypical FSTSS has been created for operation with 1.0-to-1.5 mm diam. CH shells. The main steps of IFE targets supply have been demonstrated using this system: fuel layering inside moving free-standing shells (20-to-100-μm-thick layer), and injecting the created cryogenic targets into the test chamber with the rate of 0.1 Hz.

The next step is the experimental demonstration of the FST-technologies for HiPER (**Hi**gh **P**ower laser **E**nergy **R**esearch: $E \sim 200$ kJ with a rate of $\nu \geq 1$ Hz) facility. A conceptual baseline target (**B**aseline **T**arget-2) for the HiPER project is of two types [6,7]. The dimensions are as follows: (1) **BT-2** is a 2.094-mm diameter compact polymer shell with a 3-μm thick wall. The solid layer thickness is 211 μm; (2) **BT-2a** consists of a 2.046-mm diameter compact polymer shell (3-μm thick also) having a DT-filled CH foam (70 μm) onto its inner surface. Onto the inner surface of the foam there is a 120 μm-thick solid layer of pure DT.

The goal of the design study is to facilitate the FST technology transfer from computation into engineering stage. As a result, the FSTSS-HiPER was designed [5]. This system works in a burst mode (injection of 100 targets per 1-to-10 sec). At the injection stage, we suppose to use multiple target protection methods such as sabot, protective cover, metal reflecting coatings, outer protective cryogenic layers [3, 4].

The layout algorithm of the FSTSS-HiPER is as follows:

- Pusher #1 drives 1 sabot towards a nest of the revolver
- Revolver rotates driving the sabot to the exit of the target collector
- Shuttle transfers 1 cryogenic target from the collector to the sabot
- Next rotation ensures a protective cover delivery onto the

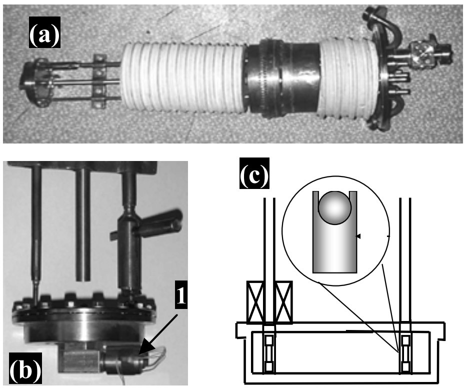

Fig. 3 Mock up of the revolver of the target-&-sabot assembly device: (a) the revolver mounted on the insert into cryostat; (b) the revolver general view (1 is electromagnet); (c) revolver schematics.

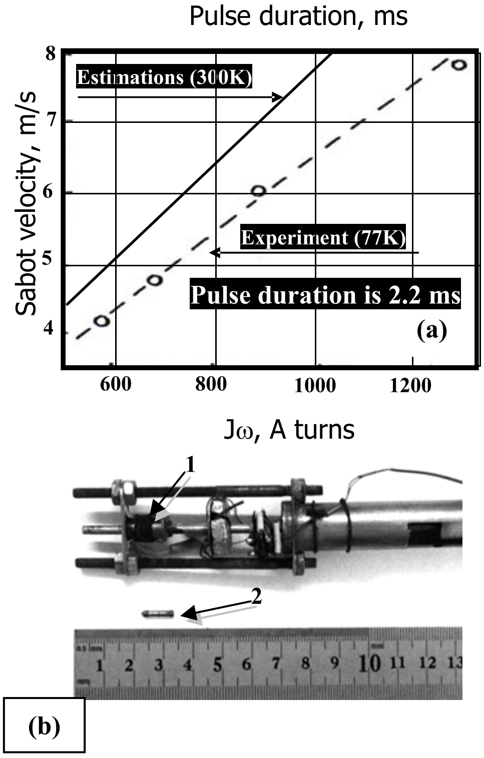

Fig. 4 Injection velocity of the ferromagnetic sabot vs. parameter $J\omega$ at 77 K (a); J is the current amplitude [A], ω is the number of turns in the coil; (b) mock up of the electromagnetic injector: 1- coil, 2– sabot from the ferromagnetic steel.

