IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

GLASS JOINTED ALUMINA VACUUM CHAMBERS

J R J Bennett and R J Elsey
Science Research Council
Rutherford and Appleton Laboratories
Chilton, Didcot
Oxon. England

Summary

Alumina vacuum chambers are being constructed for the rapid cycling synchrotron of the Spallation Neutron Source (SNS). The ceramic sections are butt jointed with a thin layer of glass to give strong, vacuum tight assemblies. This method of construction is considerably less expensive than metalized ceramic to metal jointed assemblies. A description is given of the principal ceramic chambers.

Introduction

Vacuum chambers within the magnets of rapid cycling synchrotrons must be designed to limit the eddy currents induced in them. The problem may be overcome by having sufficiently thin walled or corrugated metal chambers of high electrical resistivity. Alternatively, chambers may be constructed of insulating materials such as epoxy resin, glass and ceramic. A stainless steel vessel, in the dipole magnet of the SNS[1] synchrotron would dissipate nearly 100kW with a wall thickness of only 1mm. Clearly this is an excessive dissipation.

Epoxy resin has the advantage of being relatively inexpensive and easy to manufacture into vacuum vessels - either as separate vessels or as "potted" magnets which form an integral chamber. However, it suffers radiation damage at levels exceeding 10^9-10^{10} rads and has a high outgassing rate compared to metals, glass and ceramics. The SNS carries a very high current and even losses, less than 1%, can cause severe radiation problems.

Glass and ceramics, such as high purity (>85%) alumina, have good vacuum and radiation properties. Unfortunately, glass is mechanically weak and brittle. Consequently the walls of the glass chambers must be very thick by comparison to metal chambers. The dipole chamber for the SNS quoted above, would need 20mm thick walls. Thick walls are a disadvantage since they take up valuable aperture in the magnets. Alumina is possibly the most versatile of any of the ceramics used in industry today. It is strong, is resistant to chemical attack, has good electrical insulation and has good thermal shock resistance due to a relatively high thermal conductivity. Its ultimate tensile strength of ~ 200 MN/m^2 allows the wall thickness to approach that of metal chambers. The ultimate compressive stress is $\sim 1{,}700$ MN/m^2. Alumina vacuum vessels have been used in electron synchrotrons for example, at Daresbury and Hamburg.[2]

"Conventional" Alumina Chambers

The normal method of manufacture is to isostatically press the powdered alumina on a suitable mandrel, machine off surplus material, fire the pressing at 1600-1800°C whence the material takes on its hard, strong form and finally grind to the appropriate shape if necessary. The firing process produces massive changes in size - the volume reduces by about 50% - and it is this firing that makes it difficult to produce large, accurate ceramics from pressings alone. Grinding is an expensive process with this hard material, particularly on the bores of complicated shaped vessels. By keeping the length of the sections to 2 or 3 times their cross-section it is usually possible to maintain the accuracy of the pressed dimensions of the bore to ± 1%.

In most cases chambers have been made up of sections of alumina about 0.3m long joined together by metalizing the ends of the ceramic, brazing on thin metal rings and then welding the rings to each other to form complete assemblies. The metalizing, brazing and assembly process is costly, amounting to roughly half the total cost of the completed assembly.

The metal rings brazed to the ends of the ceramic sections must be thin to reduce the stress between metal and ceramic that inevitably occurs because of their mismatch in thermal expansion. The assemblies of many sections are therefore relatively fragile and need frequently supporting. Usually the only support is from the magnet poles themselves and care must be taken to prevent undue vibration to the chambers from the pulsing magnets. This vibration is probably the cause of some failures in the welds and braze joints. On the whole, ceramic chambers manufactured in this way have proved reliable.

Glass Joints

An alternative to the expensive jointing method described above is being used for the SNS vacuum chambers. Each end of the ceramic section is ground flat and glazed with a thin layer of suitable glass about 0.4mm thick. The sections are then placed one on top of another in a furnace where the assembly is heated to 1100°C in air to melt the glass. By locating the sections to each other with ceramic dowels in the end faces and using gravity to press the sections together, no assembly jig is required. The result is a strong, rigid chamber which can be supported at each end independently of the magnets thereby reducing any risk of failure by vibration. Moreover, since the glass joints replace the thin metal rings, the whole structure is resistant to corrosion by acids which can be formed in the air at high radiation levels.

