Ceramic Beam Pipe for the TRIUMF KAON Factory Synchroton Rings

T. Hodges, R. Langstaff, C. Oram
TRIUMF
4004 Wesbrook Mall, Vancouver, B.C., Canada

M. Featherby
Science Applications International Corp.
1043 Roselle Street, San Diego, CA. U.S.A.

C. Planner
Rutherford Appleton Laboratory
Chilton, Didcot, Berks., England

Abstract

The sections of beam pipe passing through the magnets of the two fast cycling synchrotrons of the KAON Factory accelerator are to be constructed of alumina, thereby avoiding the eddy current problems which would otherwise arise if conventional metal pipes were used. An rf shield is required inside the nonconducting ceramic pipe to provide a low impedance path for the image currents of the circulating beam.

Two schemes using different construction techniques for both the ceramic pipe and the internal rf shield are described and compared.

I. INTRODUCTION

The use of conventional stainless steel beam pipe in synchroton dipole magnets is complicated by the eddy currents generated in them by the changing magnetic field. The resulting magnetic field disturbance and heating effects can be minimized by the addition of compensating coils and cooling and/or by reducing the pipe wall thickness. To maintain mechanical stability, the surface of thin walled pipes needs to be corrugated or ribbed. The corrugated surface and thin wall require, in turn, that the pipes be fitted with internal rf shields to reduce their impedance to beam image currents to an acceptable value. Generation of eddy current loops in the rf shield structure is prevented by "blocking" capacitors, chosen to present high impedance to the low frequency eddy currents and low impedance to the high frequency image currents.

Non-conducting pipes, made from a ceramic such as alumina, are free from eddy current problems but have other limitations, not least amongst these being the considerably greater difficulty in fabrication and joining processes. The brittle nature of ceramic materials requires considerable care be taken in the design of mechanically clamped joints such as are found in support, restraint and flanged vacuum connections. From a vacuum engineering standpoint, ceramics are more prone to outgassing and have larger secondary emission factors than clean metal surfaces. A non-conducting pipe will also require an internal conducting rf shield. The choice of alumina rather than some other ceramic for the TRIUMF KAON beam pipes is based upon its considerably greater availability, established industrial usage and lower cost.

Two possible designs of alumina beam pipe have been investigated; they are referred to herein as the "reference design" and the "integrated design".

II. REFERENCE DESIGN

So named because it was used in cost estimations for the KAON Project Definition Study, this design is based on alumina beam pipe currently in use on the ISIS synchrotron at the Rutherford Appleton Laboratory.

Under contract from TRIUMF, RAL have produced a complete dipole beam pipe for one of the KAON synchrotron rings. The pipe, 4.275 m long with a rectangular bore of 96 x 113 mm was constructed from 17 straight sections, machined at the ends so that, joined end to end, they form a pipe of the required radius of curvature. The pipe sections are aligned one to the other with alumina dowels and the joints are made by fusing glass between the sections. The fusion process is carried out by stacking the sections with their glass coated ends vertically in a furnace and firing at 1100°C. An alumina flange, joined to one end of the pipe during the firing stage, is used to connect to the adjoining stainless steel vacuum section using a re-usable indium seal and circumferential clamp. The other end of the pipe is fitted with a stainless steel flange, held in position by clamps which fit into grooves in the outside surfaces of the alumina pipe; the vacuum seal is made using an indium wire seal. The latter arrangement is necessary to enable the pipe to be fed between the close fitting pole faces of the dipole magnet (which are not demountable); the flange is then assembled with the pipe in position.

The upper and lower surfaces of the rf shield, which are perpendicular to the dipole field, are made from 1.5 mm diameter titanium alloy wires spaced 3 mm centre to centre whilst the vertical sides are made from 1.5 mm thick titanium alloy sheet, Fig. 1. The shield components are held in position in the alumina pipe by machineable ceramic (MACOR[1]) frames sized to match the beam envelope in both planes throughout the pipe. At the alumina flange end of

[1]MACOR, Trademark of Corning Glass Works, Corning, N.Y.

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the pipe the rf shield wires and sheets are bent through a right angle to bring them into the plane of the flange face. The blocking capacitors, contained in a ceramic ring, are connected individually to the wires and sheets via rf spring contacts. At the other end of the pipe an array of rf spring contacts connect the wires and sheets to "ground". Thermal expansion of the rf structure relative to the alumina pipe is accommodated by allowing the wires and sheets to slide in the MACOR frames; the rf spring contacts at the demountable flange "ground" end maintaining a sliding contact.

Under a development contract RAL have improved their design in several areas. Together with the alumina pipe manufacturers[2] they have produced longer (probably optimum length for this design) sections of pipe which will halve the number of joints required and ease assembly. Simplification of the rf frames will reduce their cost and the possibility of using high density alumina in place of MACOR has been demonstrated. The alumina is superior in mechanical strength and vacuum properties but is more susceptible to thermal shock.

