Vacuum Pumping System for TPX

K. D. St. Onge
Oak Ridge National Laboratory

RECEIVED
FEB 05 1996
OSTI

Abstract — The design of the vacuum pumping system for TPX is discussed, and progress in the research and development effort is summarized. The TPX vacuum system will use cryocondensation pumps for hydrogenic divertor pumping and turbomolecular pumps for torus evacuation, glow discharge cleaning, and deuterium-helium divertor pumping. A set of poloidally and toroidally symmetric vacuum ducts will connect the torus to the vacuum pumps; this symmetry will permit simultaneous equal pumping speed at the upper and lower divertors, and it will minimize toroidal variations in divertor pumping speed. At the divertor plena the total cryocondensation pumping speed for D_2 at 65 C and 1 mTorr will be $80 \text{ m}^3/\text{s}$ and the total turbomolecular pumping speed for D_2 or He at 65 C and 1 mTorr will be $18 \text{ m}^3/\text{s}$; the system will be compatible with upgrades to improve pumping speed, to operate continuously, or to operate with D-T fuel. The cryocondensation pumps will be custom units capable of completing a low temperature regeneration cycle in 1 hour.

I. INTRODUCTION

The Tokamak Physics Experiment (TPX) vacuum pumping system will be required to evacuate the torus and the cryostat and to provide pumping services for the divertors and various diagnostic instruments. The baseline concept [1] for the TPX vacuum pumping system has been extensively revised in order to provide more flexibility in pumping services at a lower initial cost.

Some of the new requirements for the TPX vacuum pumping system are: 1) the base pressure shall be 10^{-9} Torr for species with $Z > 2$ and 10^{-7} Torr for other species; the gas load is assumed to be 10^{-5} Torr-l/s, 2) the pumping speed at the interface between the torus and the vacuum ducts must be at least $65 \text{ m}^3/\text{s}$ (upgradeable to $85 \text{ m}^3/\text{s}$) for D_2 at 65 C and 1 mTorr, 3) the divertor D_2 throughput is to be 50 Torr-l/s (upgradeable to 100 Torr-l/s) at 65 C and at pressures of 1 to 10 mTorr for a duration of 1000 s; peaks up to 200 Torr-l/s (upgradeable to 250 Torr-l/s) may be required for shorter periods, 4) for simulated helium exhaust experiments the pumping speed at the interface between the torus and the vacuum ducts must be at least $18 \text{ m}^3/\text{s}$ (upgradeable to $36 \text{ m}^3/\text{s}$) for a 90/10 mixture of D_2 and He at 65 C and 1 mTorr, and 5) the system must support glow discharge cleaning with H_2 , D_2 , or He at 350 C and 10 to 20 mTorr for indefinite periods and with a throughput of 44 Torr-l/s for helium.

Manuscript received October 4, 1995. Research sponsored by the Office of Fusion Energy, U. S. Department of Energy, under contract DE-AC05-84OR21400 with Lockheed Martin Energy Systems, Inc.

II. VACUUM DUCT CONFIGURATION

Consideration of these new requirements, along with information gathered as the design of the vacuum pumping system progressed, revealed that certain advantages would be associated with an alternate vacuum pumping duct and cryostat configuration. The baseline concept would have used sixteen vertical ducts (eight at the top of the machine and eight at the bottom) to pump the divertors and the vacuum vessel. The vertical pumping ducts would have been located behind the upper and lower divertors in order to facilitate divertor pumping, so the torus would have been pumped through the divertors. Each of the sixteen vertical ducts would have been connected to one of sixteen radial ducts that would have been routed inside the structure of the cryostat lid. The radial ducts would have been connected to cryocondensation pumps outside of the cryostat.

The new design, shown in Figs. 1 and 2, will also use sixteen vertical ducts to pump the divertors and the vacuum vessel, but it will join each adjacent pair of vertical pumping ducts with a short toroidal duct. Each of the short toroidal ducts will be connected to a corresponding radial duct that will lie inside the cylindrical body of the cryostat and will penetrate the cylindrical wall of the cryostat. Thus there will be only eight radial ducts instead of sixteen. Outside of the cryostat, toroidal ducts will connect the radial ducts to cryocondensation pumps in a manner similar to that employed by the baseline concept. In the new design the vertical, toroidal, and radial ducts will be larger than the corresponding baseline components in order to provide the same nominal conductance with fewer radial ducts.

