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Summary

Corrugated metal bellows of several meters length are a satisfactory and very inexpensive vacuum chamber for new or existing fast-cycling synchrotrons.

Introduction

Historically, vacuum chambers for fast-cycling synchrotrons have been a problem due to some combination of excessive outgassing, fragility, radiation damage, magnetic field distortion, high cost or unproven performance. For instance, high-alumina ceramic chambers with metal joints have been installed recently on the CEA,[1] NINA, and DESY synchrotrons and were proposed by LRL[2,3] for the 8-GeV booster of the 200-GeV accelerator facility. Such chambers have desirable vacuum and eddy-current characteristics, but are expensive (~\$1500/meter in production quantities), fragile, and subject to fatigue and handling failures at the joints.

Alternatively, we propose a corrugated metal bellows chamber to extend the complete length of a synchrotron magnet unit (usually several meters long). Of many possible configurations, Fig. 1 shows a specific elliptical chamber selected for evaluation in this paper. A more detailed evaluation is given in a separate paper.[4]

Fabrication and Cost

A large number of bellows manufacturers were contacted concerning feasibility and cost of the proposed chamber. Several reputable bellows manufacturers, some experienced at producing short elliptical bellows, quoted unit prices of \$90 to \$120 per meter in production quantities, which is only 10% of the unit cost for the ceramic chambers previously mentioned. This corresponds to a savings of several hundred thousand dollars for a 10-GeV synchrotron.

Vacuum

The stainless steel walls of the chambers contemplated herein should have low outgassing rates. Milleron reports that unbaked stainless steel cleaned by the Diversey process has an outgassing rate of less than 10^{-12} Torr-liters/s-cm^2 after 12 h of pumping,[5] which is negligible for most synchrotron applications. This is comparable to the outgassing rate reported by Clee for high-alumina ceramic chambers.[3] Needless to say, it is vastly superior to the outgassing rate of epoxy chambers used in some synchrotrons.

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

Structural Analysis

Bending moments, stresses and deflections were calculated using formulae and graphs for elliptical vacuum chambers.[6] The moment of inertia used in the formulae is that of the corrugated wall about its neutral axis. For 1 atm pressure, the maximum combined stress is 21 600 psi and the semi-minor axis deflection is 0.024 cm, both of which are acceptable. Analysis indicates buckling is unlikely.

Eddy-Current Distribution

For an applied 15-Hz biased-sinusoidal gradient ($k = 0.0239\ \mathrm{cm}^{-1}$) magnetic field with vertical component $B_a = 4405\ (1 + kx)\,[1 - 0.8888\ \cos 2\pi(15)t]$, the induced eddy-current density in the convoluted walls calculated for small values is[7]

$$i = \left[-3.6 + 100\left(\frac{x}{a}\right) + 9.4\left(\frac{x}{a}\right)^2\right] \sin 2\pi(15)t,$$

where units are Gauss, cm, s, and A/cm^2. Thus the peak induced eddy-current density is 106 A/cm^2 at $x = a$.

Field Disturbance

The induced eddy currents directly produce an induced magnetic-field disturbance B_i whose magnitude relative to the applied field B_a is greatest at $t = 5.0$ ms (27.2°). The LRL magnetostatic computer code LINDA was used to compute the induced field pattern shown in Fig. 2 and to compute the magnitude of the induced field and its gradient at $t = 5.0$ ms, which are shown graphically in Fig. 3, normalized to B_0, the value of B_a at $x = 0$.

No attempt has been made to assess the effect of these magnetic-field disturbances on the orbit dynamics of a synchrotron. However, since the change in gradient to reach a particle resonance stop band is of the order of $\pm$ 5%, it appears that the induced gradient (~1% of the applied gradient) might be tolerable. If desired, the field disturbance can be further reduced by (1) decreasing t and λ, (2) increasing h, (3) increasing resistivity ρ, or (4) compensation by suitable excitation of trim quadrupole and sextupole magnets.

