A TIMESHARED FORELINE AND ROUGHING VACUUM SYSTEM

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A system to perform turbomolecular drag foreline pumping and scattering chamber roughing was installed in the Surface Modification and Characterization Research Center at Oak Ridge National Laboratory. The system consists of an oil-free mechanical scroll pump that can be connected to either a roughing manifold serving four scattering chambers or to a foreline ballast tank and manifold serving five turbomolecular drag pumps. A controller mediates the demands of the two manifolds, giving priority to the foreline. Due to the low leakage from the accelerator beamlines, the duty cycle in the foreline pumping mode consists of a few minutes of operating time every few days, greatly reducing wear on the scroll pump. Significant savings are realized due to reduced consumption of liquid nitrogen for sorption pumping, elimination of oil changes and repairs to individual mechanical foreline pumps, and lower electrical power consumption.

1 Introduction

The Surface Modification and Characterization (SMAC) Research Center at Oak Ridge National Laboratory consists of 4 medium-energy ion accelerators with 8 beamlines and 7 sample chambers. High vacuum pumping prior to this project was performed by 17 turbomolecular pumps, mostly Pfeiffer 330 models, each with an oil-filled mechanical foreline pump. The mechanical pumps required 2-liter oil changes every 6 months, generating hazardous waste at a significant rate, with very high disposal costs. In addition, the turbomolecular pumps were aging and becoming a maintenance problem. It was concluded that a new approach to high vacuum pumping in the facility was needed, one with a lower waste disposal costs.
The resulting system offers not only a reduction in the amount of waste for disposal, but has resulted in significant savings in maintenance, liquid nitrogen, and accelerator downtime.

2 Design

A system using oil-free pumping to as large an extent as possible was desired. The advent of turbomolecular drag pumps, with their higher foreline tolerance (500 Pa), allowed the consideration of oil-free foreline pumps that were not possible with the non-drag style of turbomolecular pump. Diaphragm pumps were considered, but their lowest attainable pressure was barely acceptable without using multistage pumping. In addition, annual replacement of the diaphragm was required, which introduced significant cost, and the low pumping speed precluded their use as roughing pumps.

As an alternative, the use of a new style of pump was suggested, the scroll pump. In the scroll design, two intertwined spirals rotate with respect to each other, compressing the captured gas in a continuous motion. The use of Teflon seals eliminates the use of oil. Furthermore, the high pumping speeds (300–600 l/s) allow their use for roughing of the sample chambers in addition to foreline pumping. However, the high cost, upwards of $6k, made it too expensive to use a separate pump for each foreline.

It was recognized that the higher foreline pressure tolerance of the turbomolecular drag pumps allows the use of smaller diameter foreline tubing for longer distances. While the conductance of the smaller tubing is lower than the traditional DN 25 sized tubing, the higher pressures provide a comparable throughput. For comparison, the throughput of a 1-cm inside diameter tube at 133 Pa is comparable to that of a DN 25 tube of the same length at 7 Pa. Flexible PVC tubing of approximately 1-cm diameter was used to connect the turbomolecular drag forelines to a common manifold with a single scroll pump. To reduce pressure surges and to help isolate the pump forelines from each other, a ballast of approximately 360 liters volume was constructed of 20-cm outside diameter PVC pipe.

The scroll pump shares with the diaphragm pump the need for a frequent maintenance schedule. A minor maintenance procedure must be performed after every 6,000 hours of operation, with a major maintenance procedure after every 12,000 hours. The large ballast volume, combined with the low leakage rate of the beamlines and sample chambers and the high foreline pressure tolerance, permitted only occasional pumping of the ballast volume, greatly reducing the operating time.
of the scroll pump, and extending the time between maintenance procedures. Furthermore, the low duty cycle of foreline pumping allows the scroll pump to be used at other times for rough pumping of the sample chambers. Figure 1 shows the accumulated operating time of the scroll pump, which has been averaging about 4 hours per month.

![Operating Hours of the Scroll Pump](image)

Figure 1. Operating hours of the scroll pump versus months of service.

