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ARGON FROST CONTINUOUS CRYOPUMP FOR FUSION APPLICATIONS

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ABSTRACT

A cryopumping system based on the snail continuous cryopump concept is being developed for fusion applications under a DOE SBIR grant. The primary pump is a liquid helium cooled compound pump designed to continuously pump and fractionate deuterium/tritium and helium. The D/T pumping stage is a 500 mm bore cryocondensation pump with a nominal pumping speed of 45,000 L/s. It will be continuously regenerated by a snail regeneration head every 12 minutes. Continuous regeneration will dramatically reduce the vulnerable tritium inventory in a fusion reactor. Operating at an inlet pressure of 1 millitorr, eight of these pumps could pump the projected D/T flow in the ITER CDA design while reducing the inventory of tritium in the pumping system from 630 to 43 grams. The helium fraction will be pumped in a compound argon frost stage. This stage will also operate continuously with a snail regeneration head. In addition the argon spray head will be enclosed inside the snail, thereby removing gaseous argon from the process chamber. Since the cryocondensation stage will intercept over 90% of the D/T/H stream, a purified stream from this stage could be directly reinjected into the plasma as gas or pellets, thereby bypassing the isotope separation system and further simplifying the fuel cycle. Experiments were undertaken in Phase I which demonstrated continuous cryosorption pumping of hydrogen on CO₂ and argon frosts. The pumping system and its relevance to fusion reactor pumping will be discussed.

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INTRODUCTION

A project is in progress to design, construct and test a prototypical continuous cryopump to function as the primary vacuum pumping system of a fusion reactor. The pump is based on the snail continuous regeneration concept originally developed at ORNL[1,2]. The snail cryopump is a conventional cryocondensation pump with an added feature (the snail) which continuously removes the cryofrost during normal operation of the pump (analogous to a snail in an aquarium). The cryocondensation surface is designed as a simple surface such as the inside of a cylinder or a flat plate so that the snail head can periodically cover the entire surface with a simple motion. The small regeneration head rides over the cryo-surface and is made so as to form a low conductance

Fig.1 Snail Head a) Mechanical Snail b) Thermal Snail

seal between the head and the pump surface. The cryofrost is removed from the cryosurface inside the snail head shown in Fig.1. The removal process is accomplished either by a mechanical scraper blade (mechanical snail) or by direct contact with a warm surface (thermal snail). In either case, once removed the frost is sublimated into a gas. The gas is however liberated inside the snail head and is prevented from reentering the pump by the low conductance seal between the snail head and the pump surface. The gas passes through the snail head exhaust tube and are pumped by a secondary pump. The compression ratio of this arrangement is the ratio of the primary pump speed to the snail head seal conductance. Since it is fairly straightforward to produce a seal conductance of under 10L/s, the compression ratio of a 10,000 L/s pump is greater than 1000.

MASTER

A variation of the snail pump is required to pump helium, since helium does not cryocondense at practical temperatures. To pump helium continuously a snail pump is being developed based on the argon frost cryosorption process. The snail argon frost pump is a liquid helium cooled argon frost pump with two added features; a snail regeneration head and a snail argon deposition head. As in the cryocondensation pump the snail regeneration head passes over the cryosurface removing the helium doped argon frost which is sublimed and removed through the snail exhaust by a secondary pump. A second head trails the removal head which is designed to lay down a fresh deposit of argon frost. Since the argon frost is deposited inside the deposition head there is no argon gas released in the pump chamber as in conventional argon pumps. This feature should greatly alleviate potential backstreaming. The continuous regeneration of the argon also overcomes the relatively low helium capacity of argon frosts.

RELEVANCE to FUSION

Fusion reactors require high-speed pumping of helium, deuterium and tritium while maintaining the inventory of tritium in the pumps at a low level. Cryopumping is potentially the most attractive method for this task, but conventional cryopump designs require that the pump be removed from service frequently and regenerated to prevent an excessive accumulation of tritium in the pump. This frequent regeneration requires the cycling of large vacuum valves and cryogenic components which introduces inefficiencies and places a burden on the reliability of the system.

A 1,000 Mwatt thermal fusion reactor will produce 2.46 moles of helium per hour (11.6 TorrL/s). To maintain the helium concentration in the core to 3% a quantity of 70 moles per hour (331 TorrL/s) of DT will be exhausted with the helium along with some impurities. A cryopumping system based on the snail concept can achieve the performance required for such a fusion reactor while maintaining the tritium inventory to 43 grams.

COMPOUND CRYOPUMP

The pump shown in Fig. 2 is presently under construction. It consists of a compound arrangement of a snail cryocondensation pump designed to pump deuterium tritium at a speed of 45,000 L/s followed by an argon frost cryosorption pump to pump helium. An interstage baffle will isolate the two stages allowing the cryocondensation stage to intercept 90% of the D/T stream. Separate snail heads will service the cryocondensation and the cryosorption stages. Since helium will not pump on the cryocondensation stage, the exhaust of the upper snail will be primarily D/T and contain 90% of the D/T stream. The exhaust from the lower snail will contain the remainder of the D/T, the helium and the argon frost. The argon deposition head will follow the lower snail and redeposit a fresh layer of argon frost on the

pump.

All three snail heads are driven from a simple rotary linear drive which moves the snail heads in a spiral motion up and down the inside surface of the cylindrical cryosurface. The total time for the snail heads to complete one cleaning cycle is 12 minutes, so that each pump will hold 6 minutes worth of tritium inventory at a given time. Special care is taken in the design so that all of the cryopumping surface is cleaned by the snail heads. This prevents tritium from accumulating in the pump. The snail drive mechanism is located outside the vacuum chamber and is coupled to the snail head by a permanent magnet coupling. There are three spring-loaded polymer interstage seals which seal the D/T stage exhaust tube from the A/He exhaust and the argon inlet. Since these stages are internally connected the seals do not need to be absolute but rather provide a low conductance path. The three exhaust stages are stationary, metal seal conflat flanges. Instrumentation and electrical feedthroughs for the snail heaters are provided by a hard seal instrumentation feedthrough with an internal slip ring assembly.

