SPEAR3 GRADIENT DIPOLE CORE FABRICATION

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Abstract

Traditional means of core fabrication are to glue the laminations or weld them to form the yoke structure. These means result in good yoke assemblies for shorter (<0.6 meter) magnets. However, because of weld distortions or mechanical strength limitations, welding and/or gluing techniques result in cores with poor mechanical precision or limited mechanical strength for longer cores. The SPEAR3 gradient dipole magnets are up to 1.45 meters long and require distortions of <0.05 mm. Therefore, the SPEAR3 gradient dipole core design incorporated an assembly technique, originally devised for the PEPI Insertion quadrupoles and later adapted for the ALS gradient magnets. This technique involves fabricating a rigid frame for the core, precisely stacking and compressing the laminations using hydraulic jacks and granite surfaces and straight edges, and fixing the laminations in the frame by filling the grooves between the laminations and frame using steel loaded epoxy. Although this technique has been used in the past, it has never been fully described and published. This paper is written to provide a detailed description of the procedure and to present measurement data demonstrating the mechanical precision and stiffness of the resulting product.

CORE CONFIGURATION

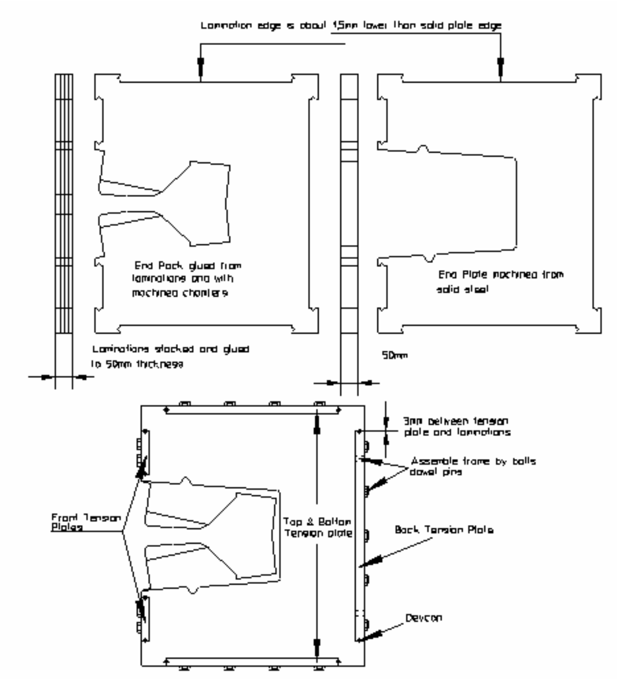

Figure1. SPEAR3 Gradient Dipole Core Configuration

As shown in figure1 above, the laminated dipole core consists of a rigid box frame which is assembled from five tension plates and two solid end plates. The tension plates are bolted and dowel pinned to end plates. After the laminations are stacked and compressed in the frame, steel loaded epoxy is injected into the grooves, permanently fixing the laminations in the frame. The frame is designed to take all the bending and twisting stresses due to the weight of the laminations and the points of support.

CORE STACKING

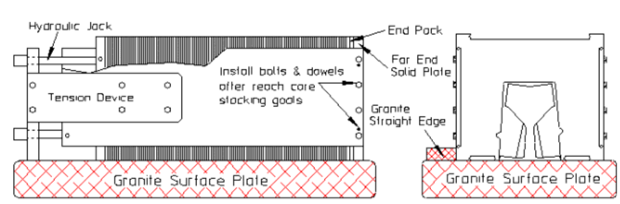

Figure2. Dipole Core Stacking

As shown in the figure 2 above, two side tension plates (top and bottom plates) are assembled to one of the end plates of the core and tension device. The laminations and the second end pack are then stacked inside of this frame assembly and indexed to granite surface and granite straight edge to ensure straightness of the core. The laminations are periodically flipped about their axes in order to maintain mechanical symmetry. Several compression stages are required as the length is built up. During the intermediate compression stages, adjustment of hydraulic jacks' extension is required. The final end pack and solid end plate are then installed and the whole assembly is compressed until the core required length and packing fraction is achieved. Bolts and dowels are finally installed. The final hydraulic pressure is chosen to achieve the following goals: a. the laminations are brought up "metal to metal"; b. the laminations, which are slightly warped, are flattened; c. compression is continued until the packing fraction is no less than 97.5%. Excessive compression will cause laminations to move laterally and cause the final core to exceed the straightness and flatness specification. Figure 3 below shows the actual compression pressure achieved during SPEAR3 dipole 109D-31 core assembly.

