RESOLUTIONS OF PROBLEMS THAT OCCURRED IN SPEAR3 MAGNET PRODUCTION

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Abstract

Some problems occurred during the SPEAR3 magnet production at IHEP, China. It was very hard to find resolution from existing knowledge of those problems. It was possible that similar problems might have happen in building accelerator magnet in other institutes before, but they were not addressed in public papers. These problems were discussed and solved by engineers from both SLAC and IHEP after conducting certain experiments. Traditionally, the magnet design and measurement data have been always well documented and addressed in papers, but the production experiences have not been recorded adequately. It is the goal of this paper to record the problems and their resolutions during SPEAR3 magnet production at IHEP China, which will certainly benefit future magnet projects.

WATER FITTING BLOCK AND BRAZE ROD MATERIAL

The original material that SLAC selected for SPEAR3 magnet water fitting block was stainless steel because of the strength it provided to internal pipe threads. During the prototype fabrication, IHEP had difficulty torch brazing the stainless steel water fitting to a coil lead that was made of copper. IHEP workshop tried coating a thin copper film on the stainless steel block to ease the brazing. IHEP selected HL303 (Ag 45%, Cu 30%, Zn 25%) made in China to braze the stainless steel block to copper bus on the prototype.

After SLAC received dipole prototype, static pressure tests up to 400 psi were done to verify the braze connections. A small water leak was noticed at 250 psi which became larger at 300 psi where the tests were stopped. Because of this brazing failure, SLAC did solder research and found that the electrochemical galvanic action between coexisting phases was responsible for corrosion of filler metal, which was the source of the interface corrosion when brazing stainless steels [1]. This research led to a silver solder called Safety Silv 50N Brazing Filler metal for stainless steel to copper brazing that contained a small percentage of nickel (1%-2%), which completely eliminated any possibility of interface corrosion. But the disadvantage of using this solder is that the technique must be "perfect" to make proper SST/Cu welds. If the temperature was too hot or too cold then the flux would prevent a good joint which would show up as a leak several days or months later. Past experience at SLAC has shown failures in stainless steel to copper braze connections. This shortcoming resulted in the SST/Cu connection being replaced by Cu/Cu one - OFHC fitting block brazed to copper coil lead. The copper to copper weld was an easier procedure to accomplish and most importantly easier to repair in the field. BCuP-5, which contains Ag15%, Cu80%, P5% without use of flux was selected for the braze operation. The size of water fitting block was increased to cope with the material change.

BUSSING CONNECTION

Connection QA

Good connections between buss and coil lead lugs are vital to prevent overheating and degradation of the contacting surfaces. To verify this connection SLAC suggested using pressure film to test the contact area between the buss and the flag. The film is made of polyester and can be cut. Accuracy is ±10% and temperature range is 41° to 95° F. SLAC selected the film with pressure range 350-1400psi for this purpose. The film was placed between the two connecting surfaces and bolted tightly, under the pressure applied by the bolts the film will turn red if there is contact between the surfaces. The mating surface that achieved 80% contact area was considered acceptable (refer to fig.1); otherwise, the surface should be trimmed. The films that were used for testing had been kept in the travellers of each magnet.

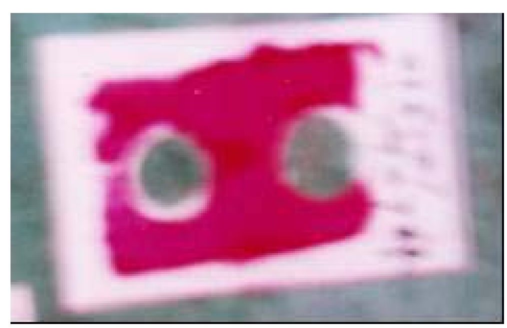

Figure 1: An Acceptable Connection

Silver Plating Procedure

The original design of SPEAR3 magnet buss connection was to use the material Penetrox P8A to enhance the electrical connection between the bus surfaces. Penetrox P8A had been used on magnets of ALS and PEPII without problem during the operation. Still, there was concern that the Penetrox will be aged and become hard over a long period causing the electrical connection to become weak and will require regular maintenance in the field. SLAC decided that Silver Plating was the best alternative in protecting the electrical connections on the magnets. It will prevent oxidize and will provide a long lasting and maintenance free connection.. An initial plating process was configured which included a flash layer of nickel which turned out to be in error.

After SLAC received the first silver plated magnets, it was found out that the silver-plating layer was flaking off from Nickel which was thought to be due to not apply silver plating immediately after Nickel plating. The activating time of Nickel was very short and it would be completely inactive in few minutes. The passivation of Nickel surface would seal any penetration of Ag, which results the separation between two layers. To avoid this problem, after Nickel plating and rinsing, one should apply silver plating while the surface was still wet.

However, another problem occurred when the silver plating along with the nickel flash plating peeled off of a bus flag (refer to fig.2). Consultants at IHEP and experienced SLAC plating department personnel pointed out that there was no need to Nickel-plate the copper because the nickel plating was suggested only for the parts that will be exposed to 300F temperatures and the silver-plating could be applied directly to the copper for room temperature connections. The Nickel plating layer was removed from the procedure and IHEP added polishing at the end of all procedures. Since then, the silver-plating quality was stabilized.