A system that uses the same pump for both foreline and rough pumping requires the use of a controller capable of mediating the demands of the two types of pumping. Furthermore, the sensitivity of the turbomolecular drag pumps to excessive foreline pressure requires that the foreline ballast receive priority over roughing. A controller with convection-type thermocouple gauges in the foreline and roughing manifolds was installed. Figure 2 show a schematic of the entire system.

The roughing lines to the sample chambers and the foreline ballast tank are constructed of PVC pipe. One concern prior to construction was whether the PVC
Figure 2. Schematic diagram of the foreline and rough pumping system.
was suitable for such vacuum service. The only problem encountered so far has been a minor difficulty in securing a seal between the PVC tubing and the rest of the system, which is constructed of stainless steel. The junctions use a threaded joint, which leaked when first installed. However, application of Teflon tape and a liquid vacuum sealant has eliminated the problem.

A more serious concern was the possibility of outgassing of chlorine from the PVC pipe. One of the chambers serviced by this system is an ultra-high vacuum chamber, and it was undesirable for it to be exposed to chlorine, which could possible occur as backstreaming through the turbomolecular drag pump. A quadrupole mass spectrometer was installed on the chamber, and no evidence of chlorine was detected at a base pressure of $10^{-8}$ Pa.

3 Performance

The timeshared system provides foreline pumping for 5 turbomolecular drag pumps and rough pumping for 3 sample chambers and a Van de Graaff accelerator. The scroll pump accumulates approximately 4 hours of operating time per month, a duty cycle of 0.6%. At this rate, it is not anticipated that the scroll pump will require either the major or minor overhaul during the remaining operating lifetime of the SMAC facility. However, the amount of time that the scroll pump operates during each duty cycles is only a few minutes, during which it operates at a temperature below the steady-state operating temperature. It is not known whether this has a significant effect on the lifetime of the pump or the interval between maintenance. However, the pump has already been in operation for 9 months, which is longer than the minor maintenance interval, and no degradation in performance has been observed.

The controller setpoints for the foreline manifold have been set to 30 and 60 Pa, respectively. This is an order of magnitude below the acceptable operating pressure of the turbomolecular drag pumps, but it provides an extra margin in case of transients, and it has not caused problems with the operation of the system. The setpoints for the roughing manifold have been set to 30 and 200 Pa. The lower limit assures that the scroll pump continues to operate until the chamber reaches the pressure at which the transition to turbomolecular pumping occurs (50 Pa).

The transition from rough to turbomolecular pumping causes a pressure surge in the foreline, as the residual gas in the chamber is rapidly compressed by the turbomolecular pump. The surge is compounded by the smaller diameter of the foreline, compared to a system with a dedicated foreline pump. The pressure surge,
if sufficiently large, will cause the turbomolecular drag pump to shut down. In practice, however, this has not been a problem. The volume of the sample chambers and beamlines, on the order of 100 liters, causes a pressure surge well within the acceptable foreline operating pressure, and the surge lasts only about 10 seconds.

In comparison with liquid nitrogen cooled sorption pumps, this pumping system offers several significant advantages for the sample chamber roughing, such as the elimination of the use of liquid nitrogen. In addition, the new system is always available (within a few minutes, if the foreline ballast is being pumped) and does not saturate as the sorption pumps do. The pumpdown is slightly slower, but still takes less than a minute of time.

4 Cost Savings

The success of the timeshared pumping system has prompted the extension of the concept to the West Lab of the SMAC facility. A similar system has been designed, with equipment and installation costs of $100k (mostly for new turbomolecular drag pumps). The payback time has been estimated to be slightly greater than 3 years. Table 1 summarizes the anticipated annual cost savings of the new system.

<table>
<thead>
<tr>
<th>Area of Improvement</th>
<th>Cost Savings ($ k/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elimination of liquid nitrogen for sorption pumps</td>
<td>13</td>
</tr>
<tr>
<td>Elimination of oil disposal</td>
<td>7</td>
</tr>
<tr>
<td>Reduced accelerator downtime</td>
<td>6</td>
</tr>
<tr>
<td>Elimination of mechanical pump oil changes</td>
<td>4</td>
</tr>
<tr>
<td>Reduced electrical power</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 1: Estimated annual cost savings of the proposed timeshared pumping system for the SMAC West Lab.

In summary, the new vacuum system has been a great success, providing improved vacuum performance at lower cost.
5 Acknowledgements

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