STRETCHFORMING VACUUM CHAMBERS FOR THE PEP-II B-FACTORY HIGH ENERGY STORAGE RING[*]

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Dipole vacuum chambers for the PEP-II HER, fabricated from copper extrusions, must follow the arc of the electron beam in order to minimize impedance losses. The 165 m bend radius requires that the chambers have a sagitta of 25 mm over each 5.84 m length. Stretchforming provides a relatively smooth continuous bend radius and results in low overall residual stresses. Structural analyses of the chamber during the forming process are discussed. These analyses are used to estimate the residual stresses in the stretchformed chambers. The impact of residual stresses on actual chamber operation are discussed. The stretchforming process and apparatus utilized during prototype testing is described. Permanent deflections of the chambers during prototype manufacture are presented and compared with predictions.

INTRODUCTION

The HER circumference is 2200 m and consists of six straight sections 120 m in length and six arc sections 240 m in length. Each arc contains 33 quadrupole magnets and 32 dipole magnets to form 16 cells per arc. The HER vacuum system design[1] consists of 32 dipole vacuum chambers positioned in the magnet gaps for each arc totaling 192 dipole chambers. The dipole chamber extrusion is about 189 mm x 60 mm x 5 mm thick with a cross-sectional area of 22.6 cm^2 (3.5 in^2). The cooling bar extrusion has a cross-sectional area of 3.7 cm^2 (0.57 in^2).

The beam orbit through the dipole magnet is curved. In order to minimize beam impedance losses, the dipole chamber is formed to this beam orbit and corresponding dipole magnet bend radius of 165 m. To accomplish this, the chambers are stretchformed to a radius of 165 m within a tolerance band of ± 2 mm. This tolerance is based on considerations of maximum allowable synchrotron heating on the chamber wall, beam stay clear requirements, chamber positional requirements and manufacturability.

A limited structural analysis of the stretchforming technique is presented that includes the estimated residual stresses in the dipole vacuum chamber and their impact on chamber performance. The apparatus and process utilized for stretchforming prototype and production chambers is presented along with data from the prototype experience.

WHY STRETCHFORMING?

Stretchforming involves first applying sufficient tension to raise the workpiece to the yield point, and then forming the part over a mandrel to a specified shape. This manufacturing process has been used successfully for many years in the aerospace and automotive industries to fabricate smoothly varying complex shapes [2].

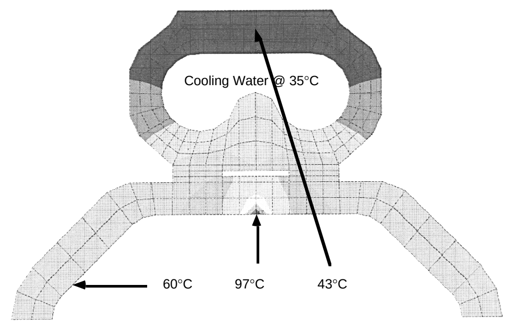

Figure 1. Chamber Temperature Distribution at the Maximum SR Heat Load of 102 W/cm

The high synchrotron radiation (SR) heat load of 102 W/cm produces a peak chamber temperature of 97°C and resulting compressive stresses of roughly 83 Mpa (12 ksi). Residual stresses due to a forming technique would be compressive and therefore add to the peak stress in the chamber during operation. A chamber curved by bending only to 165 m would contain roughly 69 Mpa (10 ksi) of residual compressive stress.

Stretchforming is the technique chosen because it minimizes residual bending stresses in the chamber. Bringing the entire cross section of the chamber to yield while bending imparts a uniform stress across the chamber. When the axial force is released, there is little residual stress (< 1000 psi) and minimal springback. The technique also provides the smoothest bend of all options considered.

Deformation using a pin press and through conventional pipe bending were tried. Using a pin press resulted in a series of small kinks which may enhance the SR heat flux. More kinks would be required to reduce the amount of enhancement. However, the process proved slow and inefficient. Conventional pipe bending was also tried but failed because the local high contact pressures

