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Structural analysis of the magnetic poles of the 20 MeV Injector Microtron.

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ABSTRACT: *Raja Ramanna Centre for Advanced Technology (RRCAT) has developed a 20 MeV Microtron used as an electron source for the 2.5 GeV INDUS -2 and 550 MeV INDUS -1particle accelerators. Due to the presence of revolving electrons inside the Microtron cavity, an Ultra High Vacuum (UHV) is required to be created inside it. This paper presents a structural analysis of the Microtron magnet poles as they are subjected to the surrounding atmospheric pressure and the magnetic force of the dipole magnets. The aim of the analysis is to determine whether the deflection produced in the magnetic poles affects the uniformity of the magnetic field inside the Microtron cavity as a slight deflection in the magnetic field can cause the electrons to change their paths and thus they will not come out of the Microtron and die out inside the cavity. The maximum deflection and stress intensity were determined using ANSYS 12.0. The estimated maximum deflection was 0.124 μm which does not have any significant effect on the uniformity of magnetic field. The estimated maximum stress intensity was 4.3 MPa which is less than the yield strength of the material used.*
Keywords- *Finite Element Analysis, INDUS particle accelerator, Microtron, RF Cavity, Simulation in Ansys.*

I. INTRODUCTION

The Microtron is a cyclic particle accelerator machine. The Microtron discussed in this paper is located at Raja Ramanna Centre for Advanced Technology (RRCAT) and is used as a source for delivering 20 MeV electron beam for the INDUS synchrotron light source facility of RRCAT as shown in Figure 1.

Figure 1: The 20 MeV Injector Microtron at RRCAT.

In this injector Microtron, a Lanthanum hexaboride (LaB_6) cathode is used as an electron source. The thermionically emitted electrons are accelerated in a cylindrical resonator called Radio Frequency (RF) Cavity (type-II). RF power is fed into the cavity by exciting the E010 oscillating mode at 2856 MHz (wavelength~10 cm) and as a result the electrons gain energy and accelerate inside the RF cavity before they enter into the first orbit. The beam comes out of the RF cavity travels in a circular orbit inside the vacuum vessel due to its interaction with the uniform dipole magnetic field acting perpendicular to the plane of the trajectory orbits. As the beam re-enters into the RF cavity, it is again fed with the RF energy. As a result the beam energy is ramped up and enters into the next higher orbit [1] [2].

Thus, it is possible for the electron beam to accelerate with different energy gain per orbit and it reaches to the higher circular trajectory orbits of increasing diameter having common tangent point located in the cavity as shown in Figure 2. The electron beam is extracted from the 22nd orbit where it reaches to energy of 20 MeV.

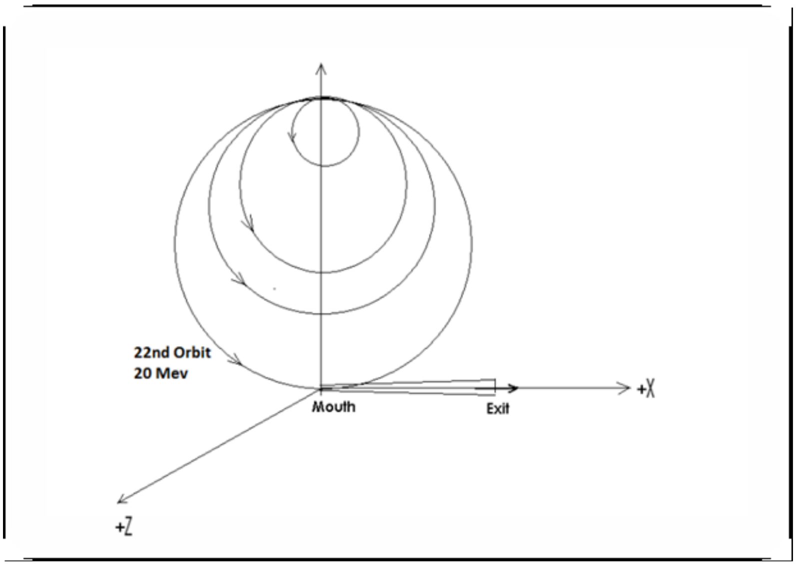

Figure 2. The Schematic Representation of the Microtron orbit.

