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Operation of the lithium pellet injector

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Abstract

A lithium pellet injection requires an accurate handling with lithium and special technique of loading the pellets. Thus, the technology for this has been developed based on the following conditions: 1) Because of chemical activity of lithium it is necessary to operate in a glove-box with the noble gas atmosphere (He, Ar, etc.). 2) A special procedure of replacing the glove-box atmosphere allows to achieve high purity of the noble gas. 3) When making the pellets it is better to keep the clean lithium in the liquid hexane so as to maintain lithium purity. 4) The pressure of the accelerating gas for Li pellets should be not less than 30 atm.

Key Words: lithium pellet, pellet injection, glove-box, pellet loading

I. Introduction

Experiments with pellet injection in general and impurity pellet injection in particular are very important since this is a very useful plasma diagnostics. On Heliotron E the experiments with injection of Li pellets were made in order to: (1) study the response of the main plasma parameters during the injection and a possible change in global plasma confinement due to injection, (2) study the plasma–wall interaction related to the lithium coating on the wall, (3) study the ablation properties of Li pellet during ECH and NBI heated currentless plasma. The analogous experiments with Li pellet injection were performed on TFTR [1] with typical size of Li pellets of 2 mm. Now the process was improved with respect to maintaining Li pellet purity. In this paper the main attention will be given not only to the technical properties of the injection but also to some features of the preparation and loading of the lithium pellets. A special routine of producing the pellets and accurate handling with lithium has allowed to achieve a high purity of the injected lithium pellets.

