Title
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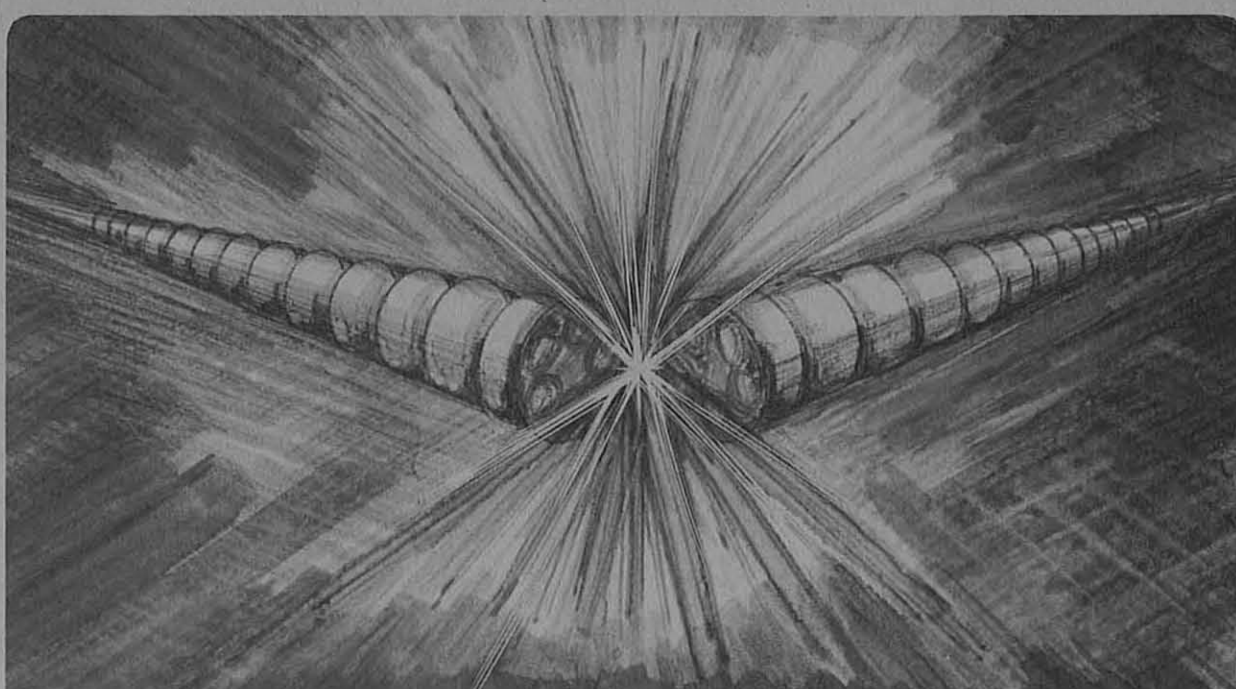

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Abstract

Three one-meter SSC type dipole magnet models have been constructed and tested using tapered keys to lock interleaving aluminum alloy collars around the coils. This design enables the coil prestress to be created by hoop tension in the collars as the keys are pressed in. This method minimizes the high coil overstress required to insert traditional non-tapered keys. In particular, collaring may be accomplished without exceeding 10,000 psi coil pressure while producing in excess of 7,500 psi coil pressure after collaring. Significantly, this design enables aluminum collars to be used with their advantage of maintaining coil prestress during cooldown. Coil prestress measured during and after the collaring of the three one-meter models will be given. A description of the design, including FEA analysis, and the forces required to key the collars, will be given.

Introduction

Twenty one 1-m long dipole magnets were constructed and tested at LBL between December, 1984 and March, 1987. These models were constructed using collar laminations, similar to Fig. 1, to prestress and position the coils. The collar material for ten models was Nitronic 40 stainless steel alloy. The collar material for the remaining eleven models was 7075-T6 aluminum alloy. Assembly of this type of collar requires pressing the interleaved top and bottom collar sets tightly around the coil package in order to insert the rectangular keys. When the external collaring force is released, the collars deflect outward (springback) and the coil stress falls off.