top of the sabot

- One more rotation drives the assembly unit to the entrance of the coil
- Assembly unit is pulled out of the revolver by the electromagnetic field of the coil
- Pre-acceleration of assembly unit up to 3-8 m/sec and its delivery along the guide tube to the start position of an injector

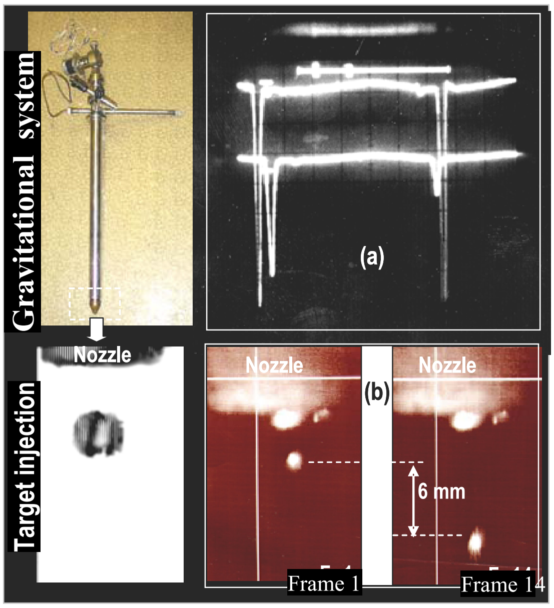

Fig. 5 Experiments with cryogenic gravitational system: (a) two-beam oscilloscope data, (b) fast video recording: 14 ms between the frames.

- Next steps are as follows: target-&-sabot-&-cover acceleration, sabot-&-target splitting, sabot removal, target-&-cover co-injection into a reaction chamber.

Figure 3 shows the mock up of the revolver of the target-&-sabot assembly device mounted on the insert into cryostat. The revolver rotates under the action of the electromagnet (coil). Operation of the revolver has been proofed at 77 K.

There were manufactured and treated the mockups of all basic and interface units of the FSTSS-HiPER that showed the capability of the system operation. In particular, the proof-of-principle experiments carried out at 77 K demonstrated the possibility of the ferromagnetic sabot to be pre-accelerated by a single coil to 3 ÷ 8 m/sec (Fig. 4).

In additional different methodology for *on-line* target monitoring were examined including high-speed video recording & two-beam oscilloscope (Fig. 5). In these experiments cryogenic gravitational system made in LPI was used. In the experiments the glass shells of 500-600 μm-diam. and 18-20 μm-thick were injected into the test chamber at 77 K. The results of the injected target monitoring have shown that target trajectory angular spread is ≤ 3 mrad, average target velocity is 0.43 ÷ 0.55 m/s.

3. Cost-Effective Target Fabrication and Injection

Preliminary estimations related to FSTSS-HiPER showed that Blocks #1 and #2 include 28 original (estimating cost ~ 180000 €) and 50 commercial (estimating cost ~ 140000 €) elements. Block #3 – requires addition design studies for estimation of cost-effective production.

The results obtained allows us to turn to a commercial-scale building of the target supply system based on the FST layering method for HiPER-scale polymer targets [5].

4. Concluding Remarks

The R&D Program at LPI is developing the science and technology base for reactor target fabrication and injection. For IFE, our estimations have shown that the FST-layering time for a reactor-scaled target (ϕ4 mm, ΔR = 45 µm, W = 200 µm) is ~ 14 sec in the case of using a protective metal coating. The mockup of the FST-layering channel (double-spiral tubular channel) was built and tested. Experimentally measured time of spherical CH capsule motion in this channel was of about 23 sec that made it possible to realize the FST-layering method for reactor targets.

We have proposed a draft design of the unit for "cryogenic target-&-sabot" assembly, which also serves as an interface unit between the FST-layering module and high rep-rate injector.

For IFE, the pilot target supply system based on the FST technologies has a double-stage accelerator [2] including (a) electro-magnetic coil for target pre-acceleration up to 3-8 m/sec, and (b) gas gun for target acceleration up to ≥ 200 m/sec. Application of two-stage acceleration brings the following advantages: reducing overall dimensions of the accelerator relative to gas gun, and increasing reproducibility of the injection velocity relative to a gas gun.

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