II. Construction of the lithium pellet injector

1. Operation of the injector.

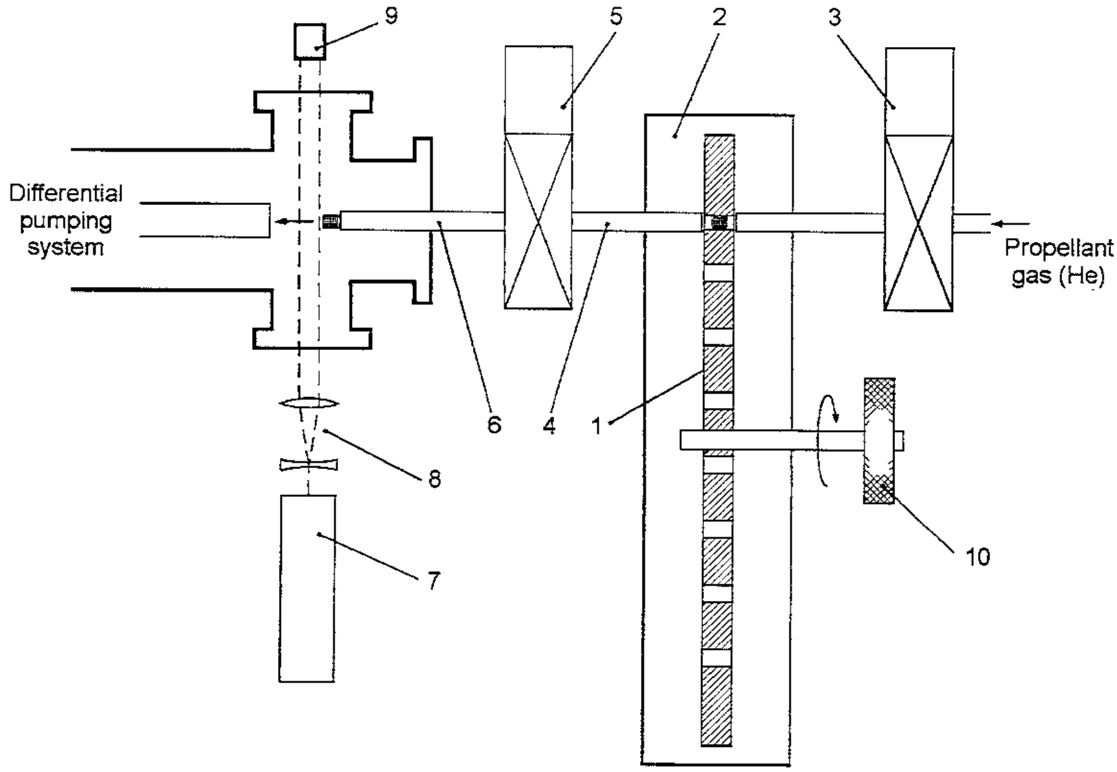

Fig. 1 Schematic view of the lithium pellet injector

The schematic view of the lithium pellet injector is shown in Fig. 1. Prior to the injection a set of 30 pellets is loaded into the disk *1* of the loading module *2*. This procedure of loading and details of the construction of the loading module will be discussed below. After the pulse of the propellant gas from the shooting valve *3* with duration of 2 - 4 ms, a pellet located on the shooting axis is accelerated and goes through the removable barrel *4*, manual valve *5*, and the main barrel *6*. The inner diameters of the removable barrel and the main barrel are 1.0 mm. The length of the acceleration path of the pellet is about 1.2 m. Then, the pellet crosses the beam of He-Ne laser *7* expanded by the beam expander *8*. The light from the beam expander goes to the light detector *9* that has two input slits with 5.5 mm distance and this allows to get a rough estimate of the pellet velocity. The accurate measurements were made by the time difference of the light detector signal and the plasma response to the injected pellet. After each shot the disk in the loading module is manually rotated by the handle *10* so to position the next pellet.

