CURRENT PROGRESS OF TAMU3: A BLOCK COIL STRESS-MANAGED HIGH FIELD (>12T) NB$_3$SN DIPOLE*

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Abstract

TAMU3 is a block-coil short model dipole which embodies for the first time at high field (>12T) strength the techniques of stress management within the superconducting windings. The dipole consists of two planar racetrack coil assemblies, assembled within the rectangular aperture of a flux return core. Each assembly contains an inner winding, an outer winding, and a high-strength support structure which is integrated within the assembly to intercept the Lorentz stress produced from the inner winding so that it does not accumulate to produce high stress in the outer winding. Iso-static preload is applied by pressurizing a set of thin stainless steel bladders with molten Woods metal and then freezing the metal under pressure. Current technology, difficulties, and present status of construction of magnet assembly will be presented.

INTRODUCTION

The Texas A&M Accelerator Magnet Laboratory is nearing completion of winding the first half of a double pancake Nb$_3$Sn racetrack coil. This coil, TAMU3, is the third stage of a series of dipole magnets [1], [2] to test and verify the tooling, assembly, and materials technology developed to manage strain degradation of A15 type superconducting Rutherford cable. Additionally, TAMU3 will be the first of the series to test the effectiveness of 'Stress Management' tooling under high-field, high-stress conditions.

TECHNOLOGY IN TAMU3

This current magnet incorporates high J_c (>2750Amm^{-2} 12T,4.2K) RRP Sn-rich medium filament diameter Nb$_3$Sn conductor from the DOE HEP conductor development program and further processed by the LBNL cabling facility [3]. An improved and more efficient S-glass insulation weave for TAMU3 increases the mechanical strength after epoxy curing by 35% and decreases the insulation thickness by almost 50% giving an almost 10% increase in the winding engineering current density [4], [5] compared to the initial designs. Much of the equipment used for TAMU1 and TAMU2 will be used with upgrades given to the temperature controlling capabilities of the Woods metal filled preloading bladder fixture [6]. An upgrade is well underway for the heat treatment equipment for safety, temperature controller calibration and control +/- 2°C, and data logging. An additional magnet winding container, or a coffin, was also machined to allow simultaneous operations to occur to both the top and bottom halves and to speed construction.

If all the performance capabilities intrinsic in the conductor are realized in the magnet, its peak field will be in excess of 14 Tesla. The next phase in the TAMU magnet series will be to split the top and bottom layers of the TAMU3 magnet design and create a bored insert between the two halves creating a collider prototype block dipole [4]. It will have better ac-losses, less snapback, and suppression of injection harmonics via field/conductor orientation plus flux plates, resulting in a robust winding module in an easy to assemble magnet configuration [7], [8].

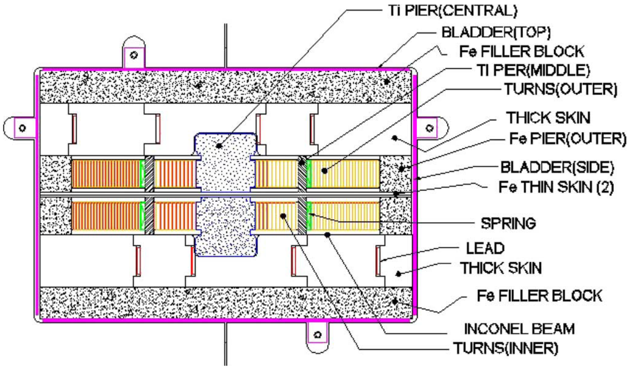

Figure 1: TAMU3 winding module components and interior bladder locations.

OBSTACLES AND DIFICULTIES IN CONSTRUCTING TAMU3

The impediments met specifically for constructing TAMU3 were more time consuming and frequent than first estimated and will be discussed at length. The sources range from unforeseen problems from the testing data analysis and autopsy of TAMU2 [4] and necessary mid-assembly revisions and upgrades to cabling and materials in TAMU3. This includes machining specialized tooling and alterations to already constructed parts to accurately conform to the new cable geometry. Additionally, five sets of all magnet parts were made in parallel and most modifications were performed on all five sets. However, this will greatly streamline constructing subsequent magnets of the TAMU series.