A comparison of the two designs revealed several advantages to the new duct configuration: 1) because there will be fewer radial ducts, the vacuum pumping system will need fewer cryocondensation pumps to provide poloidally and toroidally symmetric pumping at each of the sixteen vertical duct inlets, 2) the pumping duct cost will be lower because only eight radial duct and gimbal assemblies will be needed, 3) maintenance access to the tokamak will be improved because the cryostat lid can be removed without disturbing the vacuum pumping ducts, and 4) access to the TF coil lead connections will be better.

Proximity to the plasma will require the vertical pumping ducts and the short toroidal ducts that connect them to be made of titanium in order to limit duct activation. Preliminary neutronics analyses have shown that the rest of the vacuum pumping system can be made of stainless steel without suffering significant activation. Each radial duct will have bellows expansion joints inside the cryostat to

Figure 1. TPX Vacuum Pumping System Plan Drawing

Figure 2. TPX Vacuum Pumping System Elevation Drawing

Figure 3. TPX Vacuum Pumping System Simplified Schematic

accommodate differential movement of the vacuum vessel and the cryostat.

III. PUMPING SYSTEM DESCRIPTION

The TPX torus vacuum pumping system will use eight cryocondensation pumps and eight turbomolecular pumps for initial operations. The cryopumps will be used for hydrogenic divertor pumping, and the turbomolecular pumps will be used for torus evacuation, glow discharge cleaning, and deuterium-helium divertor pumping. Roots pumps and rotary piston pumps will be used for roughing the torus and for backing the high vacuum pumps. Fig. 3 is a simplified schematic diagram of the vacuum pumping system.

The cryocondensation pumps will be custom units that have been optimized for this application. During the TPX conceptual design phase, the decision was made to produce and test a prototype cryocondensation pump. The design of the prototype pump is nearly complete at this writing. Each pump will be built from a nominally cylindrical stainless steel vessel that is approximately 1.8 m in diameter and 1.8 m high. Each cryocondensation pump will have two 76 cm inlets, and the pumping speed at each inlet will be 67 m³/s for D₂ at 65 C and 1 mTorr. Inside each pump, cryocondensation will take place on an array of hollow aluminum extrusions cooled by boiling helium at 4.2 K. The cryocondensation technique has been chosen because this type of pump can produce very high pumping speeds at reasonable cost and because it can be regenerated faster than pumps that operate by cryosorption or cryotrapping. The

pumping array will be shielded by an "optically tight" array of hollow aluminum extrusions cooled by boiling nitrogen at 77 K. Each cryopump will have a small dedicated turbomolecular pump for use during initial evacuation and regeneration. The cryopumps will be capable of completing a low temperature (hydrogenic) regeneration in about 1 hour, so for high throughput operation the entire set of pumps can be regenerated between TPX shots, which are nominally of 1000 s duration on 75 minute intervals. For low throughput operation or for short shots, several shots could be pumped before a regeneration would be necessary.

The hydrogenic capacity of each cryocondensation pump will be limited by a site requirement that a sudden venting with air – coincident with maximum inventory – must not produce a mixture that is within a factor of two of the lower flammability limit (4%). Thus the critical variables for determination of the divertor cryopumping operating envelope will be the number of active pumps, the internal volume of the pumps, the time required to regenerate the pumps, the divertor throughput, the length of individual shots, and the interval between shots. If the initial set of eight cryopumps is operated in alternating batch mode, i.e., with four units pumping while four units are regenerating, the volumetric pumping speed at the divertor plena will be 65 m³/s for D₂ at 65 C and 1 mTorr. This is thought to be the most economical way to operate the cryopumps for moderate throughput operation, because it will allow time for a carefully controlled regeneration with low liquid helium consumption. If all eight cryopumps are active, the volumetric pumping speed at the divertor plena will be 80

m^3/s for D_2 at 65 C and 1 mTorr. This pumping mode will be able to accommodate a much higher divertor throughput, but if it is used on the standard shot schedule it will require a faster regeneration that will consume more liquid helium. The divertor pumping envelope is shown in Fig. 4.

Fig. 4 TPX Hydrogenic Divertor Pumping Envelope

Throttling gate valves located at each cryopump inlet will be used to control the volumetric pumping speed and to isolate the cryopumps during regeneration. These valves will be similar to conventional high vacuum isolation gate valves, but the gate can be stopped at any point along its travel. This throttling effect will permit adjustment of the cryopumping P-Q curve to satisfy the physics requirements for each shot. For example, it could permit the cryopump throughput – and hence the divertor throughput – to be held constant while the pressure in the divertor plenum is varied over the range from approximately 1 mTorr to 10 mTorr or higher.

