TS-SSC 90-081
R. Bossert 10-29-90

SSC 40mm Magnet Collaring Problems

40mm SSC magnets are collared by placing the collared coil into the lower half of laminated collaring tooling. The assembly is then loaded into a press. Vertical press load is applied until the upper press platten contacts the lower tooling. Hydraulic cylinders then insert the tapered keys from the side.

If no vertical shim is used and the upper platten is contacting the stop on the lower tooling (as determined by feeler gage measurements) the key slot opening in the collar laminations should be exactly the same size as the tapered keys. Negligible force should be required to insert them. We typically use a vertical shim such as the .012 shim shown in Figure 1. The coil is therefore overcompressed. This is done to allow for any manufacturing tolerances or deflections which might cause the key slot to be a slightly different size than the design specifications.

Problems have been encountered in the collaring process. Specifically, when the mold is presumed closed as shown in Figure 1, the tapered keys still require substantial side force to insert. Even if the coil is, according to all dimensions on the drawings, overcompressed by as much as .012 inches by using a vertical shim as shown, the keys will not insert without force. It appears that significantly more overcompression is required than was anticipated.

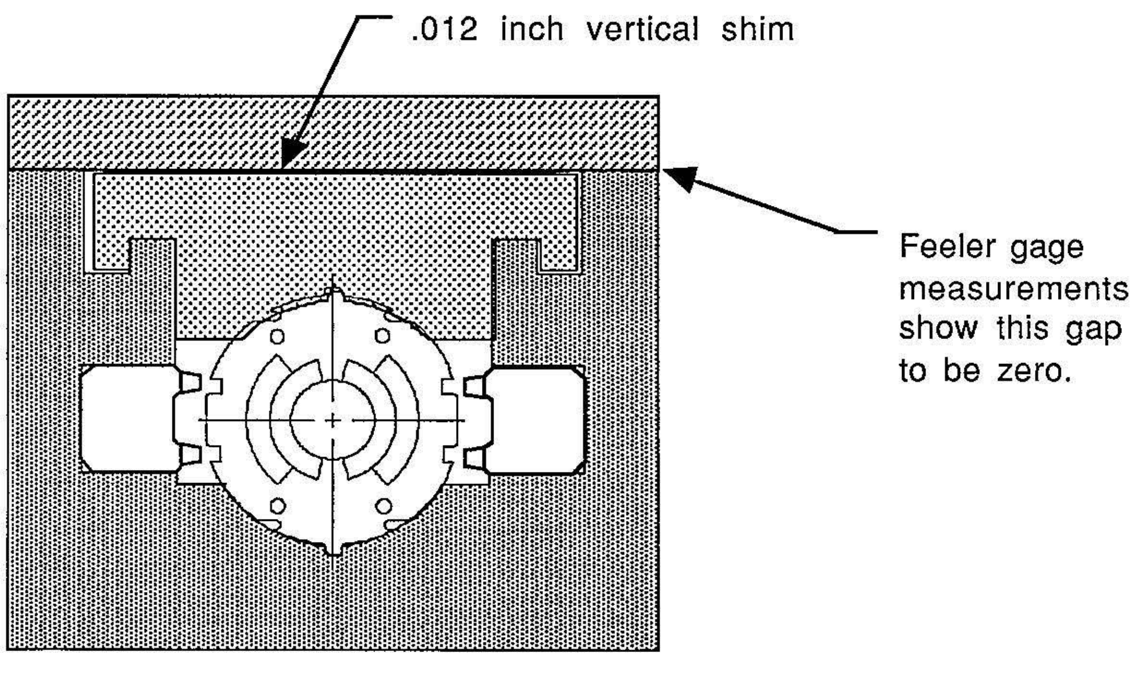


Figure 1.

Listed below are ten sections. Each one discusses a possible cause for this problem. None of them can account for the entire discrepancy. Some are unlikely to be contributing, but are added for completeness. Others are certainly having some effect.

Long SSC Collaring press (for reference)
(in Industrial Center Building)

100 ton cylinders placed side by side every 12 inches. Press capacity (at 10000 pump psi) is therefore 200 tons every 12 inches or 16.67 tons per inch. Using 1.55 square inches per linear inch as the cable cross sectional area, we have (16.67 tons/inch)(2000 lbs./ton)/ (1.55 in.2/inch) = 2.15 coil psi per pump psi. Press capacity at 10000 pump psi is therefore 21500 coil psi.