Tests[3] have been made to assess the strength and radiation resistance of the glass joints. The tensile strength of the joints exceeds 120 MN/m^2. No deterioration of strength under irradiation by 50 MeV protons up to 2×10^{11} rads was detected. Joints are invariably leak tight.

Flanges

It is not possible to easily put metal end flanges on the glass jointed ceramic sections using the metalizing and brazing technique since it is incompatible with the glass jointing. Experiments to glaze metal to ceramic have not proved successful but could possibly be developed.

The solution adopted for the SNS is to have ceramic flanges glazed to the other ceramic sections. Clearly such flanges are more fragile than metal ones since they will not bend.

0018-9499/81/0600-3336$00.75© 1981 IEEE

The vacuum system[4] is being built to UHV standards and requires metal seals. However, by using a commercial re-useable indium metal seal[*] requiring a low seal force of 30kg per cm of circumference reliable, trouble free joints are readily made without unduly stressing the flange. A 20° taper on the mating flanges is used to take a v-band type clamp. The clamp applies the force immediately over the seal so that the flange experiences only compressive forces. The clamps are of very light construction having pressed steel shoes with some spring in them to reduce any tendency to apply point loads. The mating stainless steel flange is thin so that it readily deforms to the ceramic, rather than vice-versa, again to reduce stress in the ceramic. Figure 1 shows a section through a typical ceramic to stainless steel flange joint and clamp.

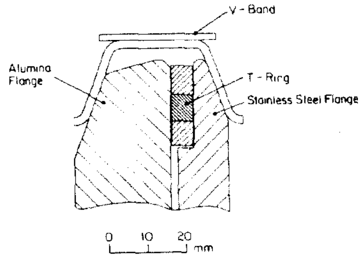

Fig 1: Typical demountable joint detail.

SNS Ceramic Vacuum Chambers

All sections[†] are isostatically pressed from a 97.6% purity alumina; the bores are not ground, but must be within ±1% of the nominal diameter. The ends are ground flat and the outer walls are partly ground. The ends of the dipole sections are ground at an angle to give the curvature. The dowels are made from the same material as the sections and are 4mm diameter, 15mm long. Figure 2 shows cross sections of the principal chambers for the various magnets in the synchrotron.

Because of the premium placed on magnet aperture, the nominal clearance between chamber wall and magnet pole is only 1.5mm and the wall thickness at the poles is 3.9 to 5mm. Elsewhere the wall is thicker, up to 15mm. The calculated maximum tensile stress in the walls is 40 MN/m^2 under vacuum load. The axial straightness and twist of the assembled chambers is determined by the grinding accuracy of the end faces - typically ± 0.01mm, and the accuracy of the dowels and holes.

The dipole chamber is nearly 5m long and curved on a 7m radius. Because of the curvature, the assembly of loose sections is unstable and two thirds of the sections have to be furnaced together first. The remaining sections are then placed on top of the joined sections which are tilted over to make the loose sections stable. A support from the furnace wall half way up the chamber prevents the assembly toppling over. Insulation is placed in the furnace to create three temperature zones, a top zone which is raised to 1100°C to glaze the last loose sections, a gradient zone where the temperature varies linearly with distance down the sections and a zone containing the bottom one third of the assembly which reaches 600°C at which temperature the glass remains firm. The temperature is elevated and lowered slowly, 50°C per hour, to reduce thermal stresses and remains at maximum temperature for 1 hour. Figure 3 shows a dipole chamber and the furnace.

The quadrupole chamber is 3m long, the other straight chambers vary, but are under 1m long. Ten vessels of each type are required except for the correction magnets of which there are about 30.