Each of the torus turbomolecular pumps has a nominal volumetric pumping speed of $3.5 \text{ m}^3/\text{s}$ for N_2 in molecular flow at 300 K. Eight of these pumps (one at the end of each radial duct) will produce a pumping speed at the divertor plenum of $18 \text{ m}^3/\text{s}$ for D_2 or He at 65 C and 1 mTorr. This pumping speed will be high enough to support simulated helium exhaust experiments with total throughputs (D_2 plus He) on the order of 10 to 20 Torr-l/s. Since the torus vacuum system is pump-limited with respect to turbomolecular pumping, the pumping speed can be dramatically increased by adding more pumps.

The torus roughing and backing system will operate from atmospheric pressure down to a few milliTorr. Depending on the operating conditions, the exhaust will be valved to either the gas cleanup system or the vent stack. The roughing and backing pumps will be mounted on three skids; each skid will hold a roots pump and a rotary piston pump. The torus roughing skid will include a $1.6 \text{ m}^3/\text{s}$ roots pump and a $0.3 \text{ m}^3/\text{s}$ rotary piston pump, and each of two torus backing skids will include a $0.8 \text{ m}^3/\text{s}$ roots pump and a $0.15 \text{ m}^3/\text{s}$ rotary piston pump.

The diagnostic pumping system will consist of manifolds and valves to permit connecting each diagnostic system high vacuum pump to the torus roughing and backing system. The system will be built around a 30 cm ring manifold that will be approximately 16 m in diameter; this manifold will be located just below the structural floor of the tokamak hall.

Each diagnostic system will install its own foreline and will provide and control its own high vacuum pump; the vacuum pumping system will provide and control the isolation valve at the ring manifold.

The cryostat pumping system will have two sets of turbopumps and backing pumps to pump down the cryostat and to evacuate any helium that leaks from the superconducting coils. Each pump set will include a $0.14 \text{ m}^3/\text{s}$ rotary vane pump, a $0.9 \text{ m}^3/\text{s}$ roots pump, and a $2.2 \text{ m}^3/\text{s}$ turbomolecular pump.

IV. UPGRADE COMPATIBILITY

The TPX vacuum pumping system will be capable of accommodating several proposed performance upgrades. The upgrades that would most affect the pumping system are: 1) steady state operation, 2) D-T operation, and 3) the addition of a pellet injector.

Fig. 4 shows that steady state operation with a divertor throughput of 100 Torr-l/s cannot be accomplished with the initial set of eight cryopumps, but the divertor pumping operating envelope could be expanded by adding more pumps. The primary constraint in such a case would be the pump envelope restrictions – the area around a tokamak is usually crowded with heating, fueling, and diagnostic equipment. Another option would be to replace the initial set of cryopumps with continuously operating cryopumps.

Because of the problems of handling contaminated vacuum pump oils, D-T operation would require replacement of the conventional roughing and backing pumps with units designed to pump hazardous and radioactive gases.

The addition of a centrifugal pellet injector would require the installation of extra equipment to pump the pellet erosion gas load from the injection line, but the divertor throughput would not increase because the injected divertor gas load would be decreased in proportion to the mass of the injected fuel pellets.

V. SUMMARY

The TPX vacuum system will use eight special $135 \text{ m}^3/\text{s}$ cryocondensation pumps for hydrogenic divertor pumping and eight $3.5 \text{ m}^3/\text{s}$ turbomolecular pumps for torus evacuation, glow discharge cleaning, and deuterium-helium divertor pumping. At the divertor plenum the total cryocondensation pumping speed for D_2 at 65 C and 1 mTorr will be $80 \text{ m}^3/\text{s}$ and the total turbomolecular pumping speed for D_2 or He at 65 C and 1 mTorr will be $18 \text{ m}^3/\text{s}$. Throttling gate valves at the cryopump inlets will be used to modify the cryopumping P-Q curve to meet the physics requirements for each shot. Ancillary equipment will provide vacuum services to other tokamak systems.

REFERENCES

- [1] K. D. St. Onge et al., "Conceptual Design of the Vacuum Pumping System for the Tokamak Physics Experiment," Proc. IEEE 15th Symp. on Fusion Engineering, Hyannis, 1993.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.