Eddy-Current Heating

The instantaneous local heating due to induced eddy currents is $w = i^2\rho$. The given chamber can be cooled quite easily, since the time-averaged power dissipation is ~40 W per meter of chamber length.

Conclusions

Long corrugated metal bellows vacuum chambers are much less expensive and much less fragile than corresponding ceramic chambers. Excellent vacuum characteristics are anticipated. The thin corrugated walls reduce eddy currents such that field distortions and heat dissipation are unlikely to be problems. Adequate structural strength is achieved with chamber dimensions comparable to those of ceramic chambers. Consequently this type chamber can be considered for retrofitting into existing synchrotrons as well as for new synchrotrons.

Acknowledgments

We gratefully acknowledge the help of J. Dorst and M. Reaney for performing the magnetostatic computations with program LINDA, and the generous guidance and support of numerous individuals at LRL and NAL.

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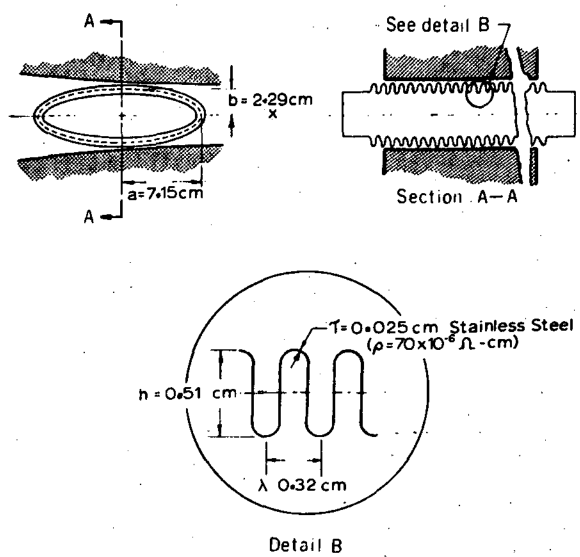

Fig. 1. Elliptical Bellows Configuration.

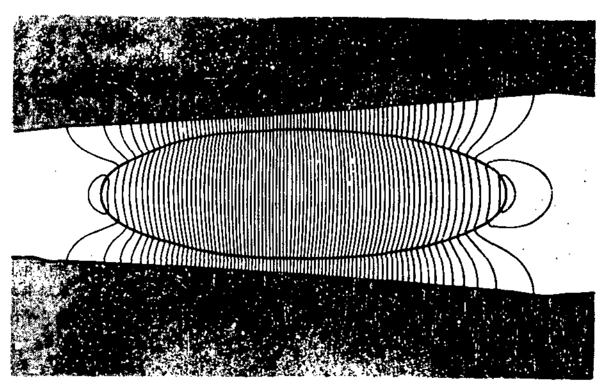

Fig. 2. Induced Magnetic Field Pattern.

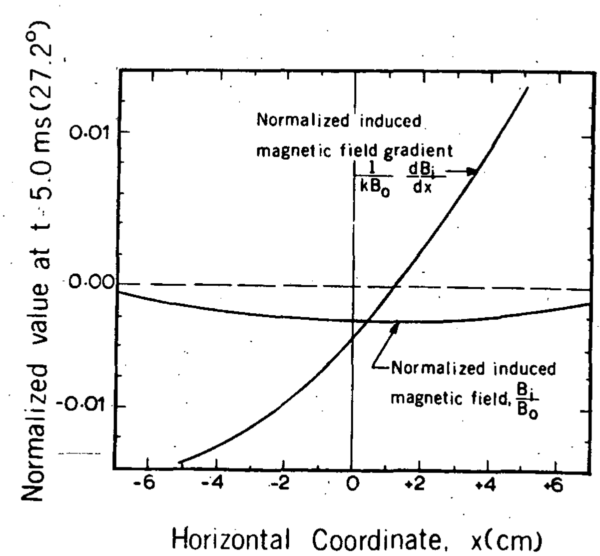

Fig. 3. Induced Magnetic Field at the Major Axis.

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