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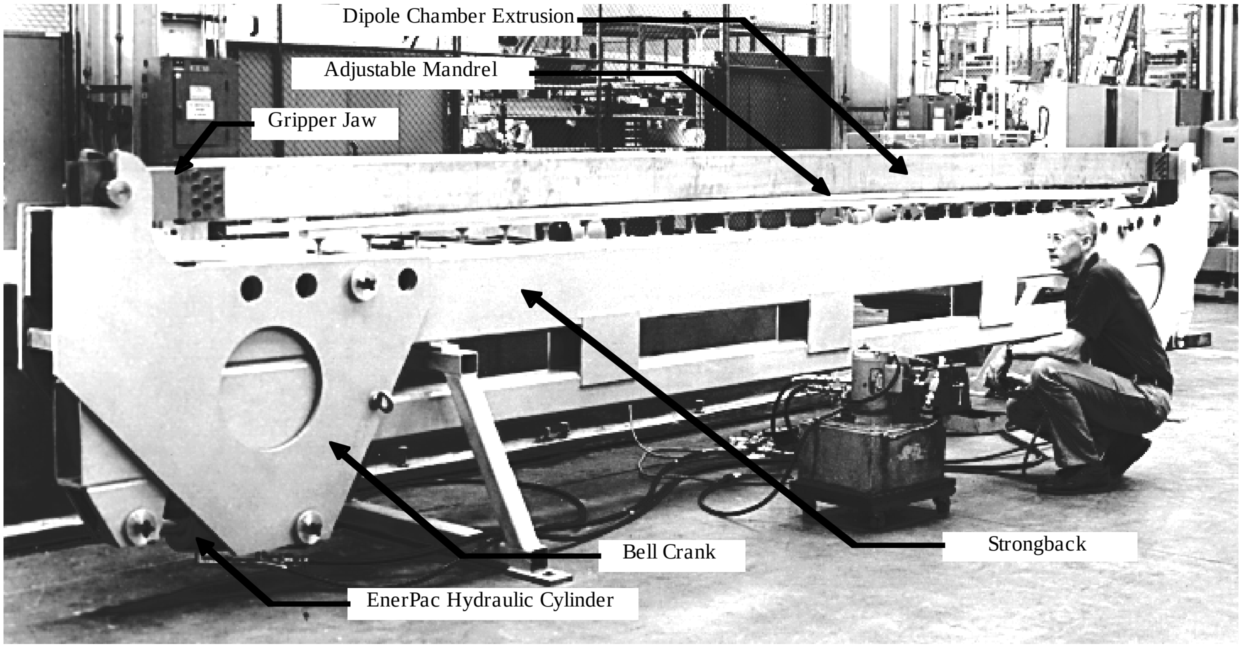

Figure 2. The stretchforming machine built by SLAC has been used successfully for prototype development.

resulted in local yielding of the material and subsequent unacceptable chamber distortion.

APPARATUS AND PROCESS

The Stretchformer built by SLAC for the PEP-II project consists of a strongback, an adjustable mandrel, a pair of bell cranks, two hydraulic cylinders and a pair of gripper jaws. The strongback is approximately twenty times stiffer than the extrusion to limit machine deflection during the process. The adjustable mandrel can be set to a radius as tight as 63.5 meters to compensate for springback. The bell cranks provide roughly a 3:1 mechanical advantage for the pair of EnerPac hydraulic cylinders. The two 50 Ton cylinders each provide a maximum tensile force of 667.4 kN (150 kips). The gripper jaws have knurled surfaces bolted tightly together to squeeze the ends of the chamber ensuring positive traction during tensioning.

While some conventional machines separate the extension and bending processes by utilizing different machine axes to first stretch then form the part over a mandrel, the SLAC machine combines both operations using the lever action of the bell cranks and the adjustable mandrel. There are four settings which allow variable amounts of tension versus the angle of the bell crank rotation. The amount of bending is controlled by adjusting the height and radius of the mandrel.

The machine settings have been adjusted empirically during the prototype phase to produce a repeatable part. The entire process begins by taking an inspected extrusion, cutting it to length and drilling the gripper jaw hole pattern in each end. The extrusion and cooling bar are cleaned for UHV and then the parts are Electron Beam (EB) welded.

The gripper jaws are installed on the chamber assembly. The mandrel radius is set to the prescribed bend radius, which is ~25 m (1000”) smaller than the final part radius to compensate for machine deflection and extrusion springback.

Approximately 1.09 MN (245 kip) of tension is gradually applied to the chamber. Once this tension is applied, the extrusion contacts the mandrel and the bending moment applied through this contact imparts a stress greater than the material yield strength of 276 MPa (40 ksi). The chamber is pulled to intimate contact along the mandrel to form it to its pre-springback shape. The force is then released and the part springs back to its final deformed shape.

The formed chamber radius is measured and compared with the desired value. If the radius is too large, the mandrel is re-adjusted and the process is repeated until the radius of the chamber is within the specified limits.