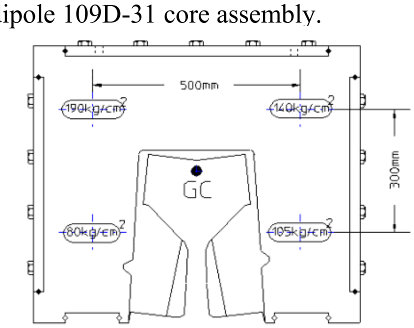

Figure3. Stacking Compression

DEVCON

Devcon-10230 Plastic Steel Liquid (B) was selected for SPEAR3 gradient dipole core injection. The viscosity of this material is very sensitive to the environment temperature. Low room temperature will cause problems when injecting through the long application tube. An ambient temperature between 72 – 75 ^{o}F was required during SPEAR3 gradient dipole production.

For the best deaeration, the Devcon epoxy (both epoxy and hardener) were pre-heated to 90 ^{o}F before mixing in a small temperature controlled oven for a minimum of half hour. This procedure allowed epoxy to out-gas trapped air to prevent voids. One should pay attention to the product number of the hardener. It may different for the same epoxy depending on the size of the epoxy container.

DEVCON INJECTION

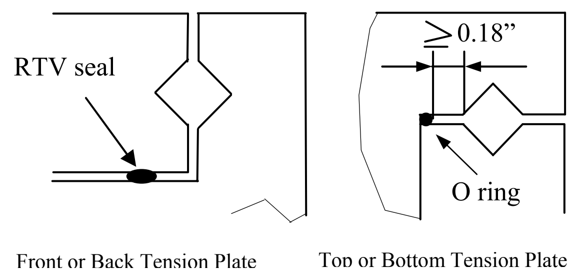

Figure4. Restrain Devcon Flow

Before injecting Devcon, the V-Groove surfaces were roughened, cleaned, dried and freed of residual oils. The gaps between tension plates and laminations were sealed to prevent Devcon epoxy from flowing out of the grooves. Figure 4 shows two sealing methods which were used for tension plates at front and back, top and bottom respectively.

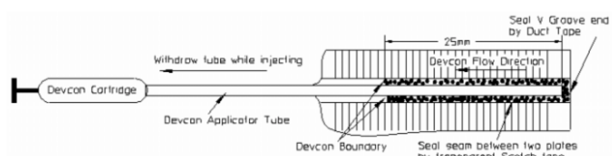

Figure5. Devcon Injection

As shown in figure 5, IHEP workshop used standard Duct tape to seal both ends of V-Grooves, at the end where the injecting tube inserts, an "X" shape was cut to allow the tube to past through the Duct tape. This "X" shape cut acted as a spill barrier when the injecting tube was withdrawn from the end of the V-Groove. IHEP workshop used transparent Scotch tape to seal the outer surface of the seam between the tension plates and the laminations to prevent the Devcon from spilling out. This transparent tape also helped locate the Devcon epoxy tube end position while epoxy was being injected into the V-Groove and the tube was being withdrawn.

Before injecting, an operator gently squeezes the handle of the injection gun to fill the applicator tube with Devcon epoxy until the Devcon epoxy starts to come up through the end of the tube. The tube is then immediately inserted into the far end of V-Groove. The pressure used for dipole core injection was approximately 45 psi, resulting in injecting period (about 5 min. for one groove). Higher pressure would break Duct or Scotch tape seal. Two technicians were needed during this operation. One technician operated the gun while the second technician observed the flow of the Devcon through the transparent Scotch tape and guided the applicator tube end position. Devcon epoxy boundary was always kept 25mm ahead of applicator tube front end; this guaranteed no air was entrained in the groove during the injecting procedure. Each gradient dipole full length V-Groove Devcon seam was completed as one continuous pass from start to finish without stopping. As the applicator tube was withdrawn at the end of the core, the end of the seam was sealed with an additional piece of Duct tape to contain the Devcon epoxy in the V-Groove until it cured. Leakage, such as leakage from Scotch tape, Duct tape, RTV or O ring seal was not allowed, to prevent voids in the filler. Voids were undesirable since they compromised the bond between the laminations and the tension plate.

MECHANICAL QUALITY

Figures 6 and 7 shows the mechanical tolerance requirements of SPEAR3 gradient dipole core both for 145D and 109D. Charts 1 and 2 are measurement results of those requirements. One can see that all measurement results stayed within the tolerance zone.

