

THE VACUUM CHAMBER FOR THE 7 GeV PROTON SYNCHROTRON

Introduction

In the initial stages of work it was considered that the designs of vacuum chambers of existing proton synchrotrons could be improved by the use of new techniques and materials. This would afford a reduction in the magnet gap and effect appreciable economies in the design of the whole machine. A new form of construction was sought and a vacuum chamber made from glass fibre and epoxy resin supported by stays attached to the magnet has been evolved.

Following a recent visit to America by members of the 7 GeV project team, questions have been raised as to whether the proposed new form of construction gives us a significant overall advantage over the earlier forms. An assessment of the various designs in relation to the 7 GeV machine is made below to assist in making a final decision as to the type of chamber to be used.

Requirements

The vacuum chamber must be evacuated to a pressure of less than 10^{-6} millimetres of mercury (air equivalent). It must consume as little of the magnet gap as possible. It must be non-magnetic, and its influence on the magnetic field due to eddy current effects must be a minimum; any such disturbance should be radially uniform. Its performance should be unaffected by radiation. It is also desirable to have free access to the outer edge of the vacuum chamber for experiments and for it to be readily removable and replaceable.

Materials

These requirements limit the choice of materials. Conductors may only be used if precautions are taken to avoid large eddy currents and their effects, and thus involve a laminated structure. High resistance materials are necessary such as non-magnetic stainless steels, Inconel, etc. For these reasons insulators are much to be preferred. Suitable materials for use under high vacuum conditions are glass, ceramics, fused silica, certain synthetic resins, and polytetrafluoroethylene.

Construction

Several designs are considered as follows:-

1. Self supporting vessel made from:-
 - (a) Solid insulating material.
 - (b) Metal laminations bonded together with insulating material.
 - (c) Insulating material with discontinuous metal reinforcement moulded in.
 - (d) Metal skeleton clad with insulating material.
2. Supported vessel using construction (a), (b), (c) or (d).
3. Double walled vessel, using one or two of the above constructions with an additional possibility for the inner vessel:-
 - (e) Very thin metal shell of high resistance material.
4. Vessel using magnet as walls.

A number of these constructions can be eliminated, even though they have been used on other machines.

The Birmingham University synchrotron uses the first design (1.(a)) in the form of moulded ceramic sections joined by rubber gaskets. Because of the larger aperture on the Harwell machine this form of construction is beyond the capabilities of the ceramic ware manufacturers and is thus eliminated.

The second method (1.(b)), has never been used. Tests have been carried out with adhesives having suitable vacuum properties and show that this scheme is not feasible with our existing knowledge. The shortcomings arise from: the unequal thermal and mechanical properties of the metal and bonding materials, making the structure susceptible to mechanical failure; short-circuiting between adjacent metal laminations; and gaseous leaks. It is of course possible that special techniques for making a satisfactory vessel of this type could be developed in time.

The form 1.(c), has been used for the Saclay synchrotron. This is one form of construction that has been seriously discussed for the Harwell machine, and is described in more detail below.

Construction 1.(d), a metal skeleton clad with insulating material to provide a vacuum seal, has been used successfully for the American 'Cosmotron' vacuum chamber. This is another possible construction which is discussed in more detail later.

A design (2.) which uses external supporting stays will permit the use of a thinner vessel wall. One of the main design difficulties is the high stress concentrations at the point where the supporting stay meets the main vessel. This construction makes possible the epoxy resin - glass fibre chamber which has been evolved and is examined in more detail below.

The use of supporting stays in combination with a clad metal structure would involve considerable design changes to the Cosmotron system because the supporting grid bars are independent of each other and it would only be possible to support those directly below the gap in the magnet blocks (one in fourteen if one inch wide bars are used). It would be necessary to put a stiffening spine along the bars to get the full advantage of the stay. This must be stainless steel for strength considerations and would introduce serious disturbances in the magnetic field. Vacuum seals would be needed where the stays penetrated the sealing membrane.

Double walled vessels (3.) have been avoided because of the complexity of assembly, vacuum sealing and pumping, and the difficulty of providing easily modified experimental facilities.