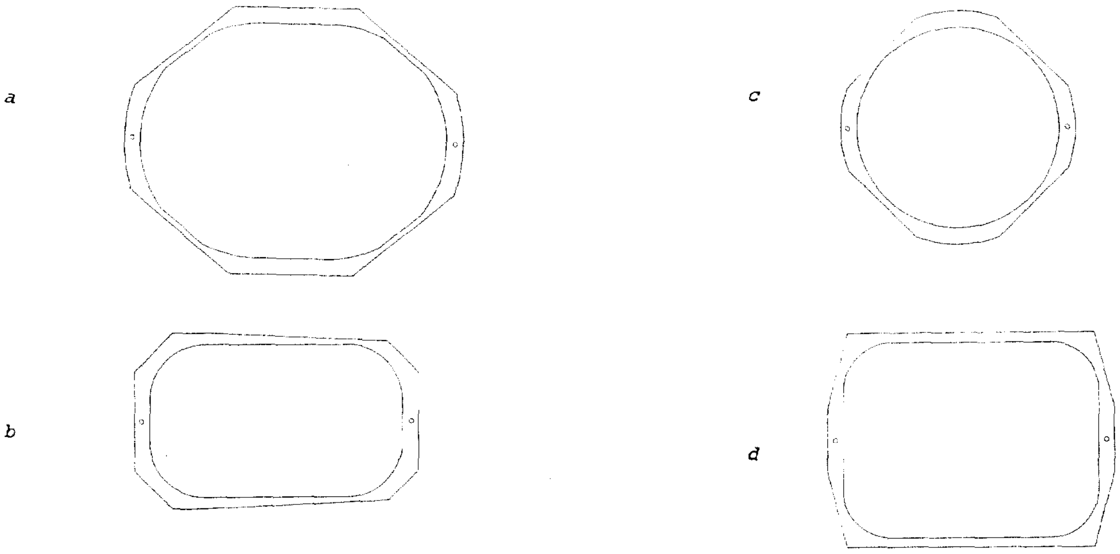

Fig 2: Principal chamber cross-section.

a) doublet quadrupole b) dipole c) singlet quadrupole d) steering magnet and octupole.

---

[*] T-Ring. Manufactured by VAT Haag Switzerland.

[†] The sections, flanges and dowels are manufactured and glazed by Wade (Ireland) Ltd ready for assembly at the Rutherford and Appleton Laboratories.

Prototype dipole, doublet and singlet quadrupole chambers have been successfully completed. The doublet quadrupole vessel (Fig 4) is straight to within ± 0.1mm. This and other straight chambers are simple to assemble but the dipole (Fig 5) requires more care due to its curvature. The prototype dipole chamber has been measured to be flat in the median plane to ± 0.8mm and to follow the curvature to better than ±0.5mm.

All the results, so far, indicate that glass jointed ceramic vessel assemblies are relatively simple and inexpensive to manufacture and result in strong, rigid vacuum tight structures.

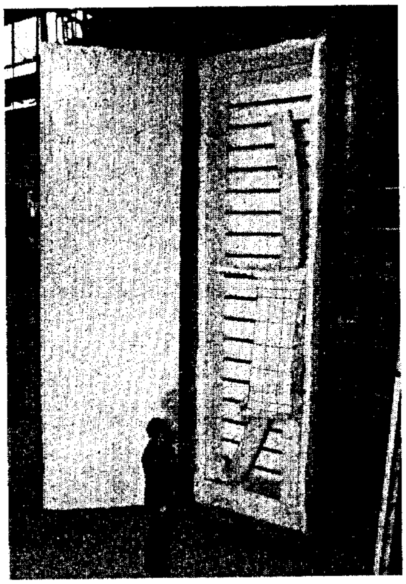

Fig 3: Dipole chamber in furnace.

References

1 L C W Hobbis, G H Rees and G C Stirling. Rutherford Laboratory Report RL-77-064/C.

2 W F Gibbons, Proc 4th Int. Vac. Cong. p255 (1968).

3 Vacuum System for an Intense Pulsed Neutron Source at the Rutherford Laboratory, J R J Bennett, R J Elsey and A J Dossett. Vacuum, 28, 507.

4 Ceramic Vacuum Chambers for the SNS Pulsed Neutron Source, J R J Bennett, R J Elsey and A J Dossett. Proc. 8th Int. Cong. Sept 1980.