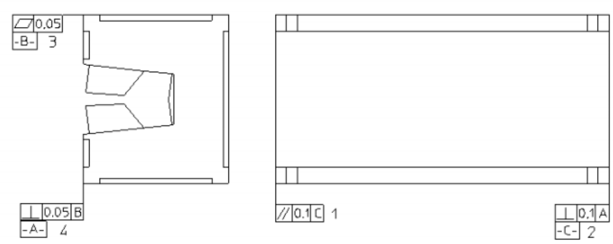

Figure6. Dipole Core Tolerance Requirement

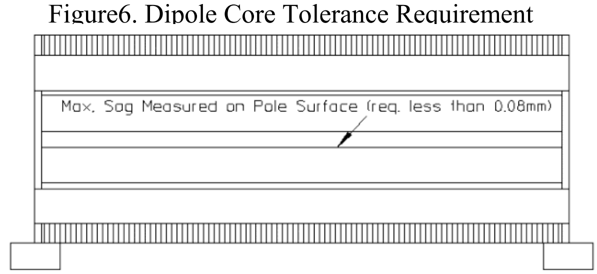

Figure7. Dipole Core Max. Sag Measurement

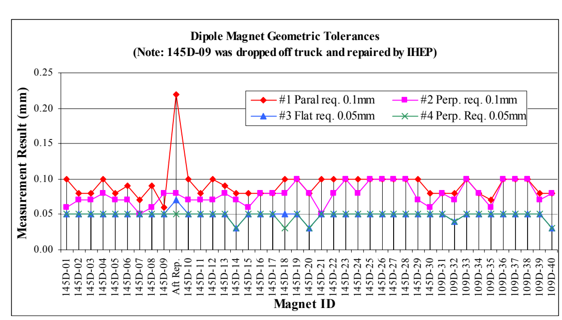

Chart1. Dipole Core Squareness Measurement Result

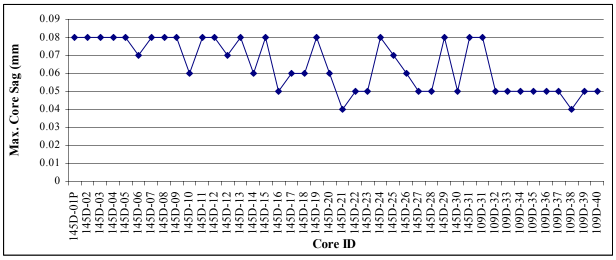

Chart2. Dipole Core Max. Sag Measurement Result

CONCLUSION

Considering the length and size of SPEAR3 gradient dipole, the achievement of the mechanical tolerances of 40ea SPEAR3 gradient dipoles is very impressive. Also, from the practical and cost point of view, Devcon application is easier to perform and results in straighter cores than the traditional welding methods. As long as the core squareness has been reached by the end of the stacking, it will not deform during epoxy cure. The traditional welding process would require highly skilled welders and careful weld sequencing to avoid thermal distortions. Even if low distortion welding sequences are developed, they can be difficult to reproduce with different welders. The technique of Devcon application is relatively easy to learn by inexperienced technicians. What he/her needs to do is just to strictly follow the written specifications step by step; a consistent result will be achieved each time.

One dipole 145D-09 dropped out the truck accidentally during in site transfer at SLAC, all six coils were damaged. This accident gave us a unique opportunity to test the stiffness of Devcon bonded core. 145D-09 was sent back to IHEP for repairs. IHEP inspector re-measured the core when receiving the damaged 145D-09. From chart 1 one can see that the perpendicularities (tolerance #2 and #4 in figure6) stayed the same as it was, the flatness of surface B (tolerance #3 in figure6) slightly increased about 0.025mm, the parallelism (tolerance #1 in figure6) jumped about 0.2mm. These measurement results showed that the core squareness was well preserved under severe impact, and demonstrated that the bonding between laminations and tension plates were very strong. IHEP installed new coils to dipole 145D-09 and used the old core. Chart3 showed the magnetic field uniformity measurement of 145D-09 before and after repairs. One can see that the magnetic field quality after repairs were identical to the original measurements.

As summarized above, we believe that a steel loaded epoxy – Devcon application is a mature, economical and easily learned procedure for longer magnet core fabrication. The mechanical precision and structural rigidity are good and robust.

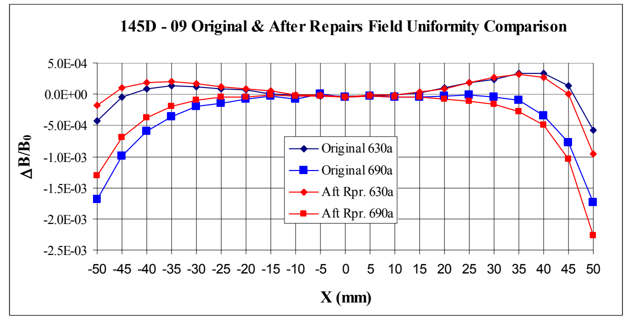

Chart3. Dipole 145D-09 Magnetic Field Quality

REFERENCES

[1] SSRL Engineering Note M337 "Gradient Dipole Magnet Core Assembly Devcon Epoxy Application Procedure"

[2] SSRL Engineering Note M308 "Gradient Dipole Magnet Core Assembly Procedure"

[3] SSRL Engineering Note M409 "Resolution of the Problems Occurred in SPEAR3 Magnet Production"

[4] SSRL Engineering Note M354 "Mechanical Quality of SPEAR3 Magnets Built at IHPE, China"