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Low Distortion Welded Joints for NCSX

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Low Distortion Welded Joints for NCSX*

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***Abstract*—The National Compact Stellarator Experiment (NCSX) required precise positioning of the field coils in order to generate suitable magnetic fields. A set of three modular field coils were assembled to form the Half Field-Period Assemblies (HPA). Final assembly of the HPA required a welded shear plate to join individual coils in the nose region due to the geometric limitations and the strength constraints. Each of the modular coil windings was wound on a stainless steel alloy (Stellalloy) casting. The alloy is similar to austenitic 316 stainless steel. During the initial welding trials, severe distortion, of approximately 1/16", was observed in the joint caused by weld shrinkage. The distortion was well outside the requirements of the design.**

Solutions were attempted through several simultaneous routes. The joint design was modified, welding processes were changed, and specialized heat reduction techniques were utilized. A final joint design was selected to reduce the amount of weld material needed to be deposited, while maintaining adequate penetration and strength. Several welding processes and techniques using Miller Axcess equipment were utilized that significantly reduced heat input. The final assembly of the HPA was successful. Distortion was controlled to 0.012", well within the acceptable design tolerance range of 0.020" over a 3.5 foot length.

Keywords- welding; welding processes; National Compact Stellarator Experiment; NCSX;shear plate design

I. INTRODUCTION

A proprietary alloy was developed for use in NCSX modular coils called Stellaloy. This is a stainless steel alloy with low magnetic permeability in the cast and as welded condition. Stellaloy exhibits good strength characteristics while at cryogenic temperatures with lower conductivity than a standard 316 stainless steel.

Welding was chosen as the joining method for the inner segment connections due to geometric constraints, size limitations, and strength requirements. Before welding could commence on the final assembly there were several factors that had to be controlled and proven. These included magnetic permeability, distortion, and as-welded internal stresses.

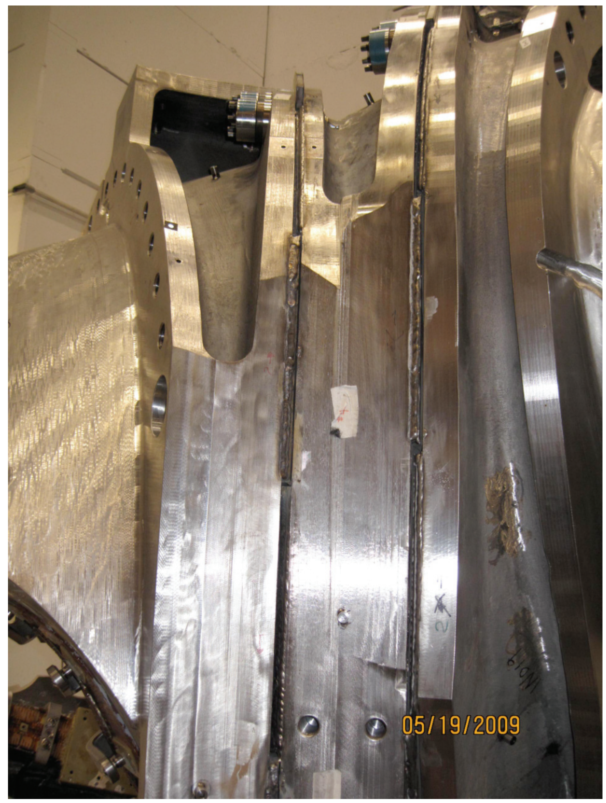

Figure 1. Nose Area Welds

II. JOINT DESIGN

Experiments on the design of the joint were completed to reduce distortion and allow access with the given geometry. The overall goal was to determine a connection that was not only robust, but also reduced spreading force and excessive heat input into the castings.

The original plan involved individual shims located with similar placement to the shims used around the perimeter of the field period at the bolted locations. These shims contained a concave semicircular weld area. The weld was placed in a 2F and 4F position on the outside of the field period. This iteration was not used due to the high heat input, high internal stresses, and unacceptable distortion due to the amount of weld.

The second iteration of the shim design was an outside lap joint. The weld was placed in the 2F position, on the side and the top of the shim. During testing of this design each shim

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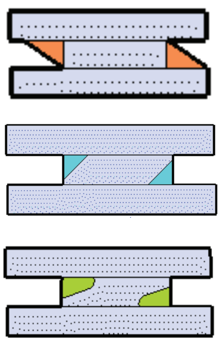
exerted more than one ton of force of separation force between the field periods, which was not acceptable.

The final iteration of the shim design was an internal lap joint. This joint utilizes a smaller shim welded between the two flanges of the coil rather than on the side. This design minimized the separation force to 0.6 tons per shim, over a 40% decrease.

The final shim design led to the use of a shear plate design. This design involved several long plates welded on one side to one coil and the other side to another coil. The inner welds were preformed in the 2F position and the outer final welds were 4F. Lap joints were the sole weld design used for the shear plate welding. Depending on the placement of the plate on the casting, a bevel, j-groove, or fillet weld prep was used. This shear plate design minimized the heat input and therefore distortion for the coil.



a.

b.

c.