The 'Bevatron' in the United States uses the magnet structure to provide mechanical strength (4.). In order to provide any latitude for shaping the pole tip contour, the pole tips must be within the vacuum sealing membrane, and the difficulties of finding a laminating adhesive which is acceptable for high vacuum is again introduced. The Bevatron requires some days to pump down to an operating pressure and some weeks to reach pressures of about 3×10^{-6} mm. Hg. This construction is more difficult to carry out on the 'C' type of magnet than on the 'H' type. For these reasons it has not been further considered for the Harwell machine.

The designs most acceptable for the Harwell machine are the 'Cosmotron' type chamber of metal ribs clad with insulating material, the 'Saclay' type with metal reinforcing ribs cast into an insulating resin, and the glass fibre-epoxy resin type with supporting stays. These are now considered in more detail and an attempt is made to summarize their relative merits and disadvantages in tabular and diagrammatic form.

Saclay type chamber (see Fig. 1)

This consists of a number of small chamber sections which are bolted together to form a complete arc, each section having elastomer seals. The construction consists of a stainless steel window frame at the radial edge of the box, with 'C' shaped stainless steel members slotting into it. This

skeleton provides the mechanical strength. The inner wall is a double laminate of stainless steel strips which is banded together with epoxy resin and glass cloth and then shaped to the requisite contour. The skeleton and inner wall are then placed in a moulding box, together with the threaded inserts for final assembly and the section is vacuum cast with a silica loaded epoxy resin.

In the evolution of this form of construction, techniques had to be developed to prevent high stress concentrations at interfaces of the stainless steel reinforcing bars and the epoxy resins into which they were cast. The curing temperature of the resin has to be limited and its best vacuum properties are not realised. This is offset by the stainless steel lining.

Cosmotron type chamber

The general form of this construction is shown in Fig. 2. Two vertical rails provide the stiffness of the assembly and these must be accurately aligned to present the minimum area to the magnetic field. Ledges are bolted to these rails to provide support for the grid bars, which are in turn bolted to the ledges with intermediary insulating pads and bushings to prevent electrical continuity. A synthetic rubber skin is then stretched over the bars and secured at the edges by bolted metal strips. The gap between the grid bars is small and since the rubber is pressed tightly against the grid bars by atmospheric pressure, only a small proportion of the rubber is exposed to the vacuum system. All metal parts are of stainless steel, the bushings are of Kel-F (monochlorotrifluoroethylene) and the skin is of 'Myvaseal'. In considering this form of construction for the Harwell machine it is necessary to use materials with better vacuum properties than the 'Myvaseal'. A model to evaluate this type of chamber has been constructed and is being used to determine suitable vacuum materials.

Epoxy resin-glass fibre chamber

This is a structure as shown in Fig. 3, the whole octant being one chamber section. Top, bottom, sides and flanges are made with cloth woven from glass fibres and impregnated with an epoxy resin chosen for its vacuum properties, mechanical properties and radiation resistance, the components then being bonded together with the primary resin. The pole face windings are secured to the outer skin of the chamber. Circumferential stiffness is given by ribs between the pole face windings and radial stiffness is given by supporting stays. Antistatic properties and enhanced vacuum properties are given by a metallic film on the inner surface. This may be a vacuum deposited film although other methods of application are being investigated.

The chamber extends beyond the poles of the magnet thus forming a duct which permits pumping from below the chamber. A uniform edge in which ports can be inserted as necessary is thus presented round the periphery of the machine for beam extraction.

A 6 ft. section of vacuum chamber of this type is under construction (completion has been delayed by industrial disputes affecting materials delivery) and should be completed by 31st August. This will be full size in cross section and will be subjected to mechanical and vacuum tests which simulate machine operation.

A paper recently circulated to the Project Committee "Appraisal of the proposed Epoxy Resin Glass Fibre Vacuum Vessel for the 7 GeV Proton Synchrotron" gives more detail, and from this it is seen that a major cause of concern is the behaviour of epoxy resins under irradiation. Tests have been carried out on the cyclotron to determine the effects of proton irradiation and to correlate these with measurements made after neutron irradiation in reactors.

