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Publication Date
1971-02-01
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February 1971

AEC Contract No. W-7405-eng-48

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Typically, 16 to 20 of the 24 pumps are operating with the rest down for maintenance and repair, including regular warmup and defrosting of the freon baffles. The vacuum space is instrumented with ion gages mounted one each in the straight sections and one in the center of a curved section. The typical base pressure readings from the gages under operating conditions range from ~0.7 to 2 x 10^-6 torr in the straight sections and ~2.7 x 10^-6 torr in the center of the curved section. At these pressures the diffusion pumps are basing out to approximately one-third of their rated full capacity. Estimating the throughput of the baffles at 30%, we compute a present system pumping speed of approximately 30,000 1/sec. Moreover, the speed rating curves for these pumps show that these pumps will base out absolutely at 4.5 x 10^-7 torr.

**Design Objectives**

It is hoped to attain an operating pressure of 1 to 2 x 10^-7 torr in the Bevatron. Since a differential pressure of 1 x 10^-5 torr in the center of the curved section above the tangent tank pressure exists, it is obvious that additional pumping must be done in the curved section. Space limitations in this area immediately rule out additional diffusion-pump and ion-pump techniques. Titanium sublimation techniques seemed unattractive because of the maintenance problems inherent in such systems and also because of the difficulty in controlling the migration of evaporated titanium in an area where laminated magnet pole tips are exposed to the vacuum. This left cryogenic pumping.

**Measurements**

Measurements of the quantity, quality, and distribution of the vacuum load were desired.

A rate-of-pressure rise technique was used to estimate the quantity of gas load. This measured quantity was later verified by taking equilibrium pressure distributions with pumps in each section turned off, which created a differentially pumped condition. Also, the transient pressure rise for each section, differentially pumped, was measured and analyzed. These measurements were compared with the load computed by using the base pressure and estimated pumping speed of the diffusion pumps. In all cases the measured value of the vacuum load agreed within ±30% of a mean value. These measurements ranged from 45 to 100 x 10^-3 torr-1/sec. The results of what we judged to be the most reliable measurement technique (simple rate of rise) typically ranged around the 60 x 10^-3 torr-1/sec value.

The quality of the vacuum load is crucial to the design of a cryogenic pumping system. In particular, we are interested in the relative proportions of residual gases in the vacuum load which are noncondensable or condensable on a 770K surface. To a lesser extent we are interested in the relative amounts of particular...
species of gases since, obviously, a large concentration of gases not condensable at 20°K obviates the use of a practical cryogenic system.

Also, particular species of condensables affect the thermal radiation properties of the surface coated with them.

An LN2 shielded ion gage installed in each tangent tank showed that a 2-to-1 pressure ratio existed without and with LN2 shielding. Also, measurements made with two different types of residual gas analyzers showed relatively large peaks at mass numbers 18 and 28 of approximately the same corrected amplitudes, which would correspond to large populations of air and water in the residual vacuum. Some small peaks in the very high mass range, where the instruments are very insensitive, and a peak for mass number 1 were also detected. These peaks indicate the presence of heavy hydrocarbons and the hydrogen ionized from these hydrocarbons. The relative proportion of this species of gas in the residual vacuum is rather difficult to quantify with any degree of confidence. In general, we conclude that the residual vacuum is approximately half water and half air.

The relative quantities of the gases in the four straight sections were easy to measure from differential pressure measurements and from relative base pressures in each of the tanks. However, the proportion of the gas in the curved section was a rather more difficult number to measure. An experiment was performed in which a nude ion gauge was mounted on a travel target assembly and marched through two quadrants. The monitored pressures were plotted against position, and the plot displayed the characteristic parabolic shape of a pipe with uniform gas generation pumped only at its ends. It should be noted that the pressure distribution presented in the figure was taken when the system pressures were unusually high. The data points were least-square fitted to a parabola which yielded the coefficients which could be related to the gas load. The gas loads computed in this manner seemed excessively large. Consideration of all the possible errors in the measured data and the assumptions made in the computations leads us to believe that the results of this experiment should be taken with a grain of salt. However, this experiment verifies the fact that a very serious pressure gradient does indeed exist in the quadrant and that pumping in the quadrant is imperative.