The pump geometry is in the form of a wide mouth dewar with the central pumping chamber isolated from the dewar guard vacuum by stainless bellows above and below the pumping chamber. This arrangement has two important effects. First it prevents the D/T process gas from being pumped on extraneous liquid helium surfaces. Second, the secondary vacuum chamber provides thermal insulation to the cryopump independent of the process vacuum. This allows the pump to operate cryostably at pressures in the milli Torr range. This is in contrast to conventional fusion beamline type cryopumps which utilize the process vacuum for thermal insulation and which undergo a cryogenic instability well below 1 milli Torr.

REACTOR PUMPING SYSTEM

The expected performance of this pump, including tritium inventories are listed in Table 1, for inlet pressures of 1 and 2 milli Torr. Operation at higher pressures, such as 5 or 10 milli Torr would be feasible and could further reduce the size or number of pumps required to pump a reactor. Note however that these pumps are already 25 to 50 times smaller than the ITER CDA pumping system which was based on inlet pressures of 0.2 milli Torr. The original snail cryopump [1], which was much smaller than these pumps, pumped deuterium continuously at a throughput of 30 TorrL/s at an inlet pressure of 15 milli Torr.

Fig.3 is a schematic process flow diagram of the snail pumping system which shows how the pumps could be used to simplify the fuel processing system. The primary pumps would be connected to the diverter with an array of pump ducts designed to match the speed of the pumps, i.e. eight 500 mm ducts to accommodate the 1 milli Torr operation or fewer or smaller at higher pressures. A series of gate valves would

Fig.2 Compound Cryopump

SNAIL CONTINUOUS CRYOPUMP SYSTEM

Fig.3 Snail Pumping System

SBIR PROJECT

Table 1
500mm ID pump unit @45,000L/s
ITER CDA baseline flow=331 TorrL/s

Inlet pressure	(milliTorr)	1.0	2.0
D/T throughput	(TorrL/s)	45	90
He throughput	(TorrL/s)	1.35	2.70
Argon req. at 50/1	(TL/s)	67	135
CO2 req. at 10/1	(TL/S)	13.5	27
Tritium flow in			
12 minutes	grams	5.7g	11.4g
Inventory per pump			
=1/2 flow	grams	2.85g	5.7g
number of pumps required		7.4	3.7
mass compared to the			
CDA system of 24 1m pumps		0.036	0.018
total flow			
inventory in all pumps		21g	21g
holdup inventory per pump		3g	3g
total holdup inventory			
in all pumps		22g	11g
total pump inventory		43g	32g

isolate the pumps. The D/T component of the primary stream would pump out on the upper cryocondensation stage and would be exhausted out the snail exhaust. The D/T stage would be backed by a special cryocondensation pump. This pump will have an entrance baffle/trap operating at 20 K which will remove the impurities from the stream. The D/T/H component would then be pumped on a cryocondensation stage at 7K. Any residual helium in this stream would collect in the volume above the pump. Periodically these pumps would be valved off, the helium evacuated by a small Normetex scroll pump and would be thermally cycled to 20K so as to melt the D/T/H and feed a cryogenic pellet extruder with a purified D/T stream for direct reinjection into the plasma. In this manner 90% of the tritium stream could be recycled directly back to the plasma, bypassing the isotope separation system(ISS).

The helium component of the plasma stream would pass over the cryocondensation pump and enter the lower cryosorption chamber where it would be pumped by the argon frost. The A/He snail will be pumped by a secondary small snail pump operating at 20K which will remove the argon from the stream for reinjection into the snail argon deposition head. The helium component with the 10%D/T stream will pass through this pump and be pumped by a mechanical pump. A Normetex scroll pump or turbomolecular pump could be used. This stream would then go to the ISS for processing. The 10% D/T/H stream processed by the ISS should be sufficient to remove and maintain the protium fraction to acceptable levels in the plasma.

Cryogenic applications F,Inc is presently funded by the DOE under the Small Business Innovation Research Program to design construct and test a prototype pumping system. This project will include the 500mm bore liquid helium cooled pump shown in Fig.2. A 200mm bore argon/helium separation pumped which will be refrigerated with a G/M closed cycle refrigerator has been constructed. The third pump designed to back the primary pump snail and produce a purified liquid deuterium stream suitable for feeding a pellet injector will also be built. This project is scheduled to be completed by 10/94.

CONCLUSIONS

The snail cryopumping system will have significant advantages for fusion reactor pumping. The continuous operation of the pump will dramatically reduce the tritium inventory in the pumping system. A complete system of pumps capable of pumping a 1000Mwatt reactor would contain only 43 grams of tritium. The continuous nature of the pumps would also eliminate the rapid recycling of the large gate valves and hundreds of secondary valves and components required to accommodate rapid recycling of conventional cryopumps. The capability of the primary pumps to operate at high inlet pressures will dramatically reduce the size of the primary pumping system and the size of the diverter to pump duct system. Since diverters are presently operating well into the milliTorr range it no longer makes sense to have the pumping system sized to operate at 0.2 milliTorr. Higher inlet pressures and the lack of pump redundancy required to regenerate conventional pumps will reduce the primary pumping system size by a factor of 25 to 50. Finally the fractionating capability of the primary compound cryopumps will result in 90% of the primary tritium stream to be separated and purified for direct recycling into the plasma via pellet injection. This will allow the plasma helium content to be maintained at 3% while sending a 30% stream to the ISS.

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