2. Dismounting of the loading module.

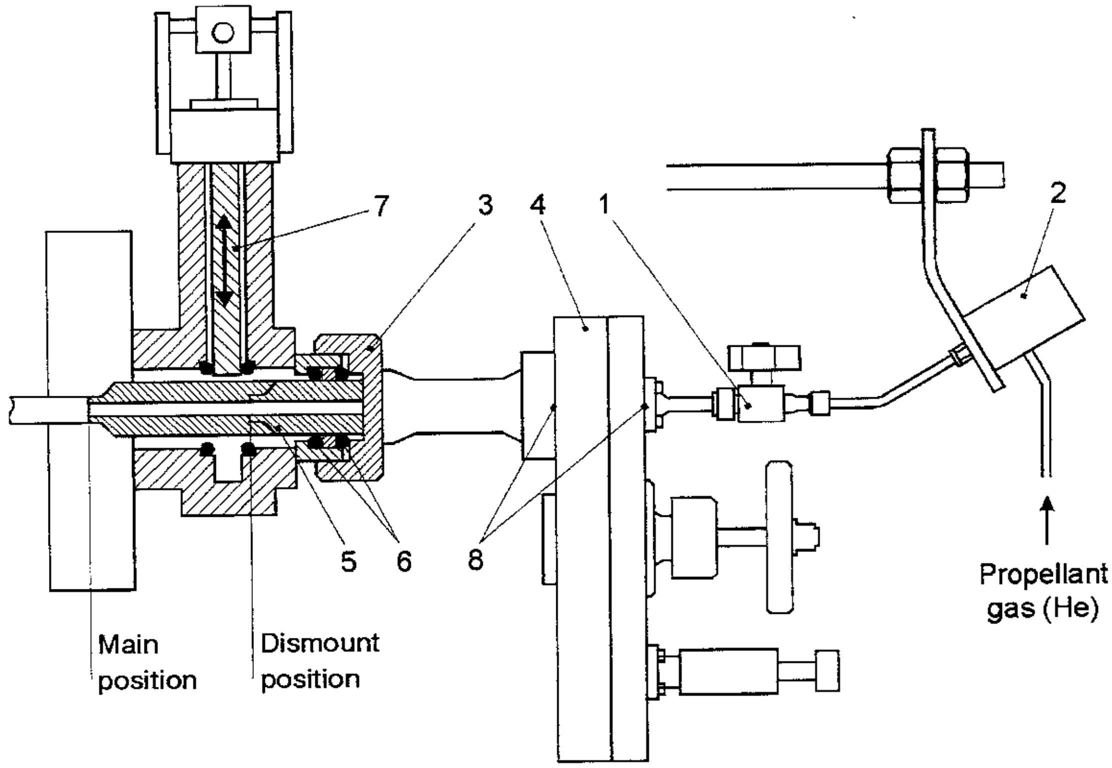

Fig. 2 Loading module and dismounting position of the injector

To load the pellets into the loading module the latter is dismounted from the injector (See Fig. 2). For that the valve *1* is closed and the accelerating valve *2* is removed. Then, the nut *3* is removed and the loading module *4* with the removable barrel *5* is shifted from the "main position" to the "dismount position". A pair of O-rings *6* keep vacuum. Then, the manual gate valve *7* is closed, thus maintaining the vacuum isolation of the differential pumping system. Finally the loading module *4* is separated at point *8* and now it can be used to load the pellets.

III. Preparation and loading of the Li pellets.

1. Physical and chemical properties of lithium.

Lithium is a very active chemical element. It reacts quickly with oxygen and water from the air and slower with nitrogen. This makes impossible any operation with lithium on the open air. In the nitrogen atmosphere due to the interaction with N_2 lithium slowly turns into lithium nitride Li_3N, warms up and reacts quicker. This does not allow to use nitrogen gas for preserving lithium purity. It seems that only the noble gas atmosphere can resolve this problem. The other way to conserve lithium may be in keeping it in a non-active liquid. Besides water lithium reacts with many organic substances except for hydrocarbons and some others. Therefore it is possible to use light liquid hydrocarbons such as hexane to avoid the contact of lithium with the outer atmosphere. At the same time these liquids are very volatile and quickly disappear during the vacuum pumping thus satisfying to the high vacuum conditions.

The physical properties of lithium also make operation with it very difficult.

Lithium is a soft but very sticky metal. Being pressed on a steel plate lithium fills in the harshness of the metal surface and easily sticks to it. After that the complete cleaning of the polluted surface is possible only by washing in a water. Among the most inert to the lithium stickiness materials are nickel and nickel oxide (NiO).

2. Operation in the glove-box.

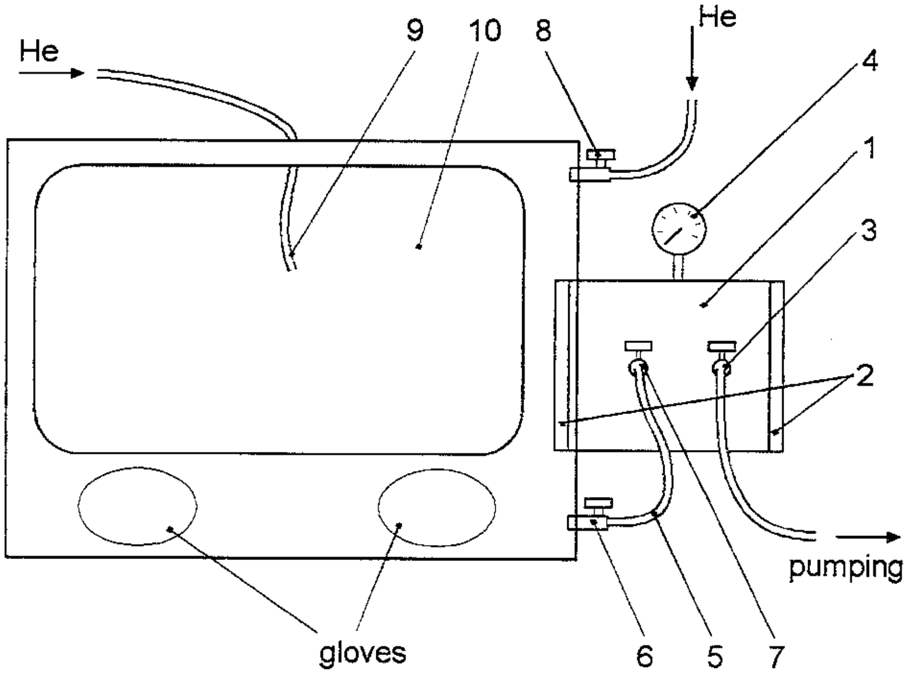

Fig. 3 Schematic view of glove-box.

