THE DESIGN, CONSTRUCTION AND TESTING OF A MULTIPOLE WIGGLER MAGNET TITANIUM VACUUM CHAMBER FOR THE SRS.

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Abstract

A vacuum chamber is required for two new insertion devices (IDs) at the SRS. The chamber has been designed, finite element analysis performed, and a prototype constructed and successfully tested. The chamber is 1208 mm in length, it has an internal aperture of 134 mm x 16 mm and a minimum wall thickness of 1 mm. The chamber has been precision machined in two halves from titanium alloy and electron beam (EB) welded in order to meet the demanding tolerances. Titanium alloy was selected in preference to more conventional ultra high vacuum (UHV) materials, due to its electron beam weldability, low distortion and outgassing rates. The design, construction and processing has been conducted to UHV standards to achieve a working pressure of 1 x 10^{-9} mbar.

1 INTRODUCTION

An upgrade to the 2 GeV, 2nd generation synchrotron radiation source operating in the UK is planned, which will reconfigure existing components of the storage ring to create space into which two new IDs will be installed [1].

The devices will provide photon beams of high flux and medium brightness at about 10 keV and allow up to 2 new stations to be built on each beamline. The magnet design is a hybrid multipole wiggler consisting of Neodymium-Iron-Boron permanent magnets and Vanadium Permendur pole pieces which has been optimised [2] to produce a high peak on-axis magnet field of 2.0T with the shortest possible period providing photons with a critical energy of 5.3 keV.

In order to realise the high field strength and reduce the volume of permanent magnet material a minimum magnet gap is required. To achieve this the amount of vacuum chamber material at the critical location between the electron beam-stay-clear zone and the poles of the ID must be minimised. In addition, the storage ring electron beam stay clear vertical aperture at the location of the ID has been assessed [3] and it has been concluded that it can be reduced, from the present 36 mm to 15 mm, without reducing the beam lifetime by more than about 15%.

2 DESIGN

Careful consideration has been given to the chamber design, material selection and construction technique, in order to meet the ID requirements and allow full integration into the SRS, Table 1.

Austenitic stainless steels grades 304LN and 316LN are often chosen as the material for fabricated storage ring UHV chambers due to low magnetic permeability requirements within magnet apertures (better than 1.005) and their high proof stress. Aluminium alloys such as 6063 T6 are also widely used, especially when an extruded chamber is the more cost effective approach. Since only two production chambers of this design are required at only 1208 mm in length, a fabricated vessel construction is preferred.

Table 1. Specification for the Vacuum Chamber

Magnet gap	19.2 mm
Maximum external chamber size at poles	18.8 mm
Horizontal electron beam stay clear	± 53.0 mm
Vertical electron beam stay clear	± 7.5 mm
Horizontal photon beam stay clear	+ 79.0 mm
Chamber length	1208 mm
Vacuum pressure with e^- beam on	1 x 10^{-9} mbar

The chamber needs to be a precision construction to meet the stringent technical requirements on size and geometric shape, therefore the design chosen is a precision machining in two halves with full penetration EB welds along each side of the chamber to reduce distortion to a minimum, Figure 1.

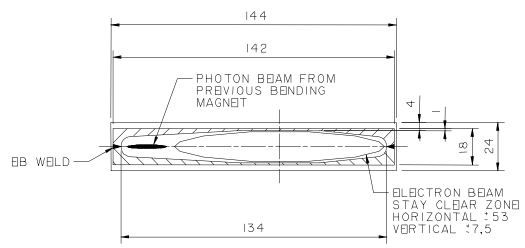

Figure 1. Section through Chamber

Low magnetic permeability stainless steels have low ferrite content and consequently higher nitrogen content making electron beam welding difficult but not impossible [5]. Titanium alloy grade Ti-6AL-4V was chosen in preference to stainless steel mainly because of its electron beam weldability. Smooth welds are possible with less than half the weld distortion compared to stainless steel due to its high welding speed and low coefficient of thermal expansion. Titanium alloys have a low out gassing rate [6], high proof stress and low density. A disadvantage is its lower modulus of elasticity which results in a greater deflection due to vacuum loading. Table 2 shows a comparison of mechanical properties for Stainless steel 316LN, Aluminium alloy 6063 T6 and Titanium alloy Ti-6AL-4V. The magnetic permeability of all three materials is better than 1.005.

