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Vacuum Properties of Sintered SmCo_5 Magnets

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VACUUM PROPERTIES OF SINTERED SmCo_5 MAGNETS

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ABSTRACT

There are many desirable applications of powerful, rare-earth permanent magnets made of sintered SmCo_5 material within vacuum systems. One application is the use of large numbers of SmCo_5 magnets to provide the undulating magnetic field in a free-electron-laser wiggler structure. Tests were conducted at Los Alamos to determine the suitability of SmCo_5 magnets in a vacuum environment of $\sim 10^{-6}$ torr. The vacuum performances of the wiggler system, with and without the SmCo_5 magnets (having $\sim 11\%$ of the total surface area) installed, were essentially identical. These tests indicate that SmCo_5 magnets have good vacuum properties and are suitable for use in many vacuum systems.

I. INTRODUCTION

Developments in permanent-magnet technology in recent years have allowed its use for a variety of applications that were formerly the exclusive domain of electromagnets.¹ In one application of permanent-magnet technology demonstrated at Los Alamos National Laboratory, a small magnet was mounted downstream from the ground electrode in the PIGMI² (Pion Generator for Medical Irradiations) proton injectors. The magnet's purpose is to trap backstreaming electrons; it was successfully used on a 30-kV proton injector (shown in Fig. 1) and on a 250-kV proton injector. Because low fields were required, and a relatively large space was available for the magnet, a low-strength ferrite magnet was used. In some beam-diagnostic equipment, electron backstreaming can cause the proton-beam data to be masked by the unwanted electrons. The

Fig. 1.
PIGMI 30-kV proton injector.

requirements for higher fields, coupled with very little available space for installing the magnets, necessitated the use of SmCo_5 magnets. This application of SmCo_5 magnets was very successful, but because of the relatively small magnet volume required, the vacuum properties were of little concern.

Another application of permanent magnets in vacuum is for quadrupole focusing magnets in linear accelerator structures.²⁻⁴ By using sintered SmCo_5 magnets in the geometry shown in Fig. 2, a 20-kG/cm magnetic field gradient over the 1-cm bore has been achieved. In a drift-tube linac, these quadrupole-magnet assemblies would be mounted in the drift tubes, as shown in Fig. 3. The permanent-magnet quadrupole would outgas into the drift-tube bore;

however, the magnet volume would be relatively small. The vacuum outside the drift tube must be $\sim 1 \times 10^{-7}$ torr to satisfy the rf field requirements, but the vacuum in the drift-tube bore can be as poor as 5×10^{-5} torr. Calculations showed that, even if the SmCo_5 magnet had an outgassing rate comparable to unbaked alumina, the vacuum requirement could be satisfied.

Fig. 2.
Permanent-magnet-quadrupole geometry.

Fig. 3.
Permanent-magnet-quadrupole assembly in a linac drift tube.

In a third application of permanent-magnet technology, Los Alamos has initiated a program to build a free-electron laser (FEL) that can generate intense bursts of light with unusually high efficiency.⁵ A schematic of the final phase in the development of the FEL is shown in Fig. 4. A smaller experiment is now being assembled, and a novel part of the experimental apparatus is the wiggler (or undulator), a magnetic structure that forces the electron beam, threading its axis, into side-to-side oscillations. To achieve a large amplitude of oscillation, the magnetic structure must generate high fields. The use of SmCo_5 permanent magnets is attractive for this application, especially if the magnets can be placed very near the electron beam. This is best achieved by placing the magnets within the vacuum system, using no barriers to separate them from the beam. Although alternative mounting methods (that is, separation of the beam and magnets by a vacuum wall) are feasible, the use of

Fig. 4.
Free-electron laser.

permanent magnets in the vacuum has the additional advantage of lowered fabrication cost and ease of assembly. The volume of permanent-magnet material is relatively large; coupled with the requirement for a very good vacuum in the wiggler, the SmCo_5 magnets' outgassing properties had to be well enough known to allow selection of the appropriate mounting method for this application.

In all of these applications discussed above, permanent magnets have several advantageous features. They require no power supplies and no cooling, have demonstrated excellent magnetic stability, and appear more resistant to radiation than electromagnets. Permanent magnets are available with a maximum-energy product $(B \cdot H) = 21$ to $24 \text{ MG} \cdot \text{Oe}$, using sintered rare-earth SmCo_5 material;^{*} by the use of advantageous geometry, permanent magnets can produce magnetic fields of useful strengths in devices that are physically much smaller than electromagnets. Permanent magnets also have disadvantages. The magnetic-field strength is determined by the amount of magnetic material present. There are no tuning "knobs," and the magnetic-field strength can be altered only by movement, removal, or addition of permanent-magnet material--procedures that also may change the magnetic-field shape. The sintered SmCo_5 magnets cannot be subjected to temperatures higher than ~ 150 - 200°C without degrading the material's magnetic properties. Finally, the material's vacuum properties may be inadequate for some applications. Manufactured by a sintering process from compacted powders, SmCo_5 magnets have a porosity of several per cent. A recent literature search produced no information on their vacuum properties, and the magnet manufacturers have no specialized information on outgassing rates; therefore, an investigation of SmCo_5 magnets' vacuum properties was conducted at Los Alamos, in conjunction with the FEL experiment. The investigation was sufficiently extensive to reveal any major problems.