Figure 2: Silver Plating Came off

DEVCON AND HARDENER

The SPEAR3 dipole magnets were fabricated using a high strength steel epoxy called Devcon to adhere the laminations to the backing plates. This is a technique which was successfully used for the Advanced Light Source magnets.

During the SPEAR3 prototype fabrication, IHEP used 1lb Devcon kit (resin #10110 combining hardener #0202) did the grooves injection successfully. A two pound mixture of Devcon was required for each full length groove of the dipole; therefore IHEP purchased large quantity Devcon kits – 25lb for magnet production, which was supplied by Devcon vendor with a combination of resin #10230 and hardener #0203. Problems occurred when 2 pound Devcon was mixed taking from 25lb kits, the cure time from 45 minutes extended to more than 24 hours.

After side by side tests with 1lb and 25lb Devcon kits and back and forth discussion with Devcon vendor, it was figured out that significant difference of curing time was caused by a different PT# combination of resin and hardener in two type of kits. The hardener #2030 that was packed in 25lb kit has a pot life of 90 minutes. The reason that the Devcon company packed a slower hardener for 25lb kit was that they assumed that one ordered 25lbs of Devcon would mix all material at once and therefore requires a longer pot life. After knowing the reason of the differences in the Devcon hardening times between two kits, SLAC decided to use the faster hardener and asked the vendor deliver special combination 25lb kits (resin #10230 and hardener #0202). During the production, IHEP workshop mixed only 2lbs of Devcon at a time (for one groove) and this ensured a consistent and uniform mixture for each groove and did not require heating of the magnet core.

DIPOLE COIL EPOXY CRACK

In the early stage of coil fabrication at IHEP, about 80% of potted coils sustained severe epoxy cracks either right after the potting or few days later. Eventually 100% of those potted coils cracked (refer to figure 3). Theoretically, a thin epoxy layer, <0.5mm is desirable to avoid cracking. But in practice, in order to cope with coil winding tolerances and necessary taper of the potting mould, the epoxy thickness is larger in some segments of the coil. Therefore, using G10 filler or reinforced epoxy filler is necessary to avoid epoxy cracking at these places (refer to fig. 4 and fig. 5). The following engineering data shows thermal expansions of four materials:

Copper: 1.7E-5 (1/C)
G10: 1.8 E-5 (1/C)
Non reinforced epoxy: 5.4 E-5 (1/C)
Reinforced epoxy: 3.6 E-5 (1/C)

One can see that non reinforced epoxy, which has high shrinkage coefficient (about 3.18 times higher than copper), should never be used as a filling material as the differential expansion rates between it and copper are great and will eventually cause epoxy cracking in potted coils .

Figure 3: Epoxy Crack

Figure 4: G10 Straps

Figure 5: G10 Filler

DIPOLE END PACK CHAMFERING

Chamfering

The first dipole end pack chamfering was done in a configuration that used a milling machine programmed for a conventional cut on one pole and a climb cut on opposite pole (refer to fig.6). The glued laminations pealed off under the conventional cut method. The technician modified the program making both poles cut under climb cut method which solved the pealing problem (refer to fig. 7).

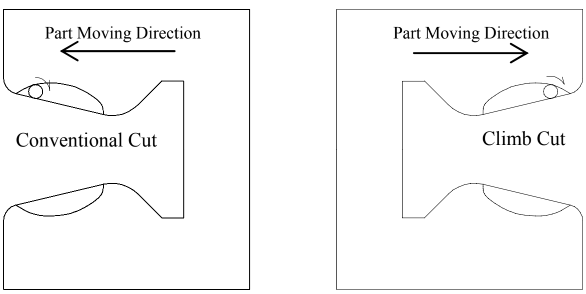

Figure 6: Both Poles Start Chamfering at Open End

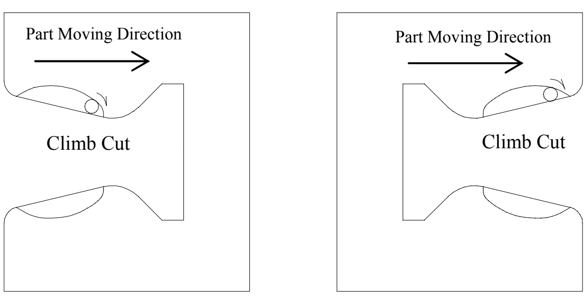

Figure 7: Start Chamfering at Different Pole End

Chamfering Configuration

During SPEAR3 145D prototype measurement, the end pack chamfer de-laminated due to magnetic field forces at the pole tip. IHEP designed a G10 block featured with a wedge piece and a base, inserted it between the pole end and the coil. This solved the de-lamination problem for the prototype and was used on all dipole production magnets to ensure there would not be a problem in the future.

[1] T. Takemoto at the 15th International AWS-WRC Brazing and Soldering Conference, Dallas Texas - April 1984.