Irradiation of the vacuum chamber can be deleterious in two respects, loss of mechanical strength and degradation of vacuum properties. The effect on the vacuum properties is a function of the amount of radiation the inner skin of the chamber receives (neglecting the masking effect of the metallic film). When high energy particles (greater than 150 MeV) traverse the chamber

they impart much less energy to the inner skin than the lower energy particles such as scattered protons at injection (15 MeV). Allowing for the angle of incidence of the lower energy particles, they would give up all their energy in the first few thousandths of an inch of the chamber wall. They can however be skimmed off by suitable aperture plates in the straight sections, and the vacuum surface of the chamber thus protected.

The effect of radiation on the mechanical properties is being determined by measurement of the cross breaking strength.

The temperature of the samples during proton irradiation was estimated to be about 130°C. Whilst this temperature is not excessive and will not damage the laminate (indeed post-cures are done at temperatures up to 200°C) the effect of radiation at this temperature will be more pronounced since each particle within the sample has more (thermal) energy and thus requires less energy from the incident protons to achieve a particular energy level.

The effects of proton and neutron irradiation are compared in Figs. 5 and 6.

In figure 5 the cross breaking strength of H.P.A. - fibreglass laminate is shown against the corresponding proton irradiation dose together with the unirradiated control samples. In general there is a variation of cross breaking strength from 70% to 130% after irradiation. However some low values are recorded (between 20 and 44%) but all of these samples delaminated during the breaking test.

The line in Fig. 5 shows the variation of flexural strength with neutron irradiation.

The dose received under proton irradiation is close to the practical maximum dose that can be obtained from the cyclotron under present operating conditions and represents 26 hours continuous operation.

In figure 6 similar plots are made of

- (1) Flexural strength of H.P.A. cast resin against proton irradiation.
- (2) Flexural strength of M.N.A. cast resin against proton irradiation.
- (3) The lines show the variation of strength of the cast resins with neutron irradiation.

The first observation is the high strength retention of M.N.A. resin both with proton and neutron irradiation. By comparison H.P.A. is considerably poorer. As a result, M.N.A. laminates are being prepared for neutron irradiation similar to that undergone by the H.P.A. laminates.

It will be seen that degradation begins to take place with the H.P.A. resin laminate when a dose of about 2×10^8 rads has been received, but there is a likelihood of improving this condition by the use of different resins. This dose probably corresponds to the full beam output being uniformly absorbed by the chamber (8 hours/day) for 1 year, but work is continuing to obtain an accurate assessment.

Summary of different forms of construction

With the Saclay and Cosmotron forms of construction the pole face windings will need to be attached to the pole tips and the magnet aperture then consists of:-

beam aperture
chamber thickness x 2
pole face windings x 2
pole face fixings x 2
tolerances and clearances.

With the glass fibre construction the pole face windings can be embedded in the chamber and the magnet gap then consists of:-

beam aperture
chamber thickness including pole face windings $\times$ 2
tolerances and clearances.

The dimensions of each type of chamber have been scaled to suit the Harwell machine and are shown graphically in Fig. 4. The influence of the magnet gap (right hand scale) on repetition rate, magnet coil turns and radial aperture is represented by the blue line. Different forms of chamber construction are shown graphically against the left hand scale and the point on the line which corresponds to the space occupied by the chamber represents the machine operation for that chamber.

The Saclay chamber is very 'clean' as a vacuum construction and with the best resins should give a good vacuum performance, although this may be modified by the length of gasket material employed.

The Cosmotron chamber presents a large surface area of steel to the vacuum and better materials for the membrane are required before it is acceptable for the Harwell machine. The gasketry involves intersecting seals, which could be a source of difficulty.

The epoxy resin glass fibre chamber, with a metallised interior, presents a good vacuum surface with conventional designs of gasket which are kept to a minimum. Experiments have shown that with suitable heat treatment very low pressures can be obtained with certain epoxy resins and even if the optimum treatment cannot be given to a 50 ft. vessel the metallising should enable the requisite pressure to be obtained.