Since beginning winding the inner coil, several design flaws were discovered that have delayed progress. These oversights are still in the process of being corrected for the current and ensuing magnets.

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Castellated Shim

A castellated shim along the left side of the Central Pier interferes with and damaged a layer of S-2 glass insulation. The shim itself was a necessary modification to account for the new cable thickness and is castellated to allow epoxy to flow during impregnation. The solution was to replace the insulation and protect it temporarily with Kapton sheets.

Bottom Inner Beam Orientation

Two integral parts of the bottom inner beam can be placed in different orientations with only one being correct. In Fig. 2, the epoxy flow holes are in the incorrect location but the pieces still are in registration with their mismatched epoxy flow channels.

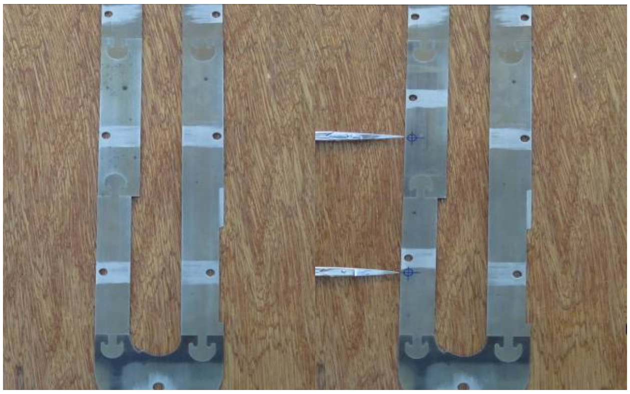

Figure 2: Pictures indicating the correct and incorrect location of epoxy channels and correct registration.

This incorrect construction permutation was not realized until 3 turns of cable were already in place. The solution required removing the central pier and winding from the magnet base and completely removing the Bottom Inner Beam assembly. The process took two days.

Cable Bend Radius and Relief

The transition pieces that bend the cable from the racetrack plane to the splicing plane had a too small bend radius which caused two separate shorts to ground of the inner winding. To correct the issue, we EDM'd out the problem material and backfilled the gaps with S-Glass. As Fig. 3 shows, the material removal allowed for the cable to bend less without the constraints of the transition walls. Very little strength and support for the cable was lost because of back filling with S-glass filaments. Also, the cable during transition was covered with an additional S-glass sock to provide another layer of insulation to further prevent any possibility of a short to ground.

STATUS AND PROGRESS OF TAMU3

Often the most difficult part of completing a magnet is getting prepared with all necessary tooling and procedures to complete the first turn. At publication, the inner winding is completed and the outer is in preparation. The key objective for TAMU3 is to verify the 'Stress Management" Technology at high field (>12T). Several components are integral to this goal and the tooling to take a first round of measurements to verify the preload on the inner winding is completed and correct..

Figure 3: Two pictures from the Nose Piece before and after relaxing the bending radius.

Capacitive Stress Transducers

Capacitive Stress Transducers are the key important component to quantify the Lorentz Force at field. Measured values will be compared to the simulated value of 5.3MN/m. In TAMU2 there was a large shift in the zero of the capacitor transducers due to the temperature cure cycle of the epoxy winding impregnation [4]. We have minimized the shift with much improved tooling that uses a small fraction of the original amount of epoxy between layers of the transducer. The new transducers have been tested and are pliable enough to be used in either curved or straight sections. To date, all of the necessary transducers have been built and they are in process of being characterized, tested, and calibrated [9]. Notice in Fig. 4 the zero value shifts in the capacitance before and after an epoxy heat cycle. The zero value decreases by an average of 24.7 pF over the hysteresis loop. The repeatability of this shift will be the determining factor for the error in determining the magnitude of the Lorentz stress from the inner winding that by-passes the outer winding.

