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RHIC

MEMORANDUM

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Title: A Possible Link Between Coil Pre-Stress Changes and Field Harmonics in RHIC Superconducting Magnets

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A Possible Link between Coil Pre-Stress Changes and Field Harmonics in RHIC Superconducting Magnets

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***Abstract*--This note attempts to establish a link between the observed changes in azimuthal coil pre-stress and field harmonics after quench and thermal cycles in RHIC superconducting magnets. Both changes can be qualitatively explained by relatively small (of the order of 25 μm or less) differences in coil geometry. It is proposed here that after a quench or a thermal cycle the collared coils do not return to their original geometry because of friction and this difference in geometry could be the source of the measured changes in coil stress and field quality of the magnets. These changes in field harmonics might put an ultimate limit on achievable field quality and its reproducibility in superconducting magnets.**

During the calibration runs of tuning shims in RHIC 130 mm aperture insertion quadrupoles, a change in several harmonics (e.g. normal and skew sextupole changes of up to 1.4 units "peak to peak" or about 0.5 unit RMS at 40 mm reference radius) was observed between two cold measurements [1]. Based on the analysis that followed, it was concluded that those differences can not be explained by variations in tuning shim magnetization or magnet yoke saturation or persistent current effects. The only remaining source should be either a non-reproducibility of the magnetic measurements or a geometrical change of the collared coil cross-section. Similar changes in harmonics were observed in the 80 mm aperture RHIC arc quadrupoles and in the dipole magnets (100 mm aperture RHIC insertion dipoles) where for the latter the measurements are considered to be more reliable [1]. These changes were not found to be a function of current and therefore it was concluded that they are related to a change in the coil geometry (or at least a part of it in the case of the quadrupoles). These changes are observed only when the magnets undergo a thermal cycle or a pressure/mechanical shock (quench). They are not observed in repeated up and down excitation runs (dc loops) with no quench or thermal cycle in between. The details of these measurements will be discussed elsewhere. To illustrate this, Fig. 1 shows the change in b_2 and a_2 in the 130 mm aperture quadrupoles QRK101 and QRK102 during tuning shim runs. To remove the harmonics generated by tuning shims and to study only the effects of quench and thermal cycles, an offset is added to the first warm run of each set. Fig 2 shows the change in b_1 and a_1 in the 100 mm aperture D0 dipole DRZ106.

Table 1 gives the result of a computer simulation where the coil midplane is moved up by 25 μm at only 0 degree location in the RHIC 130 mm aperture quadrupole. In this case only the skew harmonics will change. It can be seen that the computed change in a_2 is of the same order of magnitude as the measured ones, see fig 1. In this simulation all coil poles are kept at their original location and the effective cable thickness is changed to obtain a uniform geometry in the coil halves affected by this deformation. Another hypothesis could be that the coil is locked at one location and the effective cable thickness change is not uniform.

Table 1. Harmonics created by a 25 μm vertical shift in the coil midplane at 0 degree in RHIC 130 mm aperture quadrupoles at 40 mm radius. The other seven coil midplanes and all eight coil pole locations remain fixed. Only the skew harmonics are created. The harmonics are computed at low current where the iron is not saturated.

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
1.27	1.14	0.75	0.43	0.22	0.11	0.05	0.02	0.006	0.002