II. EXPERIMENTAL PROCEDURES

A preliminary outgassing test was first performed with miscellaneous pieces of SmCo_5 in a small stainless steel chamber. Results of this test were sufficiently reassuring to permit design and construction to proceed on an

^{*}Hicorex 90B, available from Hitachi Magnetics Corp., Edmore, MI 48829

actual FEL wiggler and its vacuum enclosure. Figure 5 shows the wiggler's stainless steel vacuum enclosure undergoing vacuum testing. The apparatus was built with conventional high-vacuum techniques that used

- copper gaskets,
- a turbomolecular pump capable of reaching 10^{-7} torr,
- a fore pump trapped with liquid nitrogen, and
- an ion gauge for pressure readings.

The ion gauge was turned off between readings to reduce the effect on the system of its own outgassing or pumping rate. The only nonmetallic part was a single Viton O-ring used in the main valve between the pump and the enclosure.

Figure 6 shows the aluminum FEL wiggler structure. Figure 7 is a close-up view of the wiggler holding some of the 314 SmCo_5 magnets. Each magnet is 0.5 cm square by 3.5 cm long. A detailed discussion of the wiggler's design and construction, and its anticipated performance, can be found in Ref. 6. Important features for vacuum considerations are

- total system volume = $5 \times 10^3 \text{ cm}^3$ ($= 5 \text{ l}$);
- total surface areas of the magnets = $2.5 \times 10^3 \text{ cm}^2$;
- total surface area of the stainless steel vacuum enclosure = $5 \times 10^3 \text{ cm}^2$;
- total surface area of the aluminum wiggler structure = $15 \times 10^3 \text{ cm}^2$.

Fig. 5.
Vacuum enclosure for FEL
wiggler and numbered mag-
nets.

Fig. 6.
Aluminum wiggler structure holding some magnets

Fig. 7.
Close-up view of wiggler and numbered magnets.

- approximately 200 stainless steel pins and bolts hold the wiggler parts together; and
- there are no blind holes.

Otherwise, the design incorporates no special features that reduce the normal virtual-leak problems caused by cracks and crannies. The magnets are quite temperature sensitive and suffer a precipitous and permanent magnetic-strength loss if heated above $\sim 200^{\circ}\text{C}$; therefore, bakeouts were limited to 60°C for 3 h. All components were cleaned by scrubbing in Freon, followed by several rinses in clean solvent. The magnets were small enough to allow an additional soak in solvent in an ultrasonic cleaner. Finally, the wiggler and magnets were assembled and then given several further Freon rinses.

The performed measurements were of two kinds: (1) the vacuum level reached after different intervals of pumping, and (2) the pressure's rate of rise after isolating the system from the pump. Each measurement was made three times: (1) with the empty vacuum enclosure; (2) with the enclosure containing the wiggler structure, but without any magnets, and (3) with the complete system, including the magnets. Because of the high-magnetic forces created by the permanent magnets and because of their susceptibility to damage by chipping, it was considered too risky in this experiment to attempt to measure the magnets' outgassing without using the wiggler structure to secure them.

III. RESULTS

The data from the various measurements were plotted as pressure versus time. The shape of the resulting curve is useful in determining the method by which gas is being introduced into the vacuum system.⁷ If the pressure rise is the result of real leaks, the result is a straight line at 45° (Curve 1 on Fig. 8). If the pressure rise is caused by outgassing, the curve tends to rise to a limiting value as the rate of particle exchange between the surface and the system equalizes (Curve 2 on Fig. 8). Both leaks and outgassing result in a combined-effects curve (Curve 3 on Fig. 8). Helium leak checks on the empty wiggler enclosure indicated a tight system. The system's pressure rise, when the system was isolated from the pump, was essentially linear. It was impossible to determine whether this behavior, observed from 10^{-6} to 10^{-3} torr, was the result of minor external leaks plus outgassing, or from outgassing

Fig. 8.
Pressure versus time for a leak (Curve 1), outgassing (Curve 2), and both leaks and outgassing (Curve 3).

alone; however, it is believed that the pressure rise was predominantly the result of outgassing.