Side cylinders are 15 ton every 6 inches. Maximum side force is therefore 30000 x 2 = 60000 lbs/ft. or 5000 lbs/ inch. This force occurs at 10000 pump psi.

Possible reasons for problem:

1.) Collar and/or tooling laminations are out of tolerance.

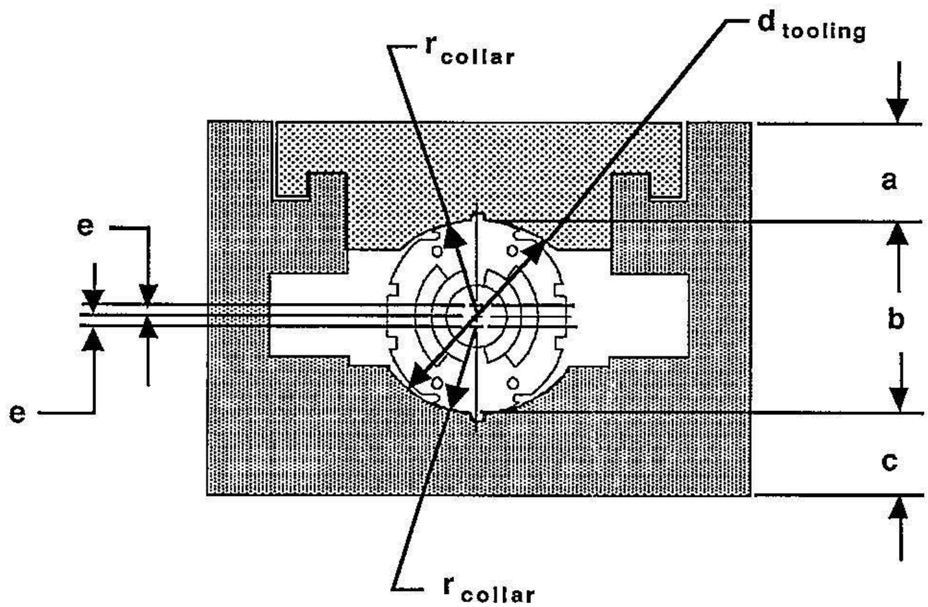


Figure 2.

<u>Design Dimensions when upper surfaces of both upper and lower tooling are coincident:</u>

$a = 2.317$
$b = 4.366$
$c = 3.067$
$d_{tooling} = 4.366$ ($r_{tooling\ lower} = 2.813$ and $r_{tooling\ upper} = 2.813$)
$r_{collar} = 2.181$
$e = .002$

<u>Actual Dimensions when upper surfaces of both upper and lower tooling are coincident:</u>

$a = 2.319$
$a + b$ on lower tooling = 6.683
$b_{tooling}$ = (a + b on lower tooling) - (a on upper tooling) = 6.683 - 2.319 = 4.364
$r_{collar} = 2.180$
$e = .002$
$b_{collar} = 2.180 + 2.180 + .002 + .002 = 4.364$
$c = 3.070$
$d_{tooling} = 4.3675$ ($r_{tooling\ lower} = 2.1835$ and $r_{tooling\ upper} = 2.184$)

The important numbers to compare are the actual $b_{tooling}$ with the actual b_{collar}. They both are 4.364. So within our ability to measure, parts tolerances are not affecting the collaring problem.

2.) The collar laminations are deforming.

The collars, when the maximum vertical load is applied, deform by approximately 8 mils on the horizontal diameter. This is the result of measurements taken by Nick Hassan during collaring of DS0312 (see "Horizontal Deflection of Collar Laminations" TS-SSC 90-070). The horizontal tooling deflection totals approximately 5 mils (2.5 mils per side). Tooling "tops" were used on both the top and bottom to make measurements of the horizontal collar diameter possible. Measurements were taken of both the horizontal deflection of the collars and the tooling in the positions shown by dial indicators in Figure 3.