A change in azimuthal stresses, as measured by strain gauges [2] on the poles of collared coils, has also been observed to occurr after quenches and thermal cycles. Though the absolute accuracy of the strain gauges used in pre-stress measurements is comparable to the observed changes, the strain gauges are considered to be more reliable in deducing a relative change [3]. Therefore it is concluded that the collared coil goes through a relative change in internal configuration. The geometry of the collared coil changes when the magnets cool down or when they are under Lorentz forces or when the pressure/thermal elongation built up by a quench act on the coil. Mechanical friction may prevent the magnet coils (or individual cables within it) from returning to their exact previous location after the thermal cycle/quench. The location of the coil midplane, for example, may shift by about 25 μm or so. To argue this mechanical non-reproducibility further, we show several strain gauge runs in Fig. 3. Here the azimuthal stresses on the poles of the coil are plotted as a function of current in a prototype 130 mm aperture quadrupole QRI002. It may be noted that the initial values of the stresses measured at low current on the four poles of the coils are different (other four poles not shown here have a similar behavior) and remain different till the curves become flat at high current (the flat curve means that no prestress is present any more, its non-zero value showing the offset of the strain gauges). Fig. 4 shows a similar behavior in the 100 mm aperture D0 dipole DRZ105. To give a measure of the effect of a change in coil azimuthal stress, in the case of the D0 dipole a change of 450 psi corresponds to a change of the coil arc length by 25 μm [4]. It can be seen from Fig. 4 that after a quench, stress changes up to 1.7 kpsi (or 30% of the original value at 4.3 K and 0 excitation current) have been measured by the strain gauge at a given pole.

It is proposed here that the two changes (coil stress as measured in strain gauge runs and field quality as measured in field harmonics) are from the same source and the two together supports the hypothesis that a D0 or QRI magnet goes through small (< 25 μm) non-reproducible geometrical changes following a thermal cycle or a quench. To establish a true correlation, the study of the link between coil stresses and field quality changes should be carried out on a same magnet. So far these two changes have been observed in similar magnets but not in the same magnet and at the same time. Nevertheless, it is believed that there is enough indication that the two effects are related. It may however be noted that the strain gauges located at the coil poles measure the local stress changes and that these local measurements may not fully characterize the redistribution of the stresses occurring across the coil after a thermal cycle or a quench, and the ensuing coil geometry/field quality variations.

SSC magnet data [5] also show a change under similar circumstances (~1 kpsi pole stress and ~.05 unit of a_1 at 10 mm). The magnitude of the change in pre-stress and field quality after a thermal cycle or a quench should depend on the magnet mechanical design. In this respect, it might turn out that collared coils built with metallic spacers/collars, have a better geometrical stability [3] under the high prestress cycles occurring during thermal cycles/quenches in medium field/large aperture or high field/small aperture magnets. However, a systematic study has to be carried out in those magnets as well to truly establish the extent of possible change.

Though the observed changes in harmonics are smaller than the standard deviation of the harmonics achieved series production (e.g ~40 % of the r.m.s. a_2 in 130 mm aperture quadrupoles before tuning shims are installed), they are larger than the resolution of the tuning shim correction [6] of the RHIC insertion quadrupoles. Therefore, these changes could set an ultimate limit on the field errors, which can not be corrected by tuning shims. These field errors might also become relevant to the reproducibility of the performance of colliders that rely heavily on a very high field quality of their insertion quadrupole magnets. Their corrector settings might need an empirical time-consuming re-optimization after each warm-up cool-down cycle of the insertion area or after a quench has occurred (e.g because of a beam loss). For the RHIC regular lattice dipoles and quadrupoles, the changes observed in field quality after a thermal cycle or a quench are too small to matter for actual machine performance. For the RHIC insertion quadrupoles their contributions were taken into account in beam optics simulation and found to be acceptable [7].

Acknowledgments

A series of discussions with Erich Willen have been very useful. He has made several proposals on how to study this effect systematically.