PROTOTYPE EXPERIENCE

Three prototype chambers were stretchformed in successive trials in an effort to achieve the desired bend radius of 165 m with a corresponding sagitta of 25 mm. Since the EB welder was not available, the extrusions were stretchformed without the cooling bar attached.

The mandrel radius was determined through successive trials and finally set at 127 m (5000”). The actual bend radii of the three extrusions is not exactly 165 m all along

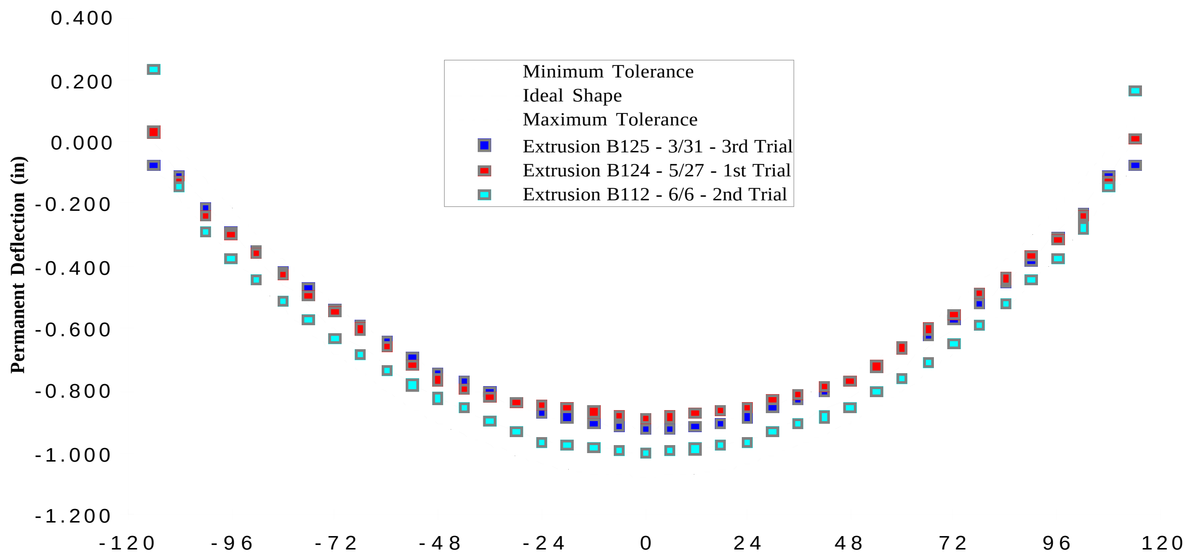

Figure 3. Permanently deflected shape of three stretchformed prototype extrusions versus inches from extrusion centerline.

the length. The center portion of the chambers are near the ideal radius, the very ends show a smaller radius and the portions between show a larger radius. This variation does not impact chamber performance significantly.

The process plot shows the relationship between applied pressure and resulting strain is analagous to the stress-strain curve for half-hard copper. The maximum cylinder pressure of 4200 psi (28.9 Mpa) equates to a total force on the cross section of 1.07 MN (240 ksi). The measured and calculated strains agree well. The peak cylinder pressure should be 15-20% higher for a chamber with cooling bar attached.

Many lessons were learned as the three chambers were successfully formed in six trials. Factors that affected each trial were jaw slippage, mandrel shape and repetitive process control. Prior to production the jaws will be modified to include the ability to grip the welded cooling bar. A more efficient method for mandrel adjustment will be added to the system. During production, the process parameters will be rigorously monitored to ensure stretchformed chambers that meet design requirements.

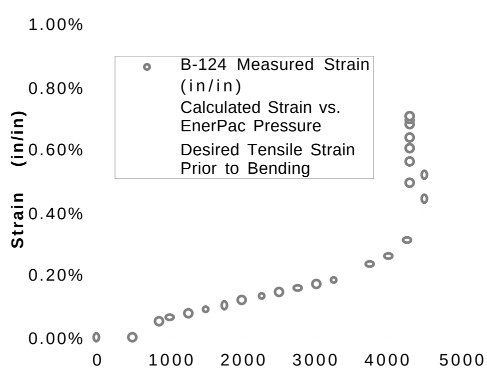

Figure 4. Process Plot of Strain in Extrusion vs. EnerPac Cylinder Pressure (psi)

CONCLUSIONS

The stretchforming process produces chambers having a relatively smooth continuous bend radius. The prototype experience with stretchforming has been favorable. The stretchforming apparatus will be modified and utilized to produce the 192 HER dipole vacuum chambers.

ACKNOWLEDGEMENTS

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REFERENCES

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