The vacuum vessel of the Microtron is a cylindrical shell made of ASME SS316L austenitic stainless steel [3]. The vacuum shell is enclosed by the magnet pole faces of a dipole magnet. The magnet poles and yoke are made of low carbon steel, IS: 2062. A pair of ultra-high vacuum (UHV) compatible Viton seals is used at the interfaces to obtain UHV in the vacuum chamber. The pole faces are simply supported on the vacuum shell which is bolted on the circular yoke at its periphery using multiple equi-spaced bolts as shown in Figure 1.

One of the magnet pole (fixed magnet pole) is rigidly supported on the support structure and is therefore structurally constrained. While the vacuum chamber is evacuated for UHV, the other magnet pole (moving magnet pole) is subjected to a differential pressure of one atmosphere and the magnetic force of attraction of the dipole magnet and is therefore expected to get deflected [1] [2]. This may perturb the magnetic field in the vacuum chamber. Therefore, the deflection of the magnetic pole is required to be estimated.

II. STRUCTURAL ANALYSIS

The aim is to estimate the deflection of the magnet pole under one atmospheric pressure differential and the magnetic force of attraction of the dipole magnet using finite element analysis (FEA) in structural domain [4]. ANSYS 12.0 software is used for this purpose. This analysis used the Tresca's Criterion of yielding or the Maximum Shear Stress Theory [5].

2.1 Modelling:

A 3-D modelling of the structure was done. The model consists of a sector of the actual circular plate. The thickness of the plate is 52mm and its radius is 700mm. An electromagnet is attached to the plate. Its radius is 514mm and has a thickness of 56mm. The sector angle is 20˚, i.e., only 1/18th of the actual model is being analyzed due to symmetry present in the model.

The material used is ASME Stainless Steel SS316L and its properties are listed in Table 1. Solid-45 element was used to model the structure and obtain the deflections and stress intensities. The model was simply supported along the line where yolk is in contact with it.

Table 1. Properties of ASME Stainless Steel SS316L.

Property	Value
Young's Modulus	2.1×10^5 MPa
Poisson's Ratio	0.3
Yield Strength	170 MPa
Ultimate Tensile Strength	485 MPa

A pressure of 0.1013 MPa due to the atmosphere and a pressure of 0.016 MPa due to the magnetic force of the dipole magnet was applied on the other face.

2.2 Calculation of Magnetic Pressure:

In order to calculate the pressure, we use the Equation 1.

$$P = \frac{B^2}{2\mu_o} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where
B: Magnetic field applied.
P: Pressure.
μ_o: Permeability of free space.

The magnetic field produced by the dipole magnet is 0.2 Tesla, therefore,

$$P = \left(\frac{0.2 \times 0.2}{2 \times 4\ \pi\ \times 10^{-7}}\right)$$

$$P = 0.0159\ MPa \approx 0.016\ MPa$$

2.3 Results:

The deflection contour is shown in the Figure 3.The maximum deflection is estimated to be 0.124µm. The stress intensity contour due to the applied forces is shown in the Figure 4. The maximum stress intensity is estimated to be 4.3 MPa which is less than the yield strength of the material.

