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# A 400-Pellet Feed System for the ORNL Centrifuge Pellet Injector*

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## ABSTRACT

**An improved and extended pellet fabrication and feed mechanism is being developed for the Oak Ridge National Laboratory (ORNL) centrifuge pellet injector that is presently installed on Tore Supra. This upgrade will extend the number of pellets available for a single-plasma discharge from 100 to 400. In addition, a new pusher and delivery system is expected to improve the performance of the device. As in the original system, deuterium ice is deposited from the gas phase on a liquid-helium-cooled rotating disk, forming a rim of solid deuterium. The rim of ice is machined to a parabolic profile from which pellets are pushed. In the new device, a stack of four ice rims are formed simultaneously, thereby increasing the capacity from 100 to 400 pellets. An improved method of ice formation has also been developed that produces clear ice. The pellet pusher and delivery system utilizes a four-axis, brushless dc servo system to precisely cut and deliver the pellets from the ice rim to the entrance of the centrifuge wheel. Pellets can be formed with sizes ranging from 2.5- to 4-mm diam at a rate of up to 8 per second. The operation of the injector is fully automated by a computer control system. The design and test results of the device will be reported.**

## INTRODUCTION

An ORNL centrifuge pellet injection system with 100-pellet capability was installed on the Tore Supra Tokamak in 1989 [1, 2]. Development of a new pellet feed system for the injector is under way; it will increase pellet capability up to about 400 pellets.

As in the original pellet feed system, a rim of deuterium ice is formed on a liquid-helium-cooled rotating disk. The copper disk is sandwiched between two disks that are fabricated from G-10 fiberglass, so that the deuterium ice can only grow on the outer rim of the copper. In the new device, however, the copper disk is made thicker (25 mm) so that four rims of ice can be formed simultaneously as opposed to the single rim of the original device. Deuterium ice is formed on the rim by admitting precooled gas into the disk chamber, while maintaining the copper disk at a temperature so that the gas is cryopumped on the rim. Ice continues to grow until it fills the space between the disk and a close-fitting copper housing, which is maintained at a temperature a few degrees above the sublimation temperature. A new operating procedure is used that produces clear ice. Previously, the copper disk was maintained at liquid helium temperature during ice formation, resulting in a strong cryopumping action of the gas onto the rim. This produced a dense opaque form of deuterium ice, which was probably amorphous. In the new procedure the disk chamber is valved off, and the liquid helium flow and gas flow are regulated so the disk temperature is maintained near the equilibrium temperature of the gas. The pressure in the disk chamber is maintained at 3 torr. These conditions produce epitaxial growth of the deuterium ice resulting in a transparent ice rim. An ice thickness of 7 mm, which is limited by the chamber geometry, is produced in 12 min.

Once the ice is formed, the gas flow is terminated and the disk chamber evacuated. The ice is then machined into the desired four-rim geometry by a copper tool. The shavings evaporate and are pumped away by a roots blower. Once the rims are formed, the tool is retracted, and the ice temperature is reduced to liquid helium temperature. The active cooling of the disk can maintain the ice for long periods of time. Active conduction cooling will be required for tritium ice storage to remove the decay heat.

In the original feed system, a pusher is used to cut through a rim of deuterium ice and transport the pellet to the acceptance position of the acceleration arbor. The difficulty with this design is that the variability in ice rim strength causes the force required to cut the pellets to vary, which affects the temporal repeatability of the pusher's stroke.

The upgraded pellet feed system incorporates a separate tool to cut the pellets from an ice rim and push rod to transport the pellets out of the cutter at the appropriate time. This results in very consistent pellet sizes. By decoupling pellet formation and delivery, the pusher stroke can be made more reproducible. It also allows the feed system to cut pellets from multiple ice rims.

A schematic of the new feed system is shown in Fig. 1. The cutter and pusher are attached to separate slides that move along independent rails. The motion of the slides and, therefore, of the cutter and pusher are controlled by independent, brushless dc motors that are connected to the slides through Ferrofluidic feedthrough and a two-arm linkage system. The carriage system has been designed to avoid any interference between the cutter and pusher assemblies.

The wedge-shaped, 1-in.-long cutter is formed from a stainless steel sheet and then heat treated to harden it. It is attached to a 1-in.-diam tube that is connected to the slide that controls the cutter's motion.

The pusher is attached to its slide with a tube that is concentric to the cutter tube. The pusher foot is open along the rear to allow a brush to support the rear of the pellet.