Table 2. Material Property Comparison [4]

Property	Aluminium Alloy Gd. 6063 T6	Stainless Steel Gd. 316LN	Titanium Alloy Gd. Ti-6Al-4V
0.2% Proof Stress (MPa)	60-180	316	900-970
Young's Modulus (GPa)	67	201	105-120
Thermal Expansion (/°C)	$22x10^{-6}$	$17x10^{-6}$	$7.9x10^{-6}$
Hardness HB	75	197	255 (measured at DL)
Density (kg/m^3)	2690	7900	4420

It is extremely difficult to weld stainless steel to titanium alloy, therefore the vacuum flanges were also made from titanium alloy Ti-6AL-4V which has a measured hardness of 255 HB compared to the 170 HB required for a good knife-edge.

The cross-section of the vessel is asymmetric to clear the photon beam on one side of the chamber and maintain a minimum span, as seen in Figure 1. To keep as much rigidity as possible in the chamber the 1mm wall section has been restricted to the pole areas only.

Finite Element Analysis of the chamber was performed using PTC Mechanica with P-type solid elements used with general convergence set to 10% on global RMS strain energy. The chamber has two lines of symmetry, therefore it was only necessary to construct a one quarter model.

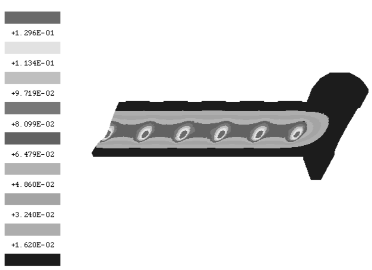

Figure 2. Deflection Contour Plot

The maximum Von Mises Stress due to atmospheric pressure loading and self weight was relatively low at 67 N/mm^2 and the maximum deflection at the centre of the thin wall section was predicted to be 0.15 mm, as shown in Figure 2.

3 CONSTRUCTION

The ID chamber manufacturing procedure consists of the following steps:

(i) Pre machining of vacuum chamber halves (VCH)
(ii) stress relieving of VCH
(iii) final machining of the VCH with length oversize
(iv) UHV clean the VCH and welding fixture
(v) electron beam weld the two longitudinal welds
(vi) UHV clean and vacuum leak test
(vii) machine weld preparations for the VC and flanges
(viii) UHV clean the VC, flanges and fixture
(ix) electron beam weld the 2 orbital flange welds
(x) UHV clean and vacuum leak test.

Machining of titanium alloy was similar to that of an alloy steel with the same strength level. Rigidity of both the work piece and the cutting tool was essential. Titanium alloy has a lower modulus of elasticity than steel resulting in spring-back when machining, which limited the achievable thin wall section. To reduce this effect fixtures were used to support both sides of the chamber halves.

Titanium also has a tendency to gall and smear onto other metals. Cutting tools need to have a good surface finish with machine speeds low and feeds as high as practical for the various operations. Special care was needed in following procedures for handling the swarf as under certain circumstances it is inflammable.

The stress relieving and EB welding of the chamber halves was conducted on a rigid flat stainless steel fixture, as shown in Figure 3.

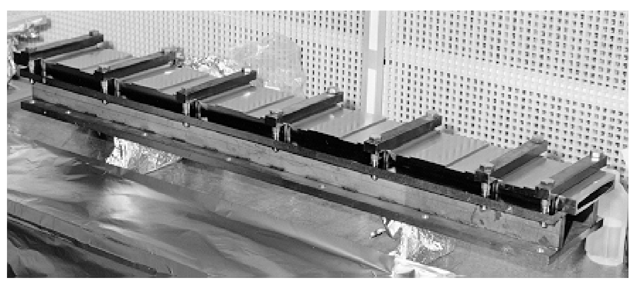

Figure 3. Vacuum Chamber on the Welding Fixture

Weld test pieces for both longitudinal and orbital flange welds were conducted to establish optimum EB welding machine settings, to achieve acceptable UHV quality internal weld beads. The longitudinal full penetration welding of the two chamber halves was conducted using a 40 mA beam at 2000 mm/min and the orbital EB welds between the pipe ends and the knife edge flanges was conducted using a 10 mA beam at 1000 mm/min to produce a 3 mm penetration depth. All welding was performed at TWI in machine EBII with gun type 100kW RF at a vacuum pressure < $5x10^{-3}$ mbar.