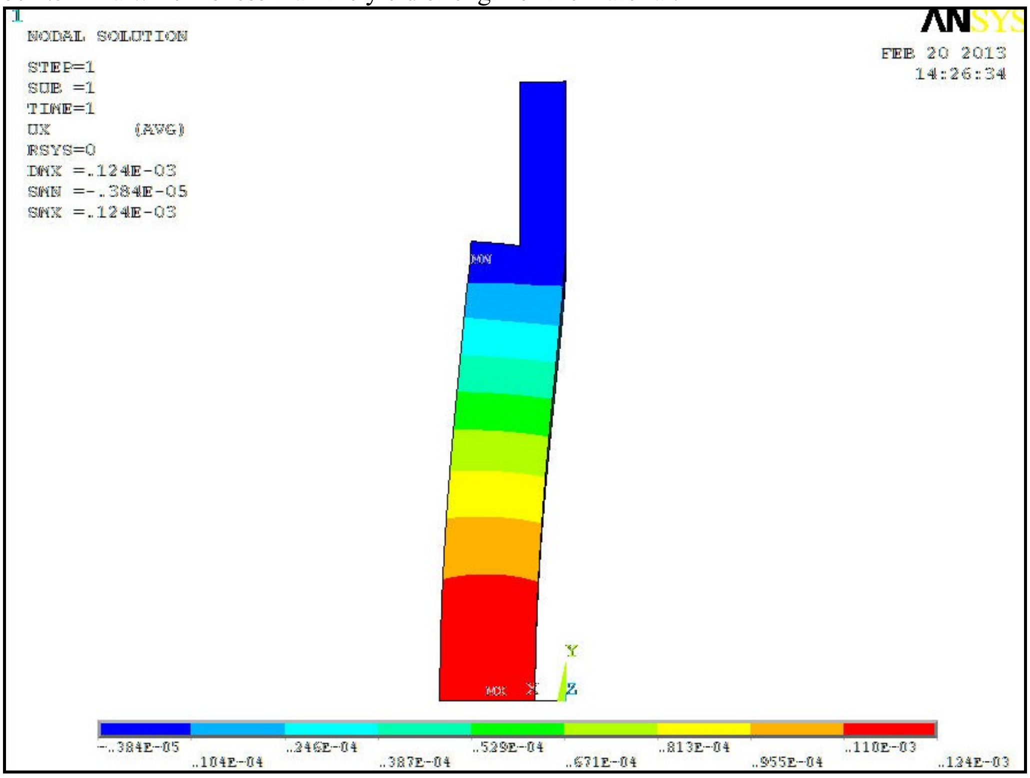

Figure 3. Displacement Contour of the Microtron Magnet Poles.

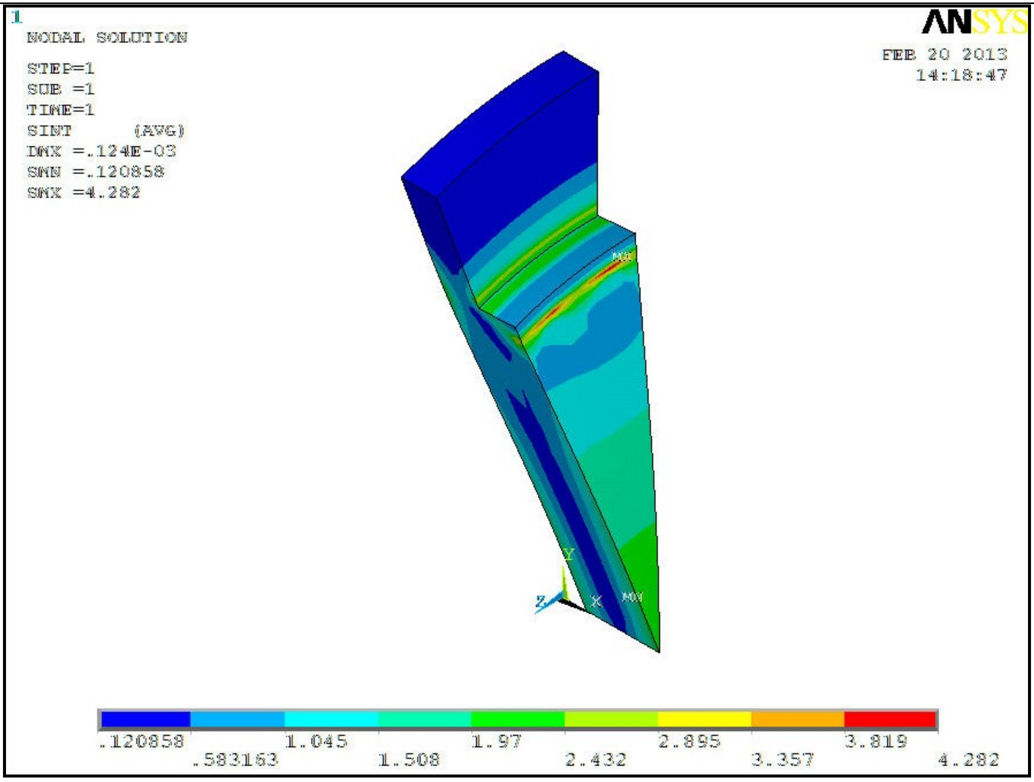

Figure 4. Stress Intensity Contour of the Microtron Magnet Poles.

III. CONCLUSION

The design of the Microtron plates is very stiff as a result of which the observed maximum deflection and stress intensity was very small. The distortion in the magnetic field is negligible and thus the design of the Microtron is satisfactory.

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