The cutter and pusher are maintained above the sublimation temperature so that the pellets form a self-lubricating gas bearing. However due to the low density and mass of the pellet, this causes the pellet to "dance" on these surfaces. To dampen the motion and control the trajectory of the pellets, a brush made of camel hair is used. The bristles extend from the rear of the cutter rod at an ~30° angle to the front surface of the cutter. The brush begins at the top of the cutter and ends approximately one pellet width from the bottom of the cutter. As the pusher travels to the end of the cutter, it transports the

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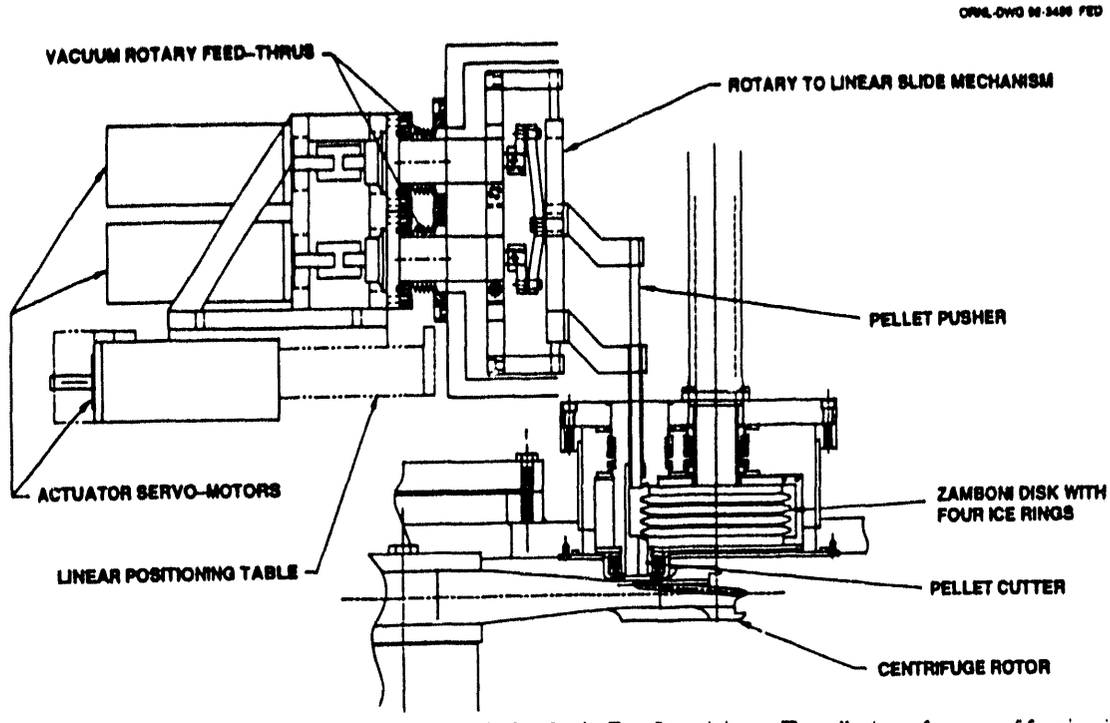


Fig. 1 Details of the upgraded pellet fabrication system and high-speed arbor for the Tore Supra injector. The pellet is cut from one of four ice rims and held in the cutter by the brush and pusher. The pusher transports the pellet out of the cutter and into the acceleration arbor. The exit velocity out of the cutter must be adequate to clear the leading edge of the acceptance groove, or it will not be cleanly accepted into the arbor.

pellet past the end of the brush. The pellet is free to separate from the pusher (which is slowing as it reaches the bottom of its stroke) without interference from the brush or the force of sublimating gas against the cutter surface.

## ICE RIM AND PELLET FORMATION

Before a pellet is formed, the top of the cutter is positioned below an ice rim, and the bottom of the pusher is positioned on the top of the ice rim. The cutter moves up through the ice rim to cut a pellet. The bottom of the pusher constrains the top surface of the pellet, and the cutter constrains the pellet from the front and sides. A brush is used to constrain the rear of the pellet.

To deliver the pellet to the arbor acceptance position, the pusher moves through the cutter and transports the pellet out the bottom of the cutter. The acceptance position is a few millimeters below the bottom edge of the cutter. The pusher and cutter are then returned to the prepellet positions, and the ice rim is rotated to place fresh ice between them. After the disk is rotated one revolution, the cutter begins working on a higher ice rim.

## SYSTEM PERFORMANCE

The motors are controlled by executing preprogrammed sequences that are stored in the motors' controller boards. A PC-based interface is used to write the sequences and adjust the feedback parameters of the motor's control loop. The sequences are initiated electronically using digital inputs to the controller boards. Several constraints on the performance of the motors must be met for the upgraded feed system to perform satisfactorily. The pellets must arrive at the acceptance position with an uncertainty of <100 μs. The pellet velocity out of the cutter must be >1 m/s. The pusher must start from a rest position, move through its minimum position, and return to the starting position without excessive overshoot that could cause interference with the next highest ice rim. The pusher and cutter must be able to form pellets and meet the critical timing requirements when working from each of the four ice rims, which are progressively further from the arbor acceptance position; finally, the entire process must be complete in <125 ms for the feed system to have 8-Hz capability.

### A. *Pellet Velocity*

The pellets will tend to separate from the pusher as the pusher begins to slow as it reaches it minimum position. If the brush extends beyond this point then the brush will constrain the pellet to the pusher, and separation will not occur until the end of the brush is reached. In this way, the dynamics of the pusher and the length that the brush extends inside the cutter determine the velocity of the pellet as it exits the cutter.