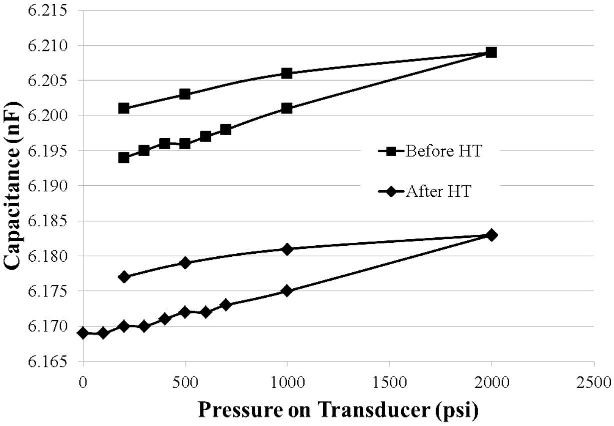

Figure 4: Transducer Hysteresis before and after an epoxy heat treatment for a single completed transducer.

Monument Measurement

The Central, Middle, and Outer 'Stress Management' Piers have counter-bored, taped holes with removable eighth-inch shoulder bolts. These shoulder bolts are utilized as measuring monuments to obtain the thickness of winding sets in order to compare them to the modelled values along the axial direction of the coil set.

Table 1: Monument Measurements

Location	Inner Winding	Gauge Block
1/3 length, left	1.617 in	1.620 in
1/3 length, right	1.613 in	1.615 in
2/3 length, left	1.618 in	1.620 in
2/3 length, right	1.615 in	1.612 in

In Table 1, Gauge blocks were EDM'd to the design dimension and placed in the winding position for the initial readings. These measurements are used to torque the coffin bolts to bring the winding to the proper load and size. Despite the differences in Table 1 being small, they are still significant because the preload on the springs has a target compression of between three to six thousandths of an inch.

Curved Preload Springs

The curved springs demand the most stringent tooling and construction precision of all the magnet parts. Currently they are the pacing issue to move the magnet forward and begin the outer winding. To bypass this concern we will use springs from TAMU2 on the first winding set of TAMU3. The springs have identical design thicknesses and the complex radii differ by less than five thousands of an inch over the roughly 1.75 inch radius. However, the curved spring design for TAMU3 has an additional quarter inch of straight section at the end of the spring. This will be compensated by grinding a stainless steel spacing shim to the thickness of the compressed spring. This change is advantageous for two reasons:

- The shim will be located and pressed up against another shim and not the cable because it is located at a transition. Therefore above the exiting cable.
- Secondly, the shim can be used as a datum for verifying the correct compression of the adjacent springs. This second datum in conjunction with the monument measurements should give an independent check of the spring deflection.

Fabrication of Insulation/Shear Release layers

The geometry of the epoxy channels coupled with the accuracy required on all of the magnet parts required that all insulation (Silane sized S-2 glass fabric) and shear release (mica) layers be cut to high precision. The layers were placed between Stainless Steel cutting templates and this produced the precision needed. The edges were initially cut with a micro oxy-acetylene torch and all subsequent glass beads rolled off while still between the templates. To reduce fraying of the S-2 glass filaments, the same torch was used to sear the edges, without creating glass beads larger than the thickness of the weave itself. Additionally, a down-draft table was constructed to reduce inhalation and skin irritation from the S-2 glass processing.

CONCLUSION

The chief objectives of the Magnet R&D program at TAMU are very likely to be realized with the completion and testing of TAMU3. This magnet will definitively test the key technology of 'Stress Management' and if successful will increase the effective engineering current by shunting Lorentz force and open higher magnetic field regions. Progress is tedious but steady with substantial foresight into subsequent magnet renditions as to conductor and tooling requirements.

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