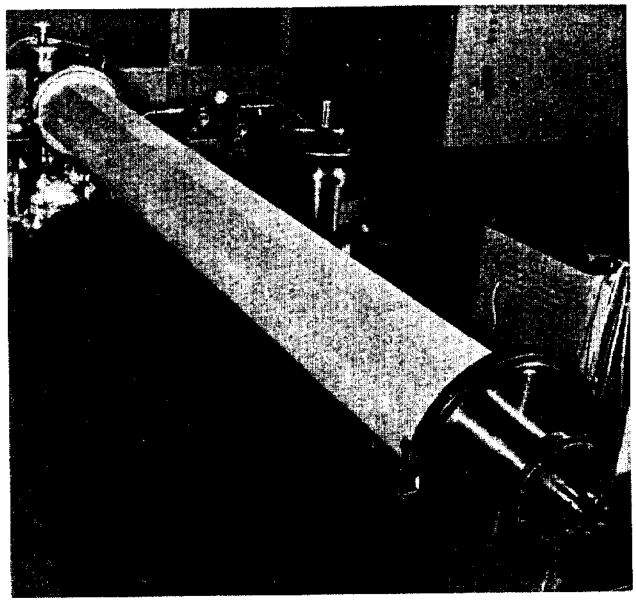

Fig 4: Doublet quadrupole chamber.

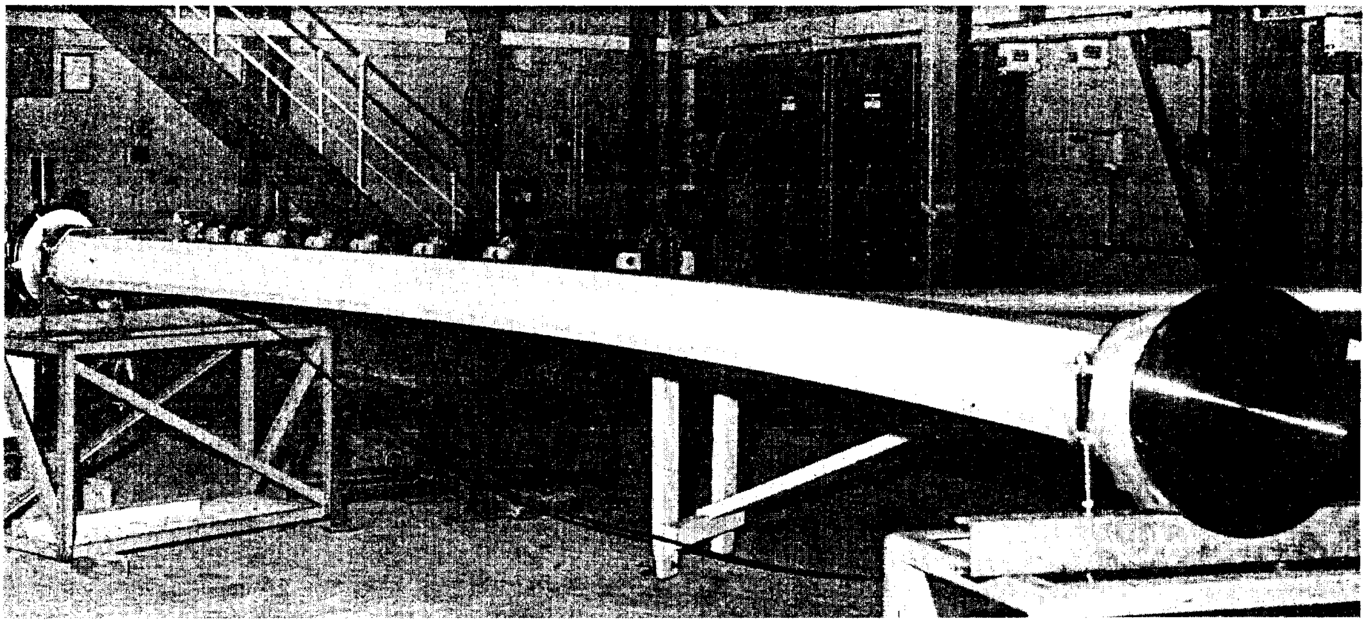

Fig 5: Dipole chamber.