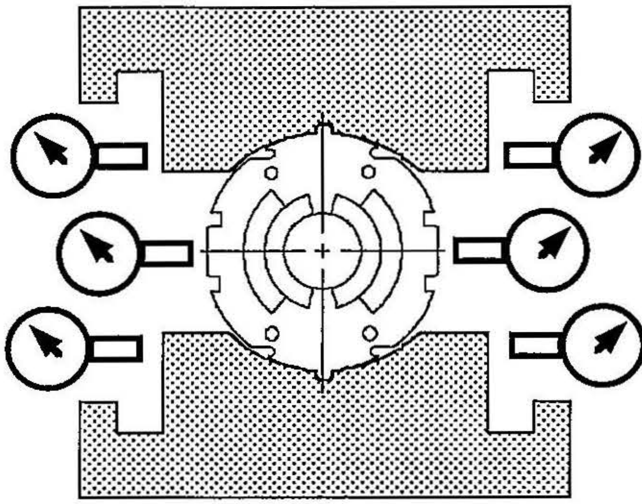


Figure 3.

There are several ways in which the collars could deflect to exhibit a horizontal increase of .008.

a.) <u>The entire collar could be taking an oval shape, becoming 8 mils wider horizontally.</u> The result of this type of deflection is shown in Figure 4.

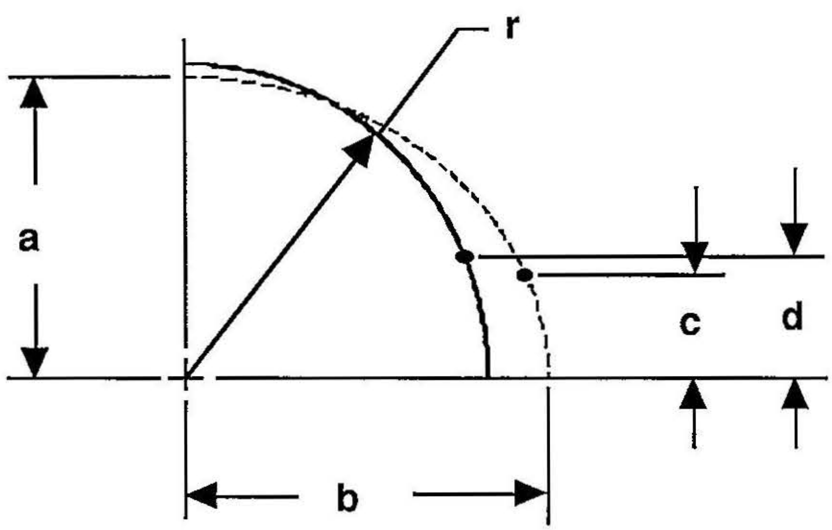


Figure 4.

The radius of the undeflected collar lamination (r) is 2.181 inches. The perimeter of an entire undeflected collar lamination (disregarding the various features such as flats and notches and assuming the collars are perfectly round) is $2\pi r = (2)(3.1416)(2.181) = 13.704$ inches. The vertical distance to the outside edge of the key slot is d.

If the collar is deflected by .008 on the horizontal diameter, the horizontal radius is $b = r + .004 = 2.185$. The perimeter is still 13.704. The first order equation for the perimeter of an ellipse is $P = \pi[2(a^2+b^2)]^{1/2}$ The vertical radius (a) is therefore $a = \{[(p/\pi)^2/2] - b^2\}^{1/2} = [(4.362^2/2) - 2.185^2]^{1/2} = 2.177$. So, assuming the collar lamination takes an elliptical shape and the perimeter remains constant, the vertical radius has been decreased by 2.181-2.177 or 4 mils. Deflection of the outside radius of the collars would therefore cause the collared coils to require 8 extra mils of overcompression.

This type of deflection would also cause a change in the height of the key slot. In Figure 4, the vertical distance to the bearing surface of the key slot of the undeflected collar is d, while the same distance on the deflected collar is c. d = .181 on the undeflected collar. As derived from a CAD layout, The difference between d and c is smaller than .0001. This means that the upper key slot has effectively closed by .0001 due to the collar deflections. This is small enough to be disregarded. It is unclear how the lower key slot deflects.