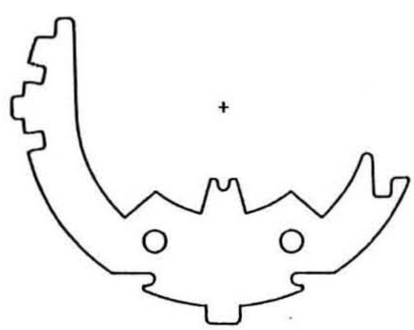

Fig. 1. Traditional Rectangular Key Collar

Coil pressure transducers were built into the collars to enable measuring inner and outer coil prestress. The measured coil prestress loss during assembly of these models averaged 57% and 70% of the maximum assembly stress for stainless steel and aluminum collared models, respectively.[1] Recent techniques at Brookhaven National Laboratory have reduced the springback loss of stainless steel collars to about 40%. Peak coil pressure during assembly of both types of collars typically ranged from 15,000 to 18,000 psi in order to achieve required coil prestress levels after cooldown. The higher springback of aluminum is offset by its higher thermal contraction and thus its smaller loss of coil prestress during cooldown.

The compressive stress peak of 15,000 to 18,000 psi during assembly of the collars may produce damage to the electrical insulation between turns and between coils; therefore, an important collar design objective is to eliminate this stress peak.

Tapered Key Approach

The objective of the tapered key collaring method is to eliminate the collar springback and resultant loss of coil prestress after assembly. The approach is to compress the coil/collar package together only enough to engage tapered keys (coil prestress will be low at this point). As the tapered keys are forced inward, the upper and lower collar halves are drawn toward each other. This develops hoop tension in the collars and additional compression in the coils. As the keys become fully engaged, the coil prestress is produced entirely by collar hoop stress and the external force pushing the collars together has fallen off to zero.

Specific Design

The tapered key collar profile is shown in Fig. 2. It differs from the non-tapered profile only in the area around the keys. A significant amount of material has been added to the collar to lower the stress in the collar and permit use of a larger key.

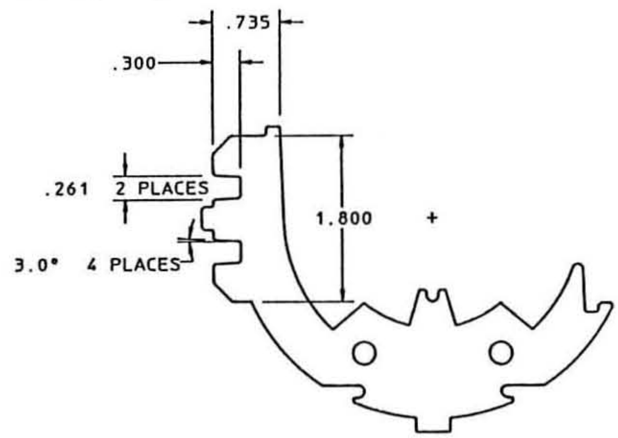

Fig. 2. Tapered Key Collar Geometry

Stresses

The stress in the collar has been analyzed using the ANSYS code. A fine element mesh was used in order to determine the stress levels at the corner of the keyways. The model geometry contains 0.02 inch radii at these corners as does the actual collar laminations. The von Mises equivalent stress in the area of the keyways is shown in Fig. 3 for a load of 7500 psi prestress. A small amount of material exceeds the 74,000 psi collar material (7075-T6 aluminum) yield strength (approximately 0.002 square inch).