The Saclay type is not readily modified for machine experiments beyond the facilities which are already available as windows (approximately 24" $\times$ 3") in each chamber section, although by dismantling an arc it can be re-assembled with certain sections of special shape. The Cosmotron chamber can be readily modified, parts being cut in the side rails as required, some of the strength thus lost being restored by suitable design of the matching attachment. The part of the chamber occupied by the pumping manifold is not easily available for experiments. The epoxy resin glass fibre chamber can be similarly modified for experiments, with the pumping part region being more available since pumping is done from below the chamber.

There is more dependence on the radiation resistance of the resin in the epoxy resin glass fibre chamber than in the other types, as they derive their mechanical strength from a metal structure, and this fact has to be allowed for in the design parameters.

NOTE:

H.P.A. Hexahydrophthalic Anhydride.

M.N.A. Methyl Nadic Anhydride.

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15th July, 1958.

Figure 1.
VACUUM CHAMBER OF
SACLAY PROTON SYNCHROTRON

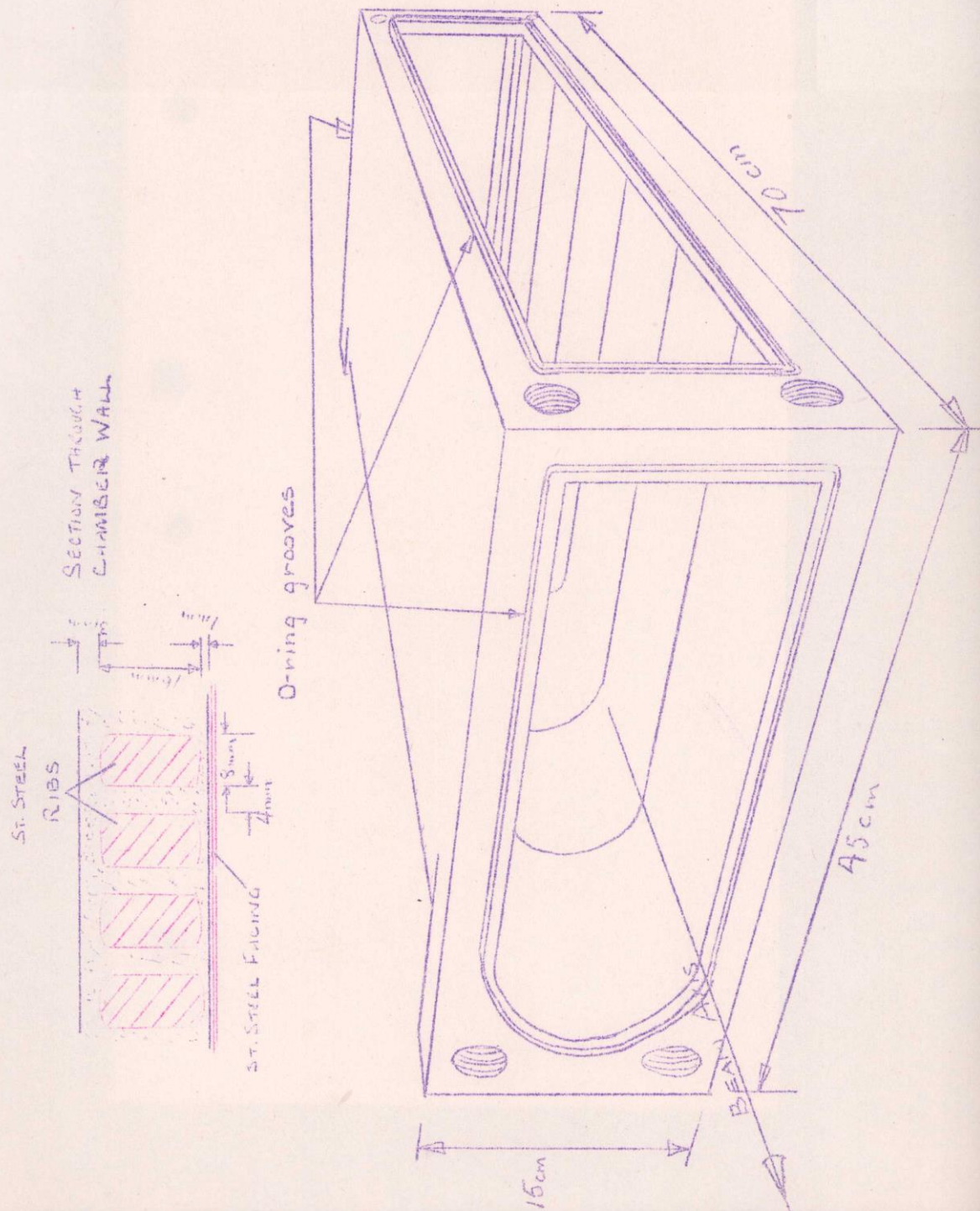


Figure 2

CORNER OF
COSMOTRON VACUUM CHAMBER

ALL FOUR CORNERS OF
BOX ARE IDENTICAL

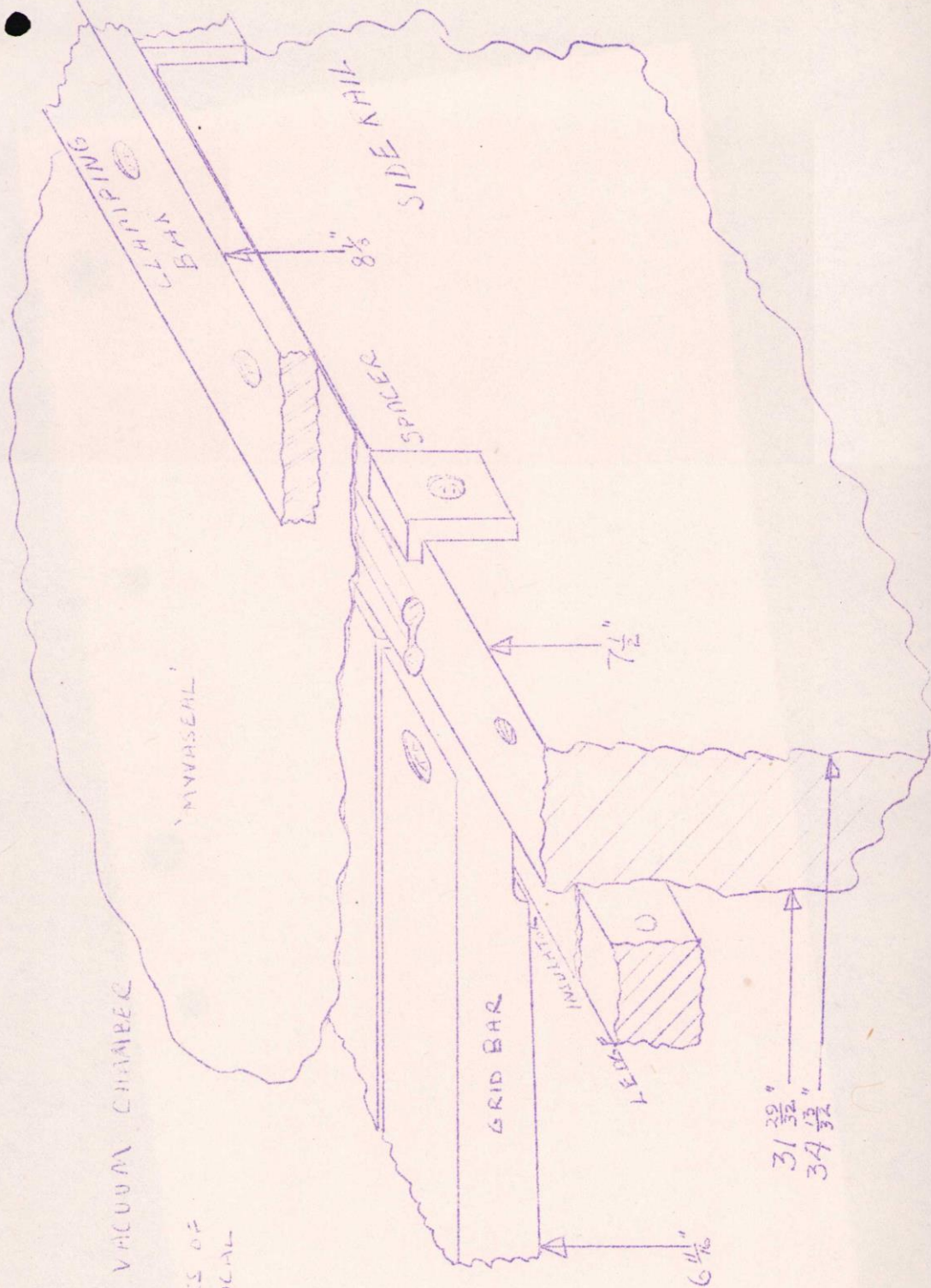


Figure 3

CROSS SECTION OF 50' LONG NEON/GLASS VACUUM CHAMBER

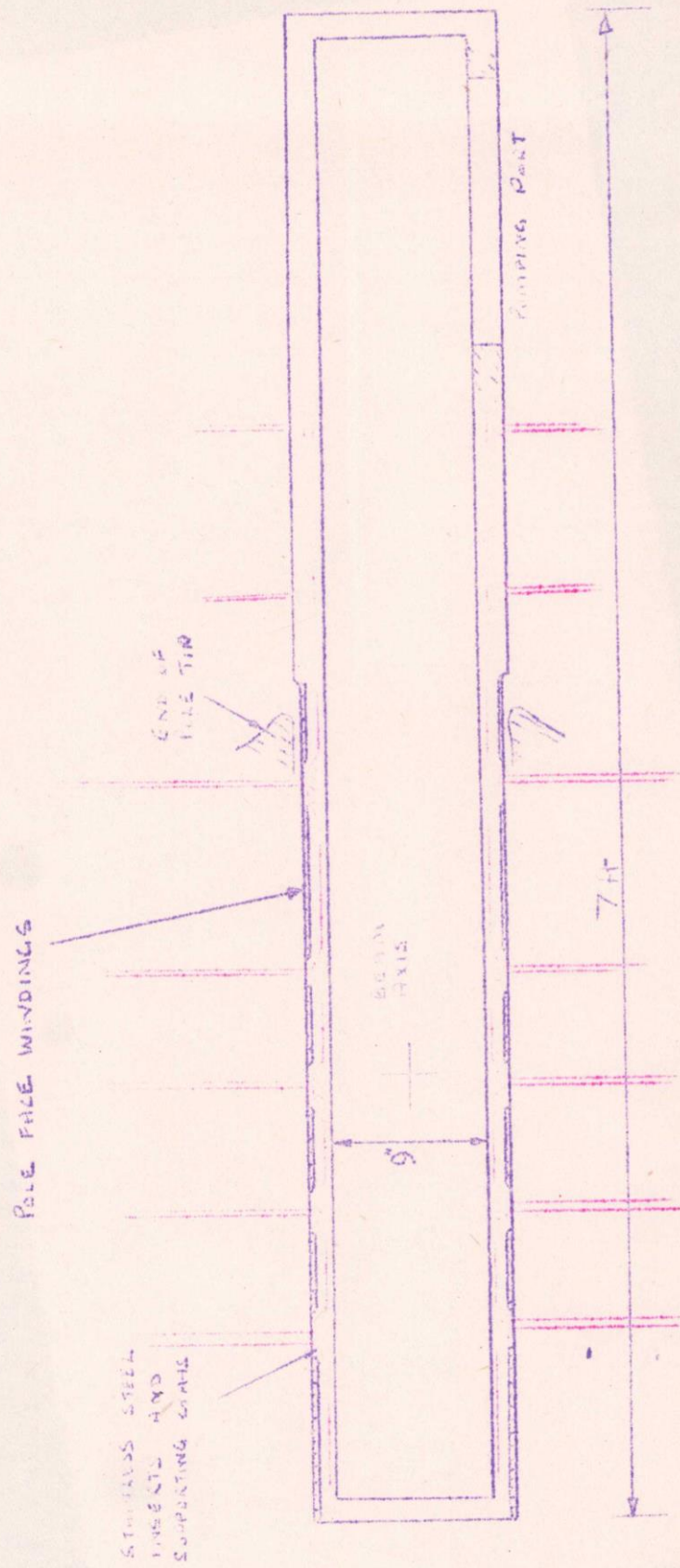


Figure 4.