Attempts have been made to eliminate the collar's ability to ovalize to conform to the tooling diameter by using radial shims when collaring. These shims are placed directly around the collars to take up the difference in radius between the collars and tooling. (This difference can be seen by comparing r_{collar} with $r_{tooling}$ in Section 1). Use of a radial shim should in theory eliminate any ovalizing of the collar lamination that does not include a corresponding tooling deflection of the same magnitude. In theory, if the collar is ovalizing, a 3 mil radial shim placed as shown in Figure 5 (for example) should provide more compression than a 6 mil vertical shim, because the 3 mil radial shim would provide 6 mils of vertical shim plus prevent the collars from ovalizing.

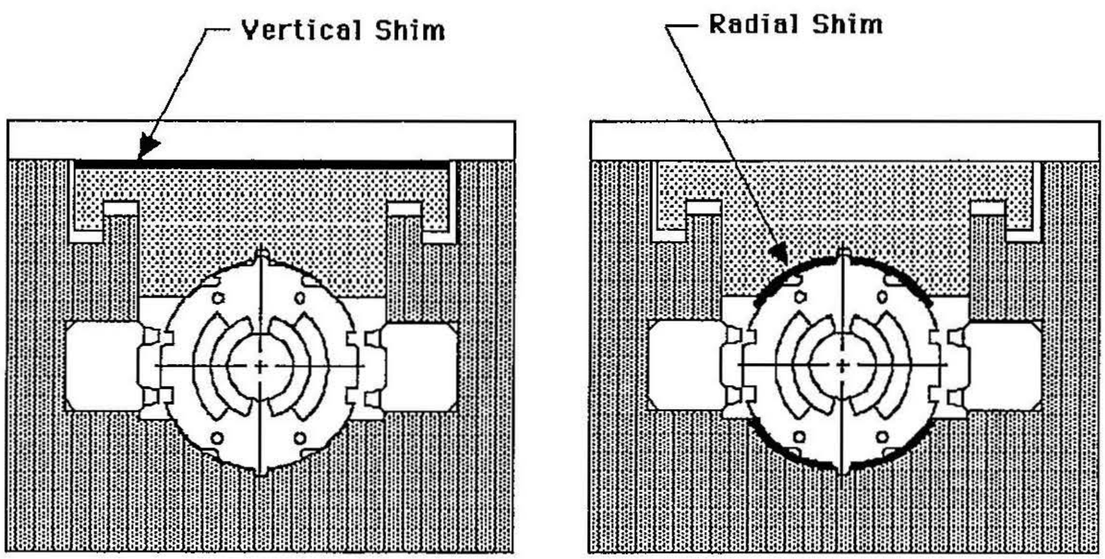


Figure 5.

If the collars were not ovalizing when no radial shim is used (or if the tooling were deflecting with the collars when the radial shim is used), the 3 mil radial shim and the 6 mil vertical shim should be equivalent. The two situations were compared in collaring experiments by Nick Hassan on magnet DS0312. There appeared to be no significant difference, indicating that either the collars are not ovalizing or the tooling is deflecting with the collars.

b.) <u>The sides of the collar lamination could be rotating outward while the height of the lamination remains the same.</u> The effects of this on the key slot are shown in Figure 6. They are drawn from a CAD layout by Nancy Bartlett.