Keys

Key material is 9% Ni steel. This is magnetically soft, but has sufficient strength and toughness for operation at

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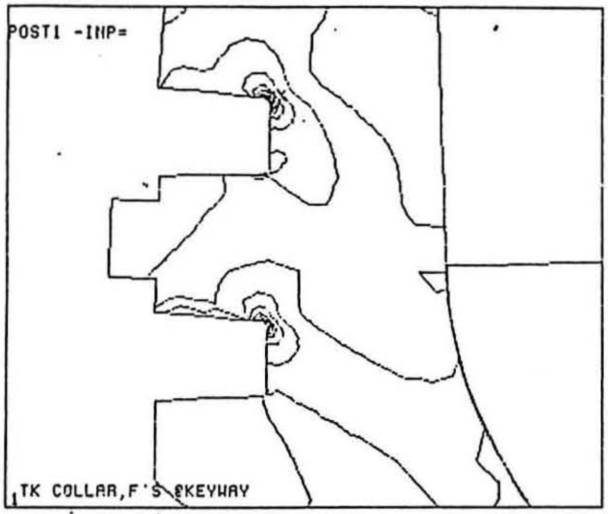

Fig. 3. Collar Stress Around Keyways. 13,000 psi Contour Spacing.

4 degrees. By keeping the key cross section large (0.300 in. X .261 in.), the key stress is reduced to approximately 5100 psi in shear. The second reason for a larger key is to reduce key to keyway bearing stress by keeping the bearing surface large. In this case, the load carried at each lamination keyway was 370 lbs. and the bearing stress is 20,600 psi. By making the key taper 3.5° (the keyway taper is 3°), the bearing load was distributed evenly across the contacting surfaces as opposed to being concentrated at the keyway root. This 0.5° taper difference was determined by looking at how much the keyway surface rotates when loaded with a uniform pressure load in the ANSYS model. Distributing the bearing load reduces the stress concentration at the keyway root as well as reducing the possibility of friction and galling problems during key insertion.

Magnetic Considerations

There is a very minimal penalty in field strength and multipole harmonics due to removal of a small amount of iron to accommodate the enlargement of the collar in the keyway area.

Collar Deflections

The collar is designed to give a circular shape to the coil O.D. when assembled with 7500 psi coil prestress; thus, the unloaded collar shape is slightly elliptical, elongated in the horizontal direction. During operation, the deflection of the aluminum collar in the horizontal direction is limited because it is in contact at the midplane with the iron yoke.

Construction of Models

Three one-meter dipole models have been constructed. During assembly, the collaring press force (primary external vertical force applied to the collars), the key force and the key position (percent of engagement) were recorded. A small amount of anti-gall lubrication was applied to each key before keying. A coil stress of approximately 10,000 psi was set on the inner coil using only the external collaring press to compress the coils. At this point, the keys can be engaged 10% to 30% of their depth before contacting the keyway taper. As the keying force was increased, the external press force was manually released in order to maintain coil stresses near their starting values of about 10,000 psi. One alternate method, which does not require the main press control, is the use of rigid stops that fix the press aperture to the correct position for initial key engagement. As the keys are driven in, the press cannot follow and cause coil stress to exceed the choosen limit. No controlled release of the main press hydraulic pressure is required. This method was used in assembly of our latest model D15A-3.

Figure 4 shows the coil prestress as a function of key engagement and keying force. A key force of 1,000 lbs./in. of key length was typically required to fully engage each key. The coefficient of friction of the key against the collar is thus 0.19. An overpressure of 30% on the keys was used to insure uniform and complete key seating.

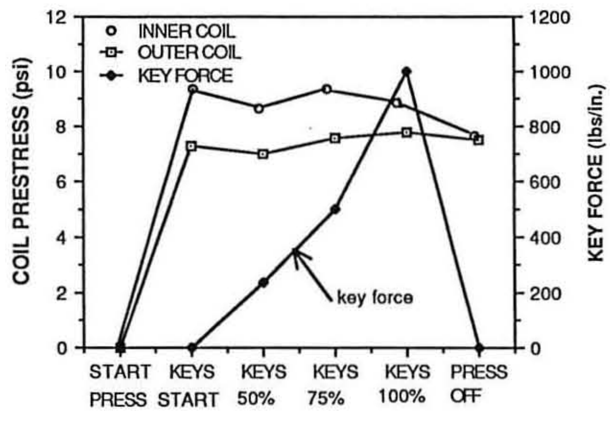

Fig. 4. Model D15A-3 Coil Stress and Keying Force.