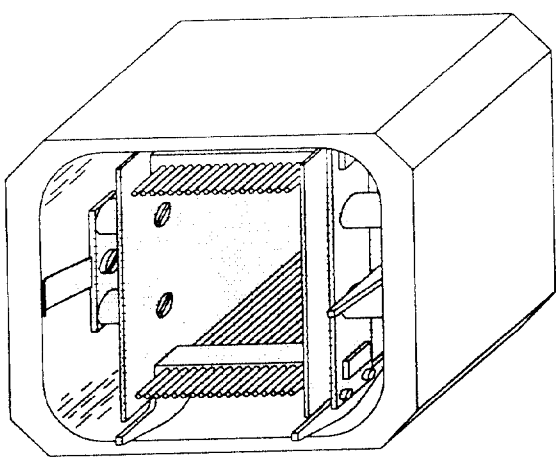

Fig. 1. rf shield of the reference design.

III. INTEGRATED DESIGN

In this design the rf shield is "painted" on the walls of an alumina pipe using a silver/glass paste[3] developed from thick film technology. For the rf shield to follow the beam profile throughout the pipe, the pipe must be both curved and of changing cross section. Development of this design is being pursued under a contract with SAIC[4]. In collaboration with a ceramic manufacturing company[5] curved pipe sections of 1.3 m length have been produced with the bore tapered in one plane; reverse tapers in two planes could be developed with more sophisticated tooling. The manufactured pipe sections also contain sets of parallel grooves which are filled with the silver/glass paste and fired to produce the silver stripes which form the rf shield, Fig. 2. Connection to blocking capacitors and "ground" would be carried out using the same technique described for the reference design.

Three pipe sections complete with rf stripes and a coupling flange have been produced which when joined together will form a dipole beam pipe. The final phase of this development would see a similar pipe being produced but the rf striping would be carried out after the pipe sections had been joined to form the complete dipole pipe.

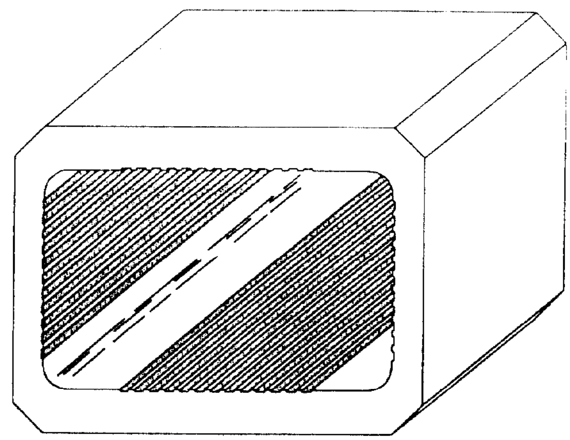

Fig. 2. rf shield of the integrated design.

IV. COMPARISON OF DESIGNS

The short, straight pipe sections of the reference design can be made to closer tolerance and are more easily assembled than their long curved counterparts; however, the longer pipes require fewer joints and less machining of pipe ends. Experience at RAL is that there is no mechanical or vacuum problem with the joints but small "step" mismatches between pipe sections must be accommodated by the rf shield, which is slid into the pipe in the reference design, or by the striping process of the integrated design.

The separate rf shield of the reference design allows the alumina pipe to be of constant cross section; it also allows removal of the shield for modification or repairs and subsequent replacement in the pipe, which could then be returned to service without resurveying. The separate shield will reduce secondary emission from the alumina walls, partially screening particles impinging on, and returning from, the pipe wall. Minor repairs to an integrated rf shield are possible but extensive damage would require complete pipe replacement.

The integrated shield design requires less vertical space and therefore allows the use of magnet elements of smaller aperture. This advantage is currently reduced by the larger dimensional tolerances on the long curved pipes but at

[2] Wade Advanced Ceramics, Burslam, Staffordshire, U.K
[3] Quantum Materials Inc., San Diego, CA.
[4] Science Applications International Corp., San Diego, CA
[5] Willbanks Int. (Div. of Coors Ceramic Co.), Hillsboro, OR.

$280 per millimetre of magnet aperture per metre of beam pipe, the cost saving from this source might be considerable as the production techniques for large curved pipes are further refined.

The reference design with MACOR framed rf shield has roughly twice the outgas rate of the alumina pipe alone; the alumina framed version adds little to the outgas load. In tests on the complete MACOR framed version however, it was shown that in 48 hours (including a 24 hour 100°C bake cycle) an adequate vacuum of 5E-9 could be produced using an ion pump half the size envisaged for synchrotron operation. The outgas rate of the integrated design has not been measured but it should not be significantly greater than the alumina pipe alone.

V. CONCLUSION

The reference design of alumina beam pipe plus rf shield has operated reliably on ISIS for over 7 years and can be regarded as a proven design. The integrated design could, with a little more development, offer an alternative at lower cost.