The results of the second and third cases (that is, with and without the magnets) essentially were identical, but qualitatively different from the first result. While being pumped, the chamber reached a vacuum of 10^{-5} torr in 1/2 h, 10^{-6} torr in 2 h, and 3×10^{-7} torr in 14 h. When isolated from the pump, the pressure typically behaved as shown in Fig. 9. In each case, the pressure increased approximately as the square root of time, a non-linear behavior ascribed to virtual

leaks in the wiggler structure. The evolving gas may be either air or traces of solvent that were trapped in the cracks; no gas analysis was attempted.

In this report, it is assumed that the system was pumped for a sufficiently long period of time to allow the surface outgassing rates to be constant. The constant outgassing rate would cause the system pressure to rise in a manner so that, using the extrapolation method indicated in Fig. 9, an estimate of 10^{-6} torr/s can be made for the maximum system pressure rate of rise. Given the total-system surface area of $\sim 22.5 \text{ cm}^2$, a system volume of $\sim 5\text{ l}$, and a maximum system-pressure rate of rise of 10^{-8} torr/s, the system's maximum surface-outgassing rate is calculated to be $2.23 \times 10^{-12} \text{ torr-l/s}\cdot\text{cm}^2$. This surface-outgassing rate is typical for the structural materials of the cavity and the wiggler structure, weighted by their relative areas. Because the system vacuum behaved in an essentially identical way, both with and without the magnets, and because the presence of the SmCo_5 magnets ($\sim 11\%$ of the total surface area) produced a negligible effect on the vacuum, the material probably has vacuum outgassing rate comparable to unbaked, but degreased, stainless steel ($\sim 10^{-11} \text{ torr-l/s}\cdot\text{cm}^2$).

Fig. 9.
Pressure versus time in sealed system, including wiggler and magnets.

IV. CONCLUSIONS

The outgassing of the SmCo_5 magnets is not significant for this application in the FEL wiggler. No definitive evidence of outgassing from the magnets was found. Because the magnets comprise $\sim 11\%$ of the total surface area of the wiggler, the outgassing properties of sintered SmCo_5 magnets are very good, probably much better than $\sim 1 \times 10^{-9}$ torr-l/s $\cdot\text{cm}^2$ that is characteristic of unbaked alumina. The major limitation imposed by the use of these permanent magnets in a vacuum system is their heat sensitivity, which prevents further reductions in outgassing by bakeouts at temperatures higher than ~ 100 to 150°C . This limitation could pose problems for the design of ultrahigh vacuum systems that use SmCo_5 magnets exposed to the vacuum.

REFERENCES

1. E. D. Bush, Jr., "Permanent Quadrupole Magnets," 1976 Proton Linear Accelerator Conf., Chalk River, Ontario, September 14-17, 1976, Chalk River Nuclear Laboratory report AECL-5677, p. 363 (1977).
2. L. D. Hansborough, Compiler, "PIGMI: A Design Report for a Pion Generator for Medical Irradiations," Los Alamos National Laboratory report LA-8880 (September 1981).
3. N. Saito, E. D. Bush, and D. A. Swenson, "Development of Samarium-Cobalt Quadrupole Lenses for Particle-Accelerator Applications," Los Alamos Scientific Laboratory report LA-7232-MS (June 1978).
4. R. F. Holsinger, "The Drift-Tube and Beam-Line-Quadrupole Permanent Magnets for the NEN Proton Linac," 10th Linear Accelerator Conf., Montauk, New York, September 10-14, 1979, Brookhaven National Laboratory report BNL-51134, p. 373 (1980).
5. R. W. Warren, "FEL Development Program at Los Alamos Scientific Laboratory," Proc. Int. School of Quantum Electronics, August 1980, Ettore Majorana Center for Scientific Culture, Erice, Sicily, S. Martellucci and A. N. Chester, Eds., forthcoming; also, W. E. Stein, C. A. Brau, B. E. Newnam, R. W. Warren, and J. G. Winston, "LASL Free-Electron Laser Experiments," Proc. 6th Conf. on Applications of Accelerators in Research and Industry, Denton, Texas, November 3-5, 1980, IEEE Trans. Nucl. Sci. 28, p. 1522 (1981).
6. R. W. Warren, C. A. Brau, B. E. Newnam, W. E. Stein, J. G. Winston, and L. M. Young, "Status of the Free-Electron-Laser Experiment at Los Alamos," to be published in the Proc. 1981 Office of Naval Research Workshop on Free Electron Lasers, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts.
7. A. Roth, Vacuum Technology, (North-holland Publishing Co., Amsterdam 1976), p. 430.