All machining, assembly, measurements and testing of the chambers was conducted in-house.

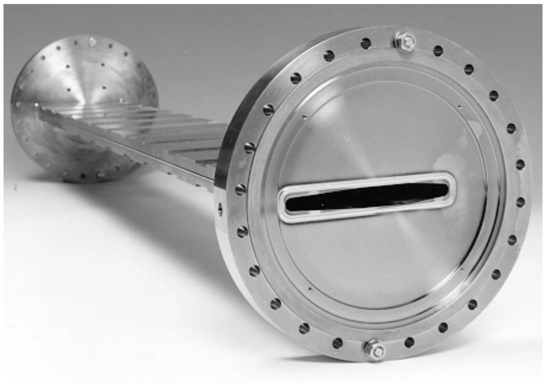

Figure 4. Completed Chamber

4 TESTING

The external faces at the position of the 11 poles have been measured on both sides of the chamber along three lines: line 2 along the centre-line of the chamber and lines 1 and 3 at the edges. Figure 5 shows the results for both sides of the vacuum chamber.

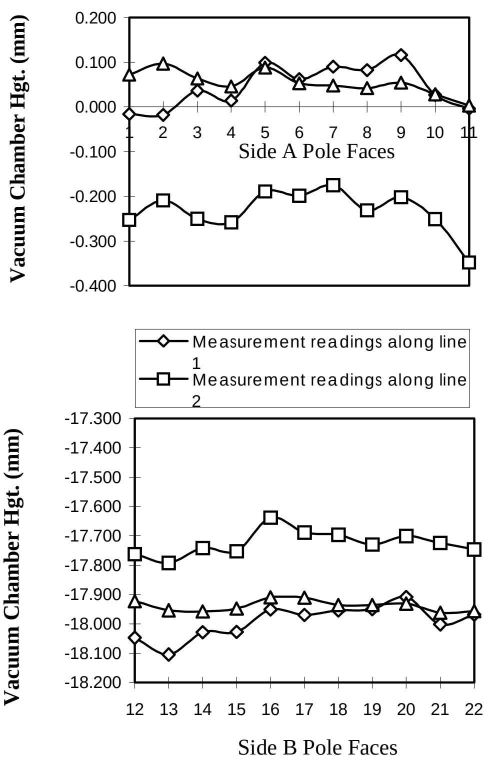

Figure 5. Flatness Measurements

Flatness of the external faces of the chamber in the area covered by the 11 pole faces, under vacuum loading was 0.3 mm. The maximum parallel plane measured over the poles occupied by chamber material without twisting the chamber was 18.2 mm, 0.6 mm less than the specified value of 18.8 mm. Table 3 shows a summary of the achieved specification.

Table 3. Achieved Specification

Magnet gap	19.2 mm
Maximum external chamber size at poles	18.2 mm
Minimum internal chamber size at c/line	15.3 mm
Flatness tolerance over 11 pole faces	0.3 mm
Vessel wall thickness at pole locations	1.00-1.15 mm

The maximum deflection measured at the thin wall area of the chamber under atmospheric pressure was 0.13 mm on each side, which is in good agreement with the theoretical value of 0.15 mm, reported in section 2.

The EB welds and titanium alloy knife-edge sealing flanges have successfully passed all vacuum leak tests to 1x10^{-9} mbar l/s, before and after a 250°C vacuum bake. Vacuum outgassing rate tests are currently being undertaken and a programme of repetitive making and breaking of titanium alloy test flanges is underway, to assess the lifetime of the titanium alloy knife-edges.

Future developments to the prototype vessel include adding four titanium alloy electron beam position monitors, two at each end of the chamber in a small space available between the magnet array and the chamber flanges. The modification is planned to be complete by November 1997 and two new production chambers by April 1998.

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