The required air pumping speed is

\[ S_{\text{req}} = \frac{Q_{\text{total}}}{P_{\text{required}}} = \frac{30 \times 10^{-3}}{1 \times 10^{-7}} = 300,000 \text{ l/sec}, \]

or, dividing by the perimeter,

\[ S_{\text{req}} = \frac{300,000}{360 \times 12} = 70 \text{ l/sec-in}. \]

Somewhat more than this speed is required since only about 80% of the perimeter of the section will pump because of the space requirements for mechanical support. Thus a design target of \(~90\) to \(100 \text{ l/sec-in.}\) is set.
It became apparent early in the evaluation of proposed geometries that the expected thickness of the condensables on the 77 K shield would affect the emissivity of this surface. Measured emissivities for surfaces with water condensate are available in the literature. These data were applied to the anticipated thickness of condensates on the Bevatron proposals and average emissivities of 0.2 to 0.4 were computed for 2 to 3 days of operation at the fairly high load levels anticipated.

This curve assumes cryodeposit density of 93 g/cm²
1 hour filler H₂O: 10⁴ g

At these emissivities a system capable of air pumping speeds of 300,000 l/sec would consume 6 to 10 kW of LN₂ refrigeration power. Any plans to regenerate a low value for the emissivity of the LN₂ surface by heating it periodically must take into account the fact that hydrocarbons which make up a finite proportion of the condensable gas load cannot be expected to clean out under reasonable temperature cycles. Thus, it appears the high emissivity values must be lived with and designed for in our relatively "dirty" vacuum environment.

Monte Carlo and Figure of Merit

Because of the expected high operating costs due to LN₂ refrigeration for a given air pumping speed, it is clear that a pump geometry of minimum convex perimeter shield for a given air pumping speed is required. A two-dimensional Monte Carlo type program was devised so that accurate predictions could be quickly made for the capture probabilities and thus the pumping speeds of various geometries. This code would use Monte Carlo techniques to trace orbits on a statistically large enough sample of particles being emitted, reflected, lost, or absorbed in a two-dimensional array of straight lines and circles. The program would then take a census of the particles absorbed and lost, to determine the probability that a Maxwellian particle will be pumped (immediately or after several reflections) before it is lost. This code considers particles emitted from a source or reflected from a surface following Lambert's cosine rule (the probability of reflection or emission from a surface in a given direction is proportional to the cosine that that direction makes with the normal to that surface).

The code should closely approximate any free molecular flow system which can be considered as essentially two-dimensional in which the dimensions of the system are much smaller than the mean free path of any particle. The proposed Bevatron cryogenic pumping system, which is very long compared with its lateral dimensions and operates in a very high vacuum, can be realistically modeled with this code. A figure of merit is then computed for various pump cross sections:

\[
m = \frac{\text{Air pumping speed}}{\text{Convex perimeter}}
\]

A sample result of the computation is included in Fig. 6. The maximum figure of merit for this particular geometry is:

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m = \frac{981/\text{sec}}{20.29\ \text{in.}} = 4.82
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Figure 2 shows the geometry currently being tested for use in the Bevatron. The computed parameters for the full-size model are reviewed on the following page.
Air pumping speed 335,000 l/sec
Condensables pumping speed 6,500,000 l/sec
Predicted emissivity after one week 0.44
Predicted LN2 refrigeration load after one week 14.8 kW
Predicted 200K refrigeration 25 W

A short test section is being tested and results of these tests should be available shortly.

Conclusion

It is felt that sufficient homework in the form of fairly reliable measurements and predictions based on essentially believable computations and data have been made and presented. The design at present is fairly well fixed. However, hardware as such has not been committed. Since a fairly wide latitude in the final geometry is allowable without severely compromising the design objectives, and since this latitude may encompass design alternatives which could greatly simplify some of the fabrication and installation problems which are, at present, apparent in the present design, we might conclude that the design could suffer further changes before final fabrication and installation.

Acknowledgments

This work owes a great deal to the design work of John Lax and the programming assistance of Carl Quong and Esther Schroeder. In addition, we would like to acknowledge the leadership in this project provided by Ken Lou and Dr. Hermann Grunder.

References

Work performed under the auspices of the U. S. Atomic Energy Commission.


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