Removing tapered keys was done by driving a wedge between the key and collar at one end of the collared section. The coil stress limit of 10,000 psi means the keys are loaded considerably when this extraction is done. None the less, it can be done where necessary without damage to keys or collars. On several occasions, collars were installed and removed without noticed deterioration of the contacting surfaces or increase in the forces required for reassembly. There was no burnishing or galling at the sliding surfaces. Overpressing the collar assembly to a higher than 10,000 psi coil stress before extraction allows the keys to come out more easily.

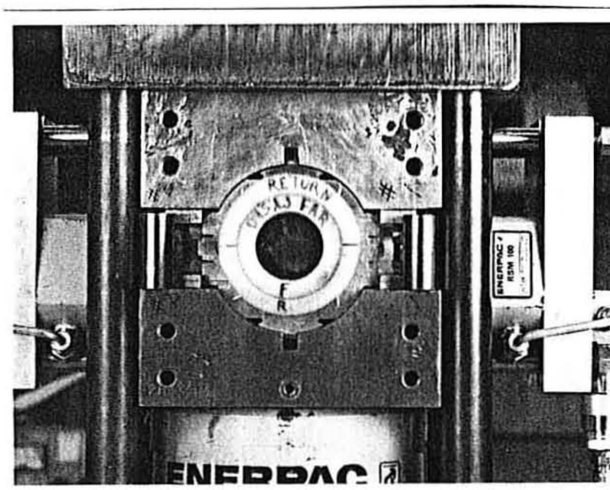

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Fig. 5 Collaring Press Set-Up Before Key Insertion.

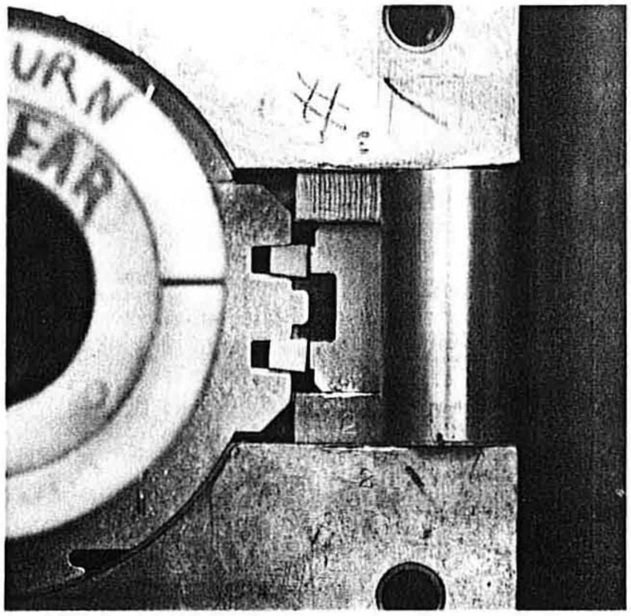

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Fig. 6. Key Insertion at 50% Engagement.

As a preliminary verification of the suitability of the 7075-T6 alloy, a 1-meter model, D15A-2, was energized repeatedly (approximately 3500 times) to the full operating field of 6.6 T; it also received several cycles to 9 T (at 1.8 K), which resulted in a Lorentz force loading 1.86 times greater than at 6.6 T. Subsequently, collars were inspected for evidence of crack formation using a dye penetrant, and none were found.

Summary

Collars of the tapered key design have worked well in three 1-m dipole models constructed to date. Insertion of the keys has proved to be a simple and trouble free operation. Room temperature coil prestress levels in excess of 7500 psi can be achieved without exceeding 10,000 psi during assembly.

Reference

1. C. Peters, "Springback, Creep, and Cooldown Prestress Losses in Twenty One Collared 1-M Models Constructed at LBL," LBID-1265, SSC-MAG-122, SSC-N-296, April 2, 1987.