References

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2. J. Muratore provided the strain gauge data.
3. E. Willen, "Private Communication".
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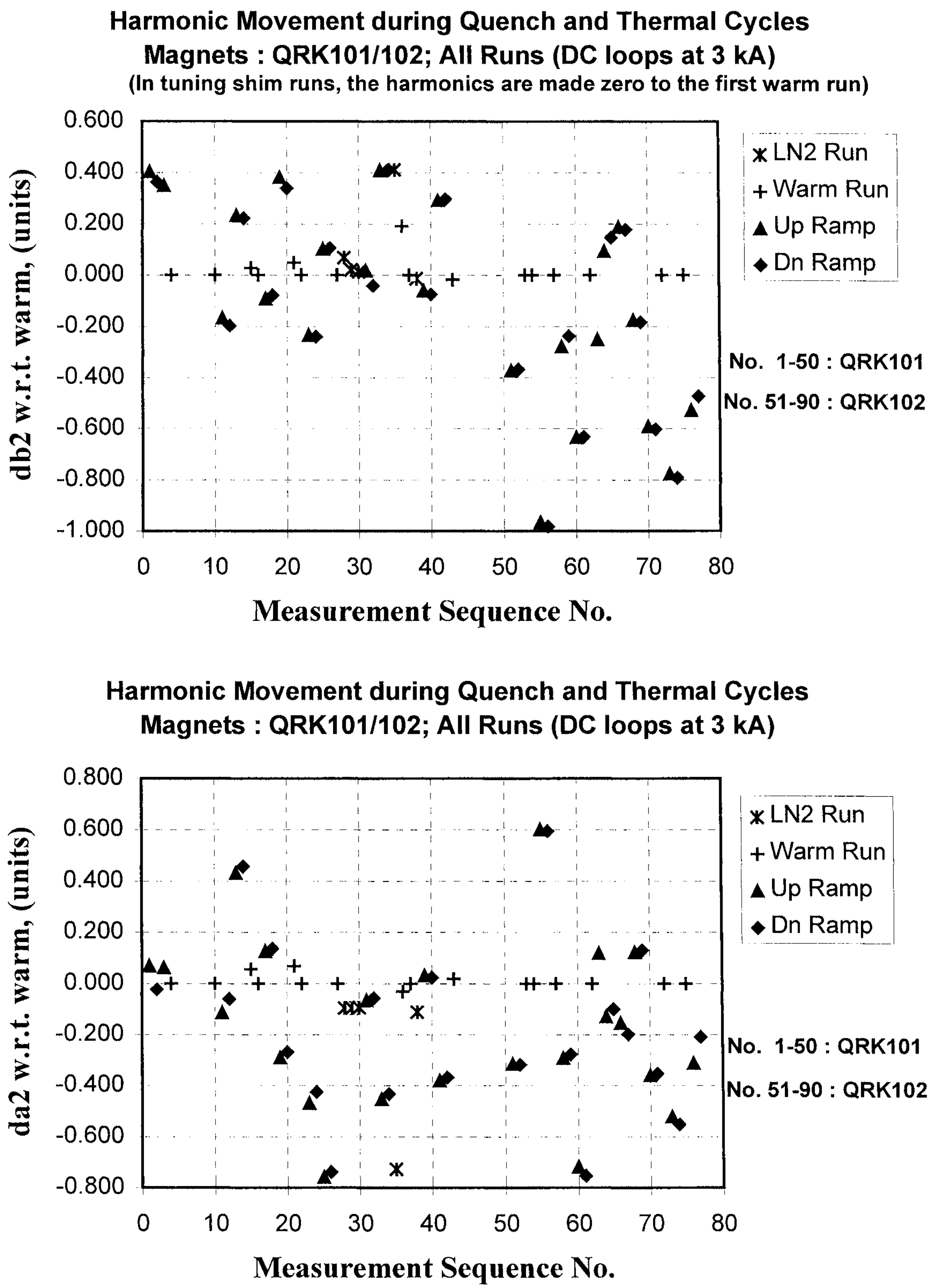

Fig 1. Changes in b_2 and a_2 caused by quench or thermal cycles in 130 mm aperture quadrupoles QRK101 and QRK102 (see text for details) at 40 mm reference radius.