Figure 2. *Lap Joint Designs* *a. Fillet* *b. Bevel* *c. J-Grove*

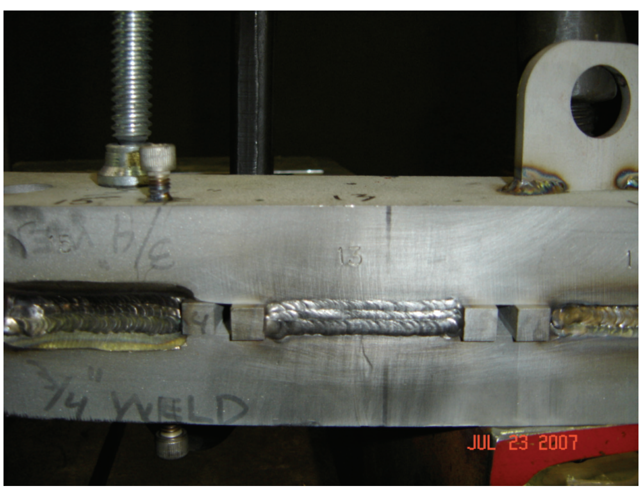


Figure 3. *Original Weld Design*

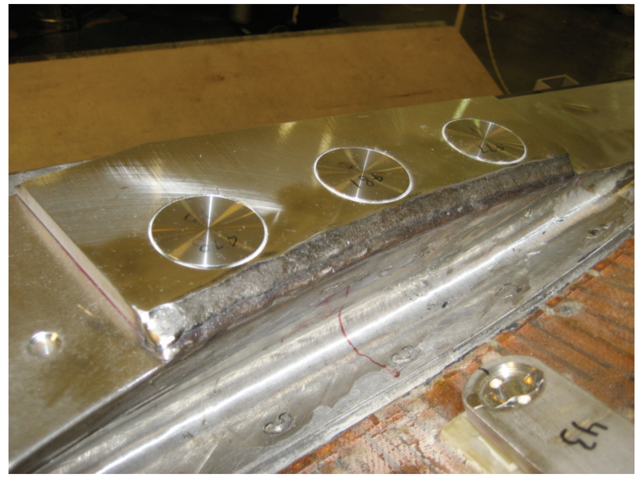


Figure 4. *Final Shear Plate Design*

III. Welding Processes

Three different welding processes were used in trials in an attempt to minimize distortion. These processes include Gas Tungsten Arc Welding, Gas Metal Arc Welding, and Flux Cored Arc Welding.

Gas Tungsten Arc Welding (GTAW) is commonly called TIG welding. This is a manual welding process involving a tungsten electrode and a separate filler material. GTAW has a low deposition rate and high heat input. It is best suited for small intricate work that requires precise clean welds.

Gas Metal Arc Welding (GMAW) is commonly called MIG welding. This is a semi-automatic welding process that uses a solid filler material wire as the electrode. GMAW has a moderate deposition rate and is best suited for work involving thin base materials. When used on thicker sections there is a high chance of lack of fusion in the root of the weld. In order to avoid this discontinuity it is necessary to run higher currents, however, this leads to higher heat inputs. To avoid the lack of fusion without the higher heat input a pulsed GMAW processed was utilized. The Miller Axcess equipment with Regulated Metal Deposition (RMD) was employed to perform this pulsed process. This form of GMAW pulses the voltage and wire feed speed. RMD allows for higher currents and for better fusion with a lower heat input than other wise possible with conventional GMAW.

Flux Cored Arc Welding (FCAW) is similar to GMAW in that it is a semi-automatic welding process using a tubular filler material as the electrode. The tube contains a flux for cleaning and shielding and metallic particles as filler material. Since the filler is in particulate form it requires less heat input to reach the melting point in comparison to GMAW. FCAW is also run at greater wire feed speeds allowing for greater deposition rates over a given period of time.

The use of FCAW reduced the heat input and excessive distortion for the coil. It was also found that these welds had an acceptable level of magnetic permeability for use on this project.

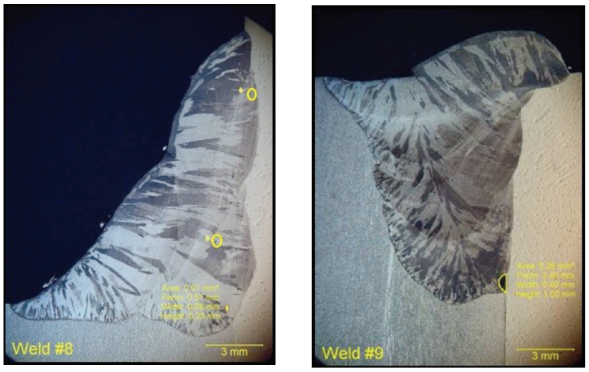


Figure 5. *J-Grove with lack of fusion in root and FCAW fillet weld*

Figure 6. GMAW Weld

Figure 7. RMD Weld

Figure 8. Final FCAW Weld

Heat Input (kJ/in)	Min	Max
GTAW & GMAW	104	127
FCAW	54	67

Figure 9. Heat Inputs

IV. Weld Procedure

An intricate procedure involving weld placement was developed to lessen distortion and evenly distribute the welding heat. The welds were placed in a specific order along the lengths of the shear plates. The direction of travel of each bead was also covered in this procedure to create alternating steps. These methods allowed for even heating of the shear plates and castings. This kept the distortion even over the length of the part.