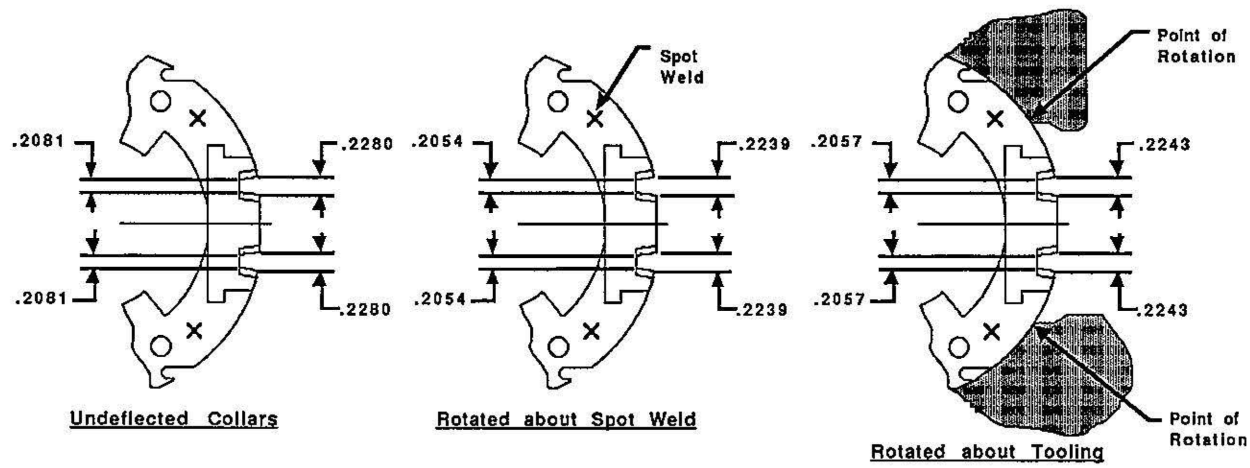


Figure 6.

Three different situations are shown. The undeflected collars show the key slot size if no rotation were taking place. Two types of rotation are shown. If the collar sides are rotated about the spot weld, the key slot is effectively made smaller by .0041 on the outside surface and .0027 at the bottom. If the collar sides are rotated about the corner where the tooling contacts the collar, the key slot is made smaller by .0037 at the surface and .0024 at the bottom. In either case this effect would cause approximately 4 mils of additional overcompression to be required. The key slot configuration changes do not seem to be very sensitive to the point of rotation.

c.) Some combination of 2a.) and 2b.) is occuring. In this case, the extra overcompression needed would be somewhere between the .008 in 2a.) and the .004 in 2b.).

These measurements need to be verified by future collaring experiments. Specifically, it must be determined whether the measured .008 and .005 deflections of collar and tooling laminations are real or due to deflections in the press.

3.) The tooling laminations are deforming.

The study of tooling deflections can provide insight into the collaring problem in two ways. Studying tooling deflections can lend support to collar deflection hypothesis such as 2a and 2b. Tooling deflections could also directly affect the problem.

3a.) Do measured tooling deformations support the theory that the collars are ovalizing?

The measurements by Nick Hassan on DS0312 show the collaring tooling deforming by a total of .005 in the horizontal direction (as stated in Section 2), while the collar deflection is larger at .008. The horizontal collar deflections should be expected to be larger than the tooling deflections if the collar is ovalizing as in Section 2a, because the diameter of the undeflected collar is smaller than the diameter of the tooling. The collar would deflect first until it contacted the tooling. The collar and tooling would then deflect together. The tooling should therefore deflect somewhat (but not as much as the collar) if collar ovalizing is taking place.

The measured value has the collars deflecting by ≈ .003 more than the tooling. The measured collar diameter is .008 less than the measured tooling diameter (see r_{collar} vs. $r_{tooling}$ in Section 1). The tooling deflections, which are measured at a point approximately 30 degrees above the centerline, should show a smaller difference by cos30 or .866 than the difference in diameters. So the tooling deflections should be expected to be about .007 less than the collar deflections or .001. The actual deflection of .005 is therefore more than expected, although the measurements are rather crude.

3b.) Do tooling deflections support the theory that the collars are bending as in 2b?

The measured tooling lamination deflections seem to be inconsistent with the idea of the collars rotating significantly about the tooling as in the third part of Figure 6. The collars would have to be ovalized before they contact the tooling by an amount that would already account for almost the entire .008 horizontal deflection. Rotating about the spot weld, however, is not precluded by the tooling deflections.

3c.) Could the tooling deflections be contributing directly to the collaring problem?

It seems unlikely that two dimensional tooling deflections could contribute to the collaring problem. The height of the tooling (dimension **a** in Section 1) does not change if the tooling bends as assumed in 3a. Direct compression of the upper tooling at full press capacity is under .001.

4.) The press platten is deflecting in the transverse direction.

The collaring tooling is compressed by two plattens. The plattens consist of boxed I beams as shown in Figure 7.