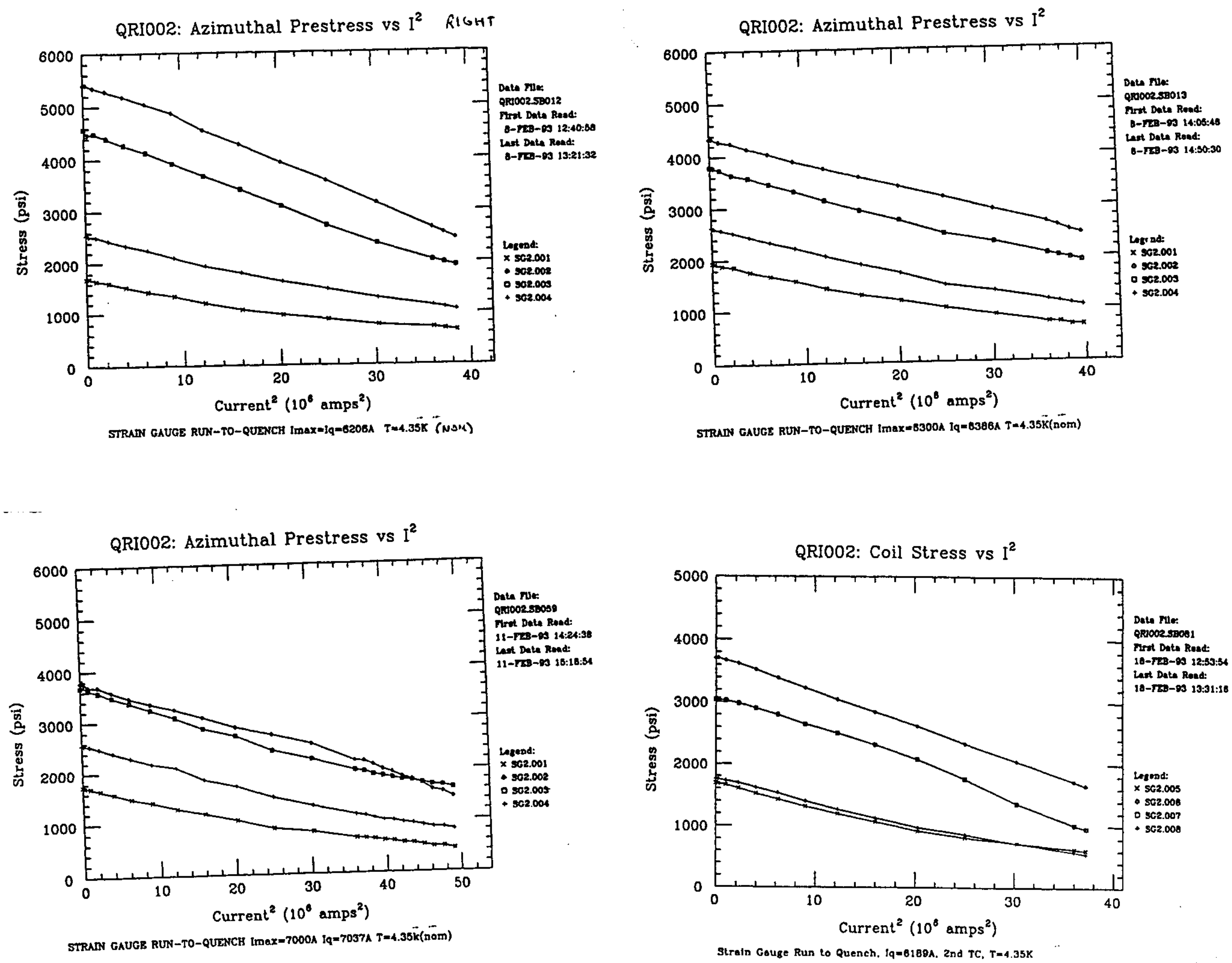

Fig 3. Measured azimuthal stresses on the four poles of 100 mm aperture dipole DRZ105 as a function of current. There was either a quench and/or a thermal cycle between any two set of strain gauge run (Courtesy J. Muratore).