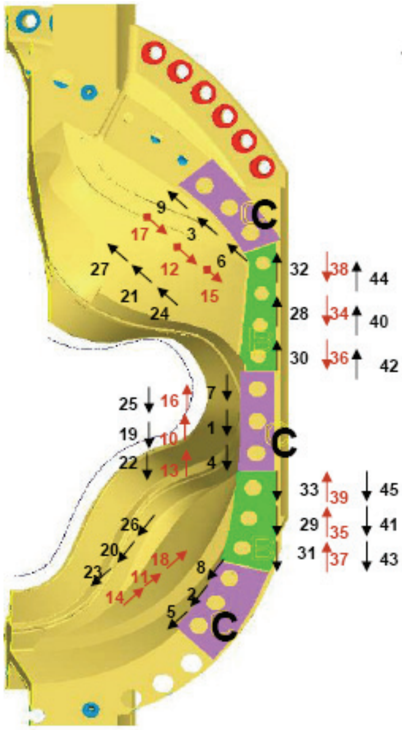


Figure 10. *Welding Order*

V. Stress Reduction

Welding in any form causes a rise in internal stress of the part. These stresses needed to be reduced in the weld zones of the coil castings. The methods chosen to reduce the stress could not affect the machined casting or the epoxy impregnated magnets. Stress relieving through thermal processes could not be preformed because heating or cooling would destroy or crack the coil forms. Full vibratory stress relief concurrent with welding was avoided due to the possible effect on the casting or loosening of the coils. The chosen stress relieving process was peening of the weld and heat affected zone. This process was shown, through testing, to reduce deflections in the welded plates. An air hammer with a blunt tip was used to perform the peening. The process was carried out between weld passes.

During testing, the shear plates were observed to deflect significantly. Original tests had distortions of over 0.200". Tack welds were used as a physical constraint to minimize this distortion. Three to four tacks were made on the opposite side of the plate to be welded. After welding and stress relieving was completed the tacks were removed. Deflection was maintained to approximately 0.0125".

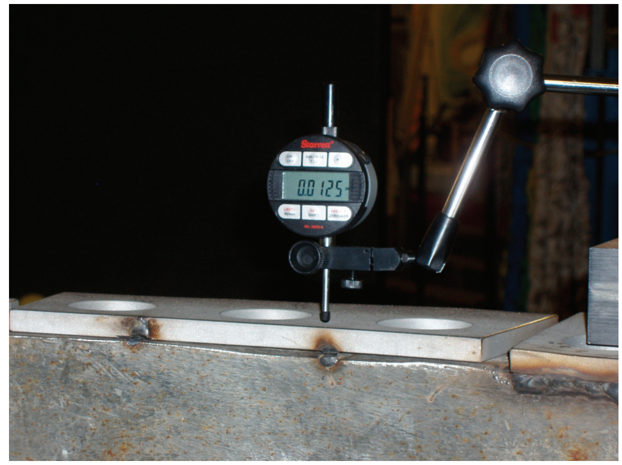


Figure 11. Tack Welds

VI. Conclusion

The final assembly of the HPA was considered successful. Distortion was maintained to well within the acceptable design tolerance allotted for this stage of the assembly process. The largest distortion seen along the magnet track was 0.009".

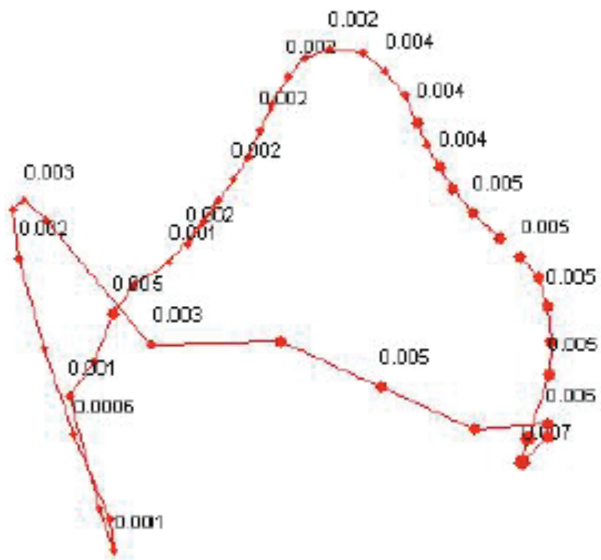


Figure 12. Distortion of magnetics

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