According to the above remarks all the work with lithium is performed in the hermetic glove-box filled with helium gas. A schematic view of it is shown in Fig. 3. It has a 15 cm cubic sluice *1* from organic glass with two doors *2* that can be hermetically closed. The sluice can be pumped out to low vacuum through valve *3* and filled with helium. The vacuum level in the sluice is monitored by the vacuum gauge *4*. By means of such a sluice it is possible to insert and remove some necessary tools and the loading module itself without direct contact of the inside atmosphere of the glove-box with the outside air.

To simplify the connection of the pipes, the pumping of the glove-box and filling of the sluice are performed through the pipe *5*. The valve *6* is always open and the valve *7* is open only for equalizing the pressure in the sluice and the glove-box. The helium supply to the glove-box is performed mainly through the valve *8*. The need of pipe *9* will be explained later.

It is important to note that the glove-box itself can not be pumped out totally but only to 0.9 atm due to a high force of the air pressure, especially on the wide plastic glass window *10*. Therefore a complete evacuation of the air from the glove-box seems to be difficult. A usual way of ventilation by simultaneous filling with helium and pumping out is not appropriate because of a high waste of helium gas required to achieve a pure enough helium atmosphere. For this reason to fill the glove-box by helium or to refresh its atmosphere, the following procedure is used.

Before the operation, a polyethylene balloon of a size bigger than the glove-box is put into the glove-box in the compressed state. It should have only one hole about 1 cm size. Then a pipe *9* (See Fig. 3) that goes inside and supplies Helium is inserted into the balloon and fills it with helium. At the same time the remaining atmosphere of the glove-box is pumped out through the pipe *5*. The balloon should be big enough so to occupy almost all the space of the glove-box and remain flexible for the best fitting in the shape of the glove-box. Then the filling is stopped and the remaining free space between the balloon and the walls of the glove-box is ventilated with helium through the valve *8* for a few minutes. After that the helium supply and pumping are stopped and the pipe *9* is removed from the balloon. The latter is blown out and removed from the glove-box through the sluice. After such a process the purity of helium atmosphere keeps the surface of a cleaned lithium piece gleaming for about 15 minutes.

3. Loading of the Li pellets.

The process of producing of the lithium pellets is shown in Fig. 4. Usually lithium in the form of rods is stored in a container with mineral oil. A lithium rod can be cleaned from the oil by a tissue moistened in the hexane. Then, it should be also cleaned from some impurities that may be mainly on the surface.

Because of lithium softness it is very easy to produce a thin lithium layer by pressing the lithium piece between two thick metal plates joined by 4 bolts. We should note that to avoid the problem with lithium stickiness it is better to use metal plates covered by nickel or nickel oxide. It is also good to moisten the surfaces of the plates with some amount of hexane before pressing.

In the next stage, the prepared lithium layer is used for punching out the pellets by means of a special pipe. The process is similar to cookie making. The pipe is made from stainless steel with inner diameter 1 mm, outer diameter 3 mm, and length about 120 mm. The working edge of the pipe is sharpened at 45° angle.

As it was mentioned above, the time life of the lithium purity is limited, and to prolong this time it is a good way to keep the lithium layer in a hexane bath while punching out the pellets. Since lithium floats in the hexane, it is better not to make the bath too deep. On the other hand, hexane is very volatile and the required additions of the liquid become frequent. The optimal depth of the hexane bath is about 1 cm.