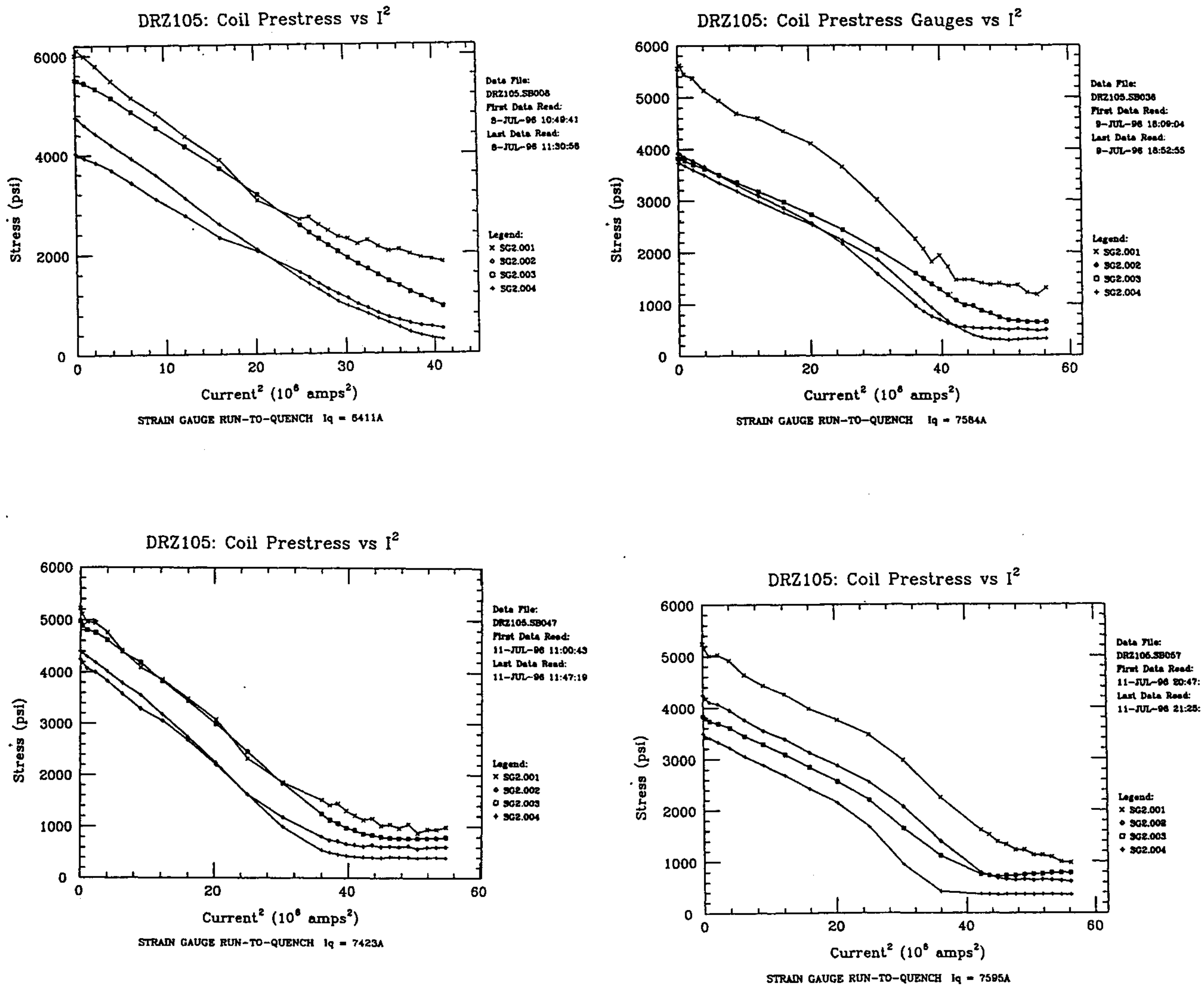

Fig 4. Measured azimuthal stresses on the four poles of 100 mm aperture dipole DRZ105 as a function of current. There was either a quench and/or a thermal cycle between any two set of strain gauge run (Courtesy J. Muratore).