Effect of Chamber Construction
on Magnet Gap
and Machine Operation.

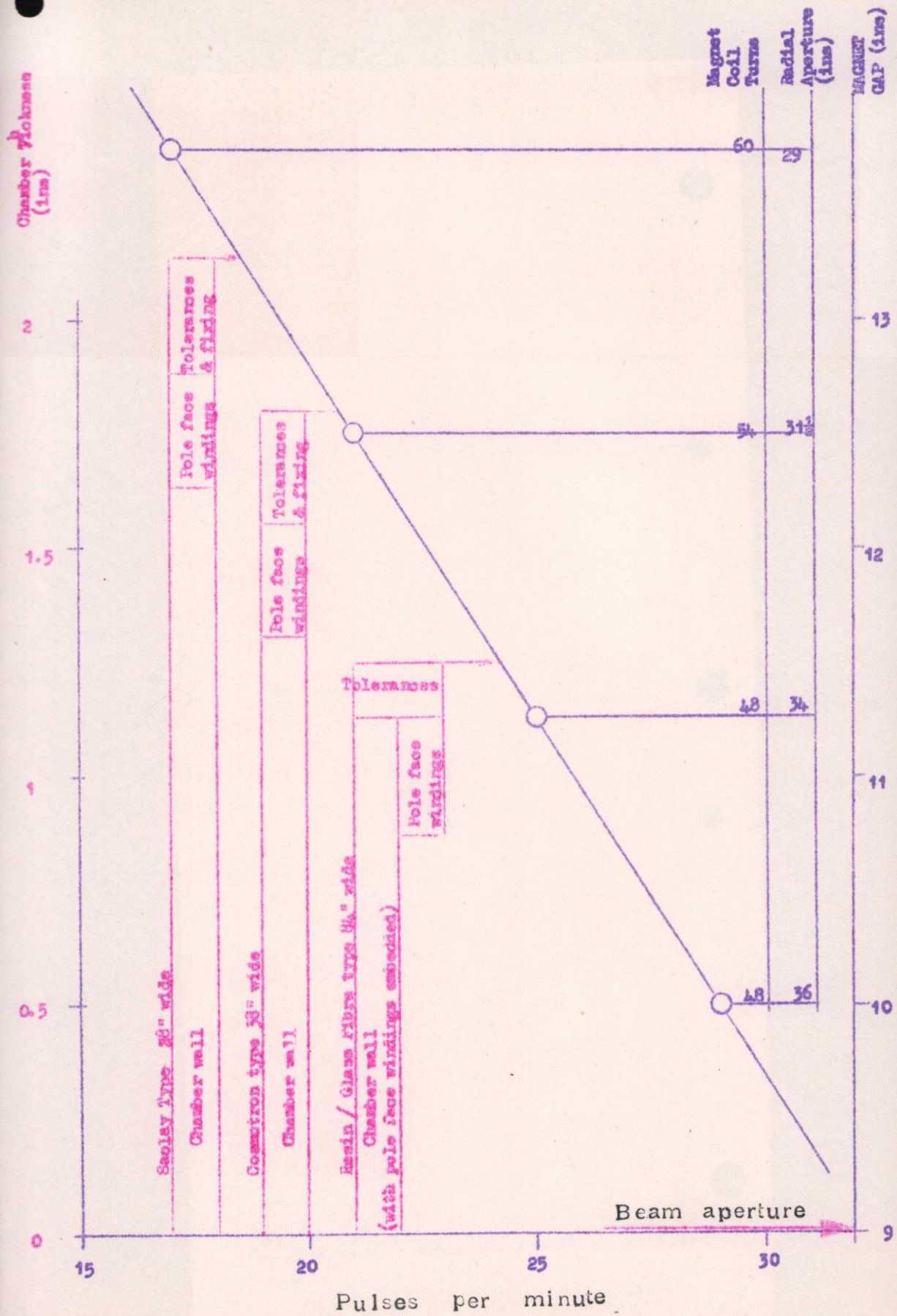


Figure 5 Irradiation of