Finally, the pellet is loaded into the disk as shown in Fig. 5. A special wire with

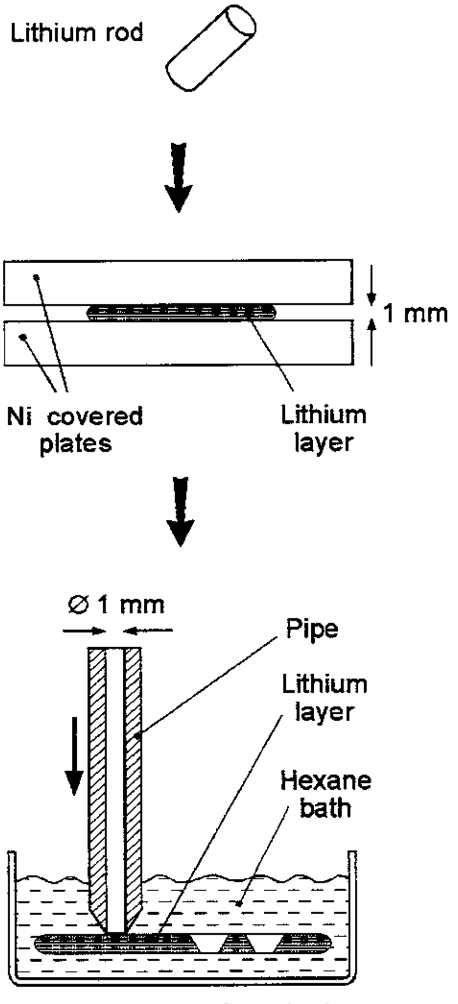

Fig. 4 Process of producing lithium pellet.

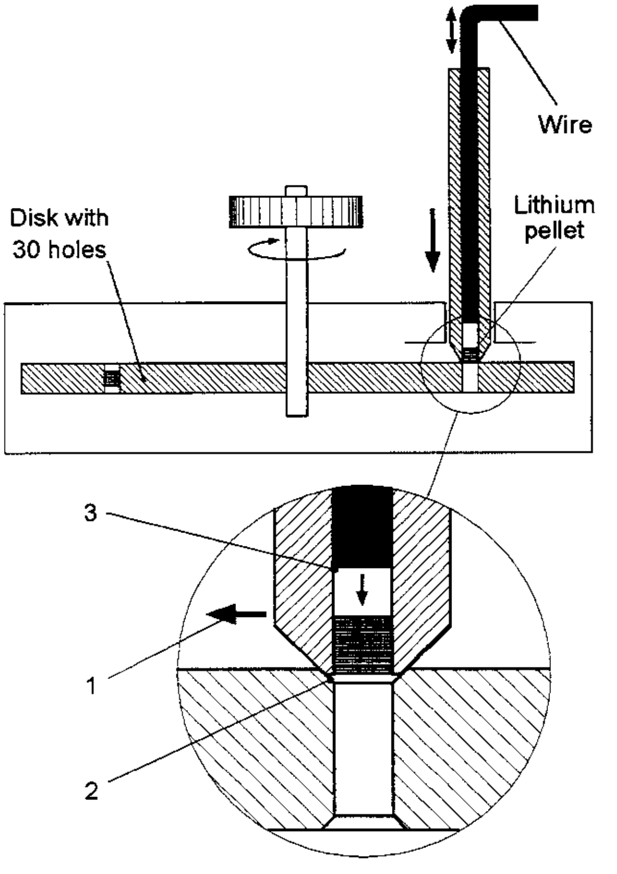

Fig. 5 Loading method of a pellet into the disk.

diameter 1 mm and bent end is inserted into the pipe. Then the pipe is set upon the next hole in the disk and the pellet is pushed out by means of the wire. The length of the straight part of the wire is 0.5 - 1 mm more than the length of the pipe. This provides a correct location of the pellet inside the disk with 3 mm thickness. To make the pellet remain in the disk after pushing out it is necessary to make a side movement by the pipe as shown by arrow *1* in Fig. 5.