Pellet velocity places an upper limit on the maximum achievable pellet velocity after acceleration. To be accepted by the acceleration arbor, a distance equal to the pellet's width (4 mm) plus the leading edge of the acceptance groove (1 mm) must be cleared in one-half of an arbor revolution, or it will be hit by the arbor hub. The accelerated pellet velocity is proportional to the tip speed of the arbor. The pellet velocity out of the feed system places an upper limit on the arbor rotation period, which limits the arbor tip speed and therefore accelerated pellet velocity.

For this system, the distance to be cleared is ~5 mm, and the arbor must be rotated at (~100 Hz) to attain pellet velocities on the order of 800 m/s. Therefore, in one-half of an arbor revolution (5 ms) the pellet must travel 5 mm, and to do that it must have a velocity of at least 1 m/s.

### *B. Working with Multiple Ice Rims*

To avoid any time delay differences due to increased distance from the higher ice rims to the arbor acceptance position, the pellet formation sequence is performed in two phases. First, the pellet is cut from the ice rim, and then the cutter and punch are simultaneously lowered to a position below the first ice rim. At the proper time, the pellet is pushed out of the cutter. Testing has shown that if the pusher stroke begins with the pusher at too low a position, the required pellet velocity out of the cutter cannot be achieved, but if the motion begins too high the arrival of the pellet to the acceptance position will have too large of an uncertainty. Much of the development process has focused on synchronization of the pusher and cutter motions and tuning of the pusher stroke.

### *C. Pellet Timing*

The polling rate of the motor controller inputs is not adequate to meet the stringent timing requirements of the pellets arrival time to the arbor acceptance position. To make the timing reproducible, a sample and hold circuit was added to the pusher motor's control circuit. The electronic signal to begin the pusher stroke causes the switch to output the prestroke voltage for a period that is adequate to ensure that the command voltage to the motor has been issued by the motor controller. This is done to hold the pusher still until commanded to move. When the hold period has elapsed, the switch closes, and the command voltage to the motor reaches the motor at the precise time, every time. This produces a very consistent pusher motion, although occasional movement during the hold period is the main contribution to pusher stroke irreproducibility.

## TEST RESULTS

Figs. 2 through 4 are bottom views of the feed system during bench testing. Fig. 2 shows how the pellet is held in the proper orientation while in the cutter. The brush supports the pellet from the rear and keeps it against the cutter and pusher.

Figs. 3 and 4 show two consecutive pellets just after they exited the cutter. A mirror is used to provide an additional side view of the pellet.

## CONCLUSION

A new pellet feed system for the Tore Supra centrifuge pellet injector is being developed. The new system will be capable of producing up to 400 pellets for fueling long pulse plasma devices. The system uses separate tools to cut the pellets and deliver them to the acceleration arbor. The allows for improvement in the consistency of pellet size and delivery time, which should improve injector reliability. After bench testing of the system demonstrates that all of the required conditions for operation have been achieved, the feed system will be tested on a spin tank at ORNL. Upon the successful completion of the spin tank experiments, the feed system will be shipped to France for installation on the existing injector, hopefully in early 1994.

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Fig. 2 Photograph of a pellet exiting the cutter. The pusher transports the pellet from the edges as the brush constrains it from the center.

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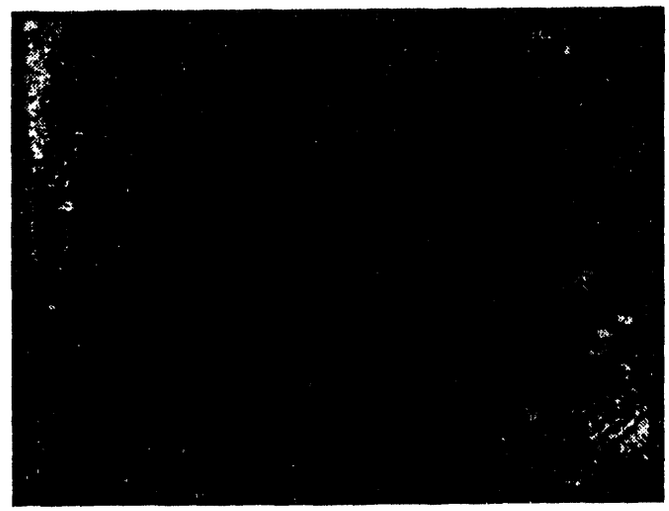

Fig. 3 Pellet that has exited cutter. A mirror is used to provide an additional side view.

ORNL-DWG 93M-3849 FED

Fig. 4 Next pellet after that shown in Fig. 3. The system was operated at ~1 Hz. Pellet size, arrival time, and orientation must be consistent for reliable injector operation.

## REFERENCES


[1] C. A. Foster, "Pellet injection and toroidal confinement," IAEA-TECDOC-534, International Atomic Energy Agency, 1989.

[2] C. A. Foster et al., "ORNL centrifuge pellet fueling system," *Fusion Technology*, Book of Abstracts, p. 318, Proceedings of 17th Symposium on Fusion Technology, Rome, Italy, September 14, 1992.


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