hexahydrophthalic anhydride laminate

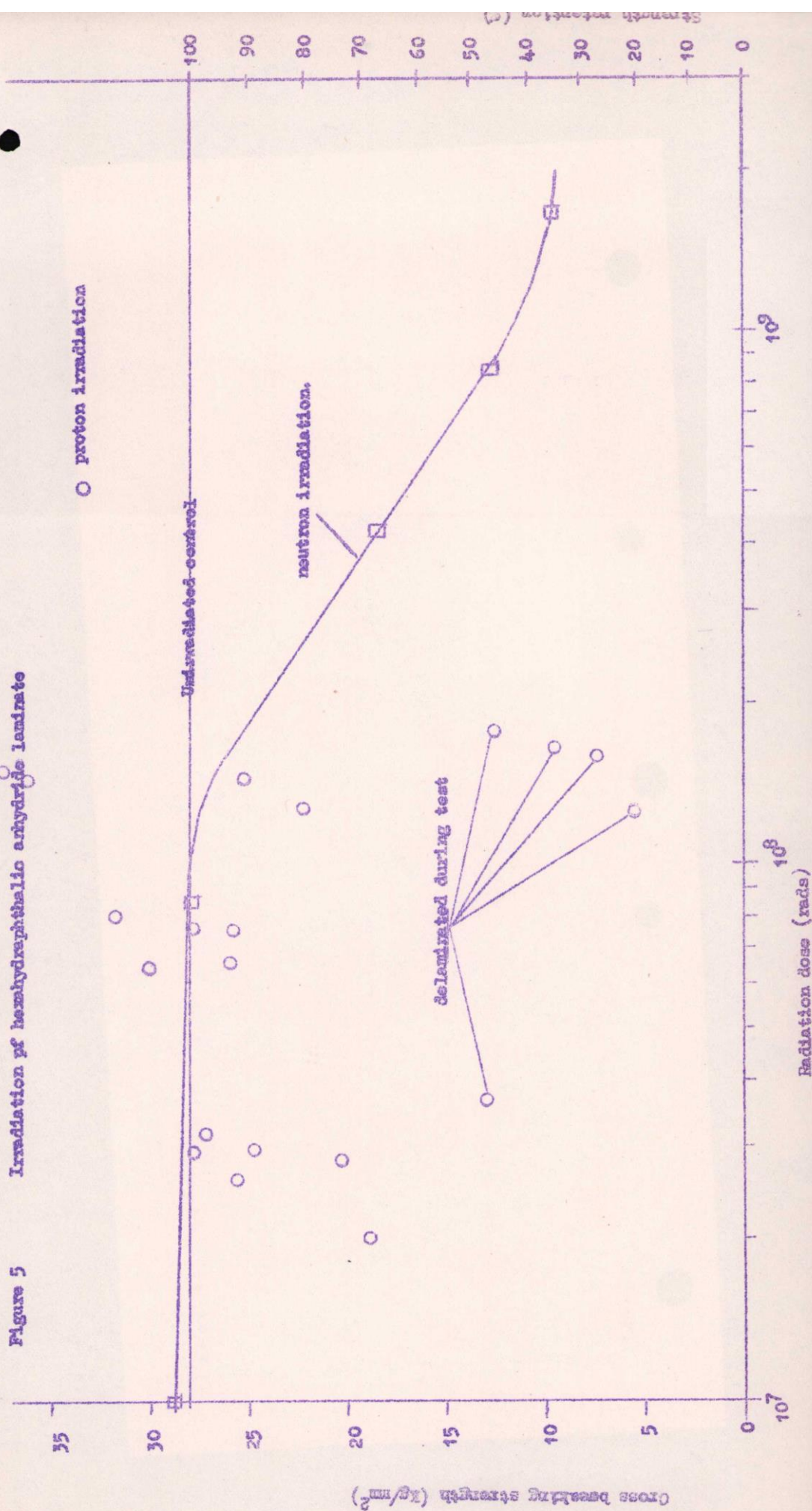


Figure 6 Irradiation of H.P.A. and M.N.A. cast resin