There are several points that should be mentioned. First, the holes in the disk should have chamfers (at point *2* in Fig. 5), which help to centralize the pipe on the axis of hole. Second, the pushing edge of the wire should be as flat as possible (right angle at point *3*), so to completely remove the lithium from the pipe. Third, the edge of the pipe should not be very sharp, otherwise after each punching it will be getting blunt and will harden the movement of the wire. At the same time the output hole of the pipe should not be wider than 1 mm, so to prevent lithium from getting in between the pipe and the wire.

However even with observing the above conditions lithium penetrates inside of the pipe and glues the wire and the pipe after loading 2 - 4 pellets. Physical cleaning is unsuitable in this case. Instead, a washing in the water completely dissolves the lithium in few seconds. Since the water must not be present in the glove-box, the tools should be washed and dried only after the loading procedure is completed. Therefore it is necessary to have a set of pipes and wires (about 10 pairs), that will be enough to load all the pellets.

The exact positioning of the disk with pellets is provided by a special finger *1* with spring (see Fig. 6). The disk *2* with pellets has a radial set of corresponding hollows *3*.

The O-rings *4* are designed to prevent the propellant gas from getting into the loading module during the injection. Another function of these O-rings is to isolate the inner space *5* with pellets from the outer atmosphere. In fact, only 29 pellets are loaded, and the hole opposite the shooting axis is left empty. After the loading module is removed from the glove-box, the inner space of the disk with pellets is pumped out through the hole *6*. Thus, 29 pellets are isolated from the air and the loading module can be mounted back on the pellet injector. In this state the loaded pellets may remain during 20–30 hours before the injection. After that the injection will become difficult because lithium slowly absorbs impurities from the stainless steel of the disk and sticks to it.

IV. Testing of the lithium pellet injector

The main purpose of the laboratory tests of the lithium pellet injector was to achieve a high probability of the injection and to define the main reasons that made the injection unstable. Among these reasons it is necessary to mention (in the order of decreasing of their probability):

1) Pellet may fall out from the disk during the mounting of the loading module.
2) Pellet may remain in the disk after the shot of the propellant gas.
3) Pellet may stop at the joint of the

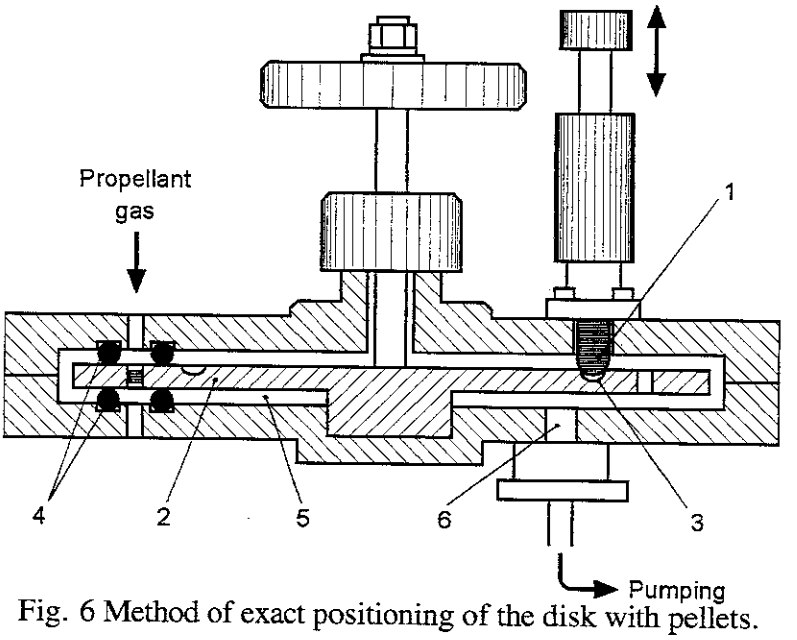

Fig. 6 Method of exact positioning of the disk with pellets.

removable barrel and the main barrel (see "main position" in Fig. 2).

4) Pellet may stop in the main barrel.

Let us discuss the above problems and their solutions.