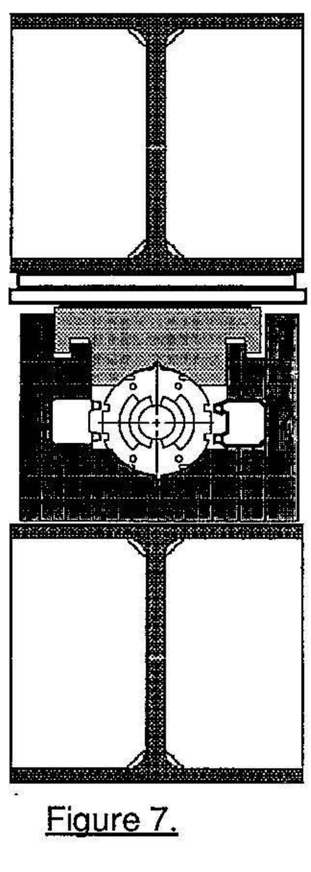


Figure 7.

When the vertical cylinders are powered, the upper platten is acted upon by three forces. Two rods pull down on it from positions 28 inches apart. These forces are reacted by the coil pushing up on the platten in the center. The upper platten can deform into the shape shown in Figure 8. If this situation exists, the gap can appear to be zero as shown while the collared coil is not completely closed. Preliminary finite element analysis by Eric Haggard has indicated that the deflections may be significant. To determine the magnitude of this effect, a solid steel rod of the same outside diameter as the inside diameter of the tooling will be placed into the collaring tooling in the long press. Gaps will be measured at the full range of press pressure. The change in gap (subtracted from the expected compression of the steel rod) will determine how much the platten is deflecting. The steel rod is expected to be available by Nov. 14.

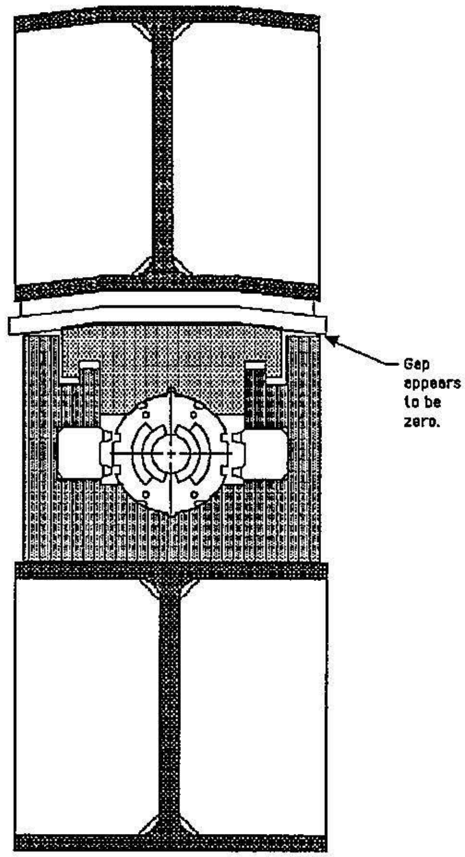


Figure 8.

Miscellaneous Note:

The direction of the deflections in the upper tooling described in this section, if the tooling follows the platten deflections, are in the opposite direction as the ones discussed in Sections 2 and 3. Here the surface of the tooling is convex, while previously it was concave. The sections appear to be contradictory.

In some of the pressings of DLO300, DLO301 and DLO302 there was a 1/16 inch thick piece of rubber placed between the platten and a steel cover plate which contacts the upper tooling. This rubber has a very low modulus. Since it is confined in all directions it is assumed that the bulk modulus, rather than the Youngs modulus, can be applied to it's deflections. This could be verified by a test. If it was deflecting then it could have contributed to the problem. The rubber has since been replaced by aluminum, so it can probably be disregarded.

5.) The press platten is deformed in the transverse direction in it's free state.

Measurements were taken of the lower press platten in the free state. They show that the platten varies in concavity over it's length. It is concave in the transverse direction by as much as .006 across it's width, although the degree of concavity varies widely. It is doubtful that concavity in the lower platten could contribute to the problem.

The upper platten was not measured because it is covered by the upper tooling. It is likely, however, that it is deformed by amounts similar to that in the lower platten. If it is, this could conceivably account for a few mils of the problem.

If this is part of the problem it would cause the necessary overcompression to vary longitudinally as the platten concavity varies. Experience in collaring has not shown this to be a problem. It is also unclear whether or not this effect would be negated by platten deflections discussed in Section 4.

6.) Misregistration of spot welded pairs might cause the key slot to be effectively smaller than the design.