The first tests were made with the disk that had holes with diameter 1.1 mm. In average 20% of pellets fell out from the disk before the injection due to accidental shakes of the loading module. In the new construction of the disk the diameter of the holes is 1.0 mm. This allows to reduce the percentage of the losses to 3 - 5 %.

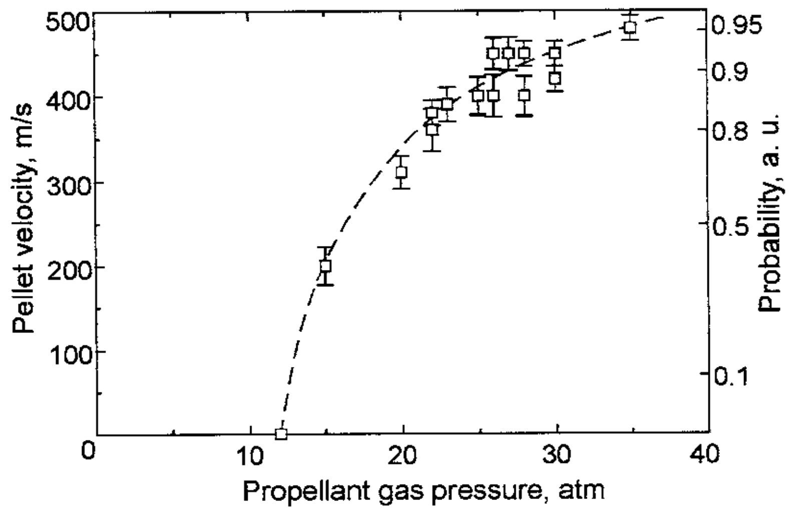

Fig. 7 Dependence of the pellet velocity on the propellant gas pressure.

On the other hand, with reduced diameter of the holes, the effect of stickiness of lithium pellets to the disk has increased with simultaneous decreasing of the accelerating force. Fig. 7 presents a dependence of the pellet velocity on the propellant gas pressure for the disk with 1.1 mm holes. The error bars represent average errors of measuring the pellet velocities. The right axis of the plot approximately shows the injection probability. A fairly stable injection can be performed if the propellant gas pressure is not less than 30 atm. For the new construction of the disk a pressure of 40 atm is required. From the Fig. 7 one can see that the range of pellet velocities is very narrow. With higher propellant gas pressure the velocity dependence becomes slower and achieving the velocities higher than 500 m/s is very difficult. On the other hand, decreasing of the pressure leads to unstable injection and at the pressure less than 15 atm no pellet can be shot from the disk.

Also, as it was mentioned above, the stability of injection can be increased by reducing the "waiting" time between the loading of pellets and the injection.

The problems with stopping of the pellets on the acceleration path can be also solved by increasing of the propellant gas pressure. Duration of the propellant gas pulse does not significantly affect the dependence in Fig. 7, because for the acceleration the very first moment of 1 - 2 ms is important. Increasing of the pulse duration leads to a higher undesirable pressure jump in the differential pumping system.

The lithium pellet injector have been installed on Heliotron E and has shown reliable operation. The spectrometry has observed no increment of light emission of such impurities as nitrogen or oxygen, which proves a high purity of the lithium pellets.

V. Summary

A lithium pellet injection requires an accurate handling with lithium and special technique of loading the pellets. Among others the following points should be underlined:

1) Because of chemical activity of lithium it is necessary to operate in a glove-box with the noble gas atmosphere (He, Ar, etc.).

2) A special procedure of replacing the glove-box atmosphere allows to achieve high purity of the noble gas.

3) When making the pellets it is better to keep the clean lithium in the liquid hexane so as to maintain lithium purity.

4) The pressure of the accelerating gas for Li pellets should be not less than 30 atm. Therefore it is difficult to obtain pellet velocities of less than 400 m/s.

Observance of these conditions has allowed to achieve a stable injection of the high purity lithium pellets.

Acknowledgments

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