Spot welded pairs are typically misregistered by .001 to .003 mils. They are only spot checked. Since there are a very large number of spot welded pairs in a magnet, it is statistically probable that a small number are misregistered by much larger amounts. It is not likely that the small number of highly misregistered pairs contribute to the key insertion problem, because these few laminations would probably just locally groove the keys. The "normal" misregistration of .001-.003 mils could contribute, however, because it is likely that most of the lamination pairs are misregistered by this amount. A description of the possible effect of misregistered pairs follows.

Lamination pair misregistration is a combination of three orientations; vertical, horizontal, and angular. The horizontal misregistration has no significant effect on the collaring problem. Angular misregistration changes the vertical, horizontal and angular position of the key slot, but the vertical changes are the only ones which significantly affect the collaring problem. Vertical misregistraion will therefore be the only type considered in this discussion. The amount of change in the key slot size depends on both the amount and direction of the vertical misregistration.

Misregistered pairs come in two types with respect to the vertical misregistration. They are shown in Figure 9. The shaded laminations are assumed to be on top of the line-only laminations (in other words, closer to the reader). "Top in" means the top lamination is closest to the center of the bore of the magnet. "Top out" means the top lamination is farthest from the bore of the magnet.

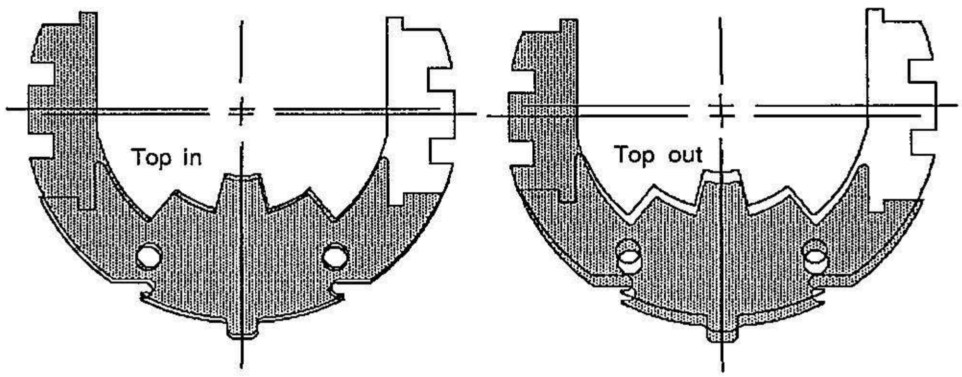
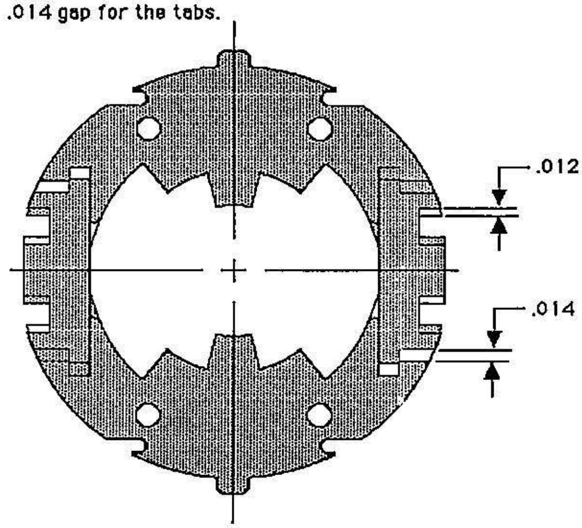


Figure 9.

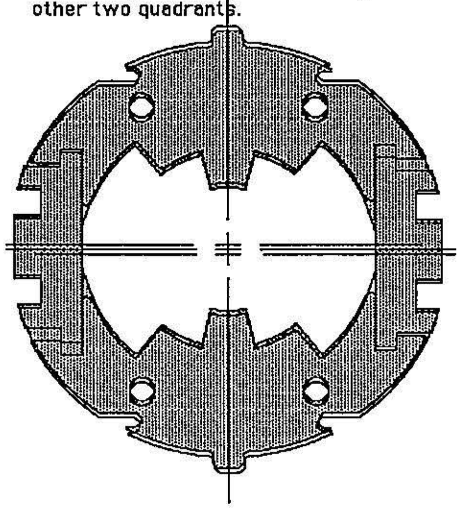
Figure 10 shows the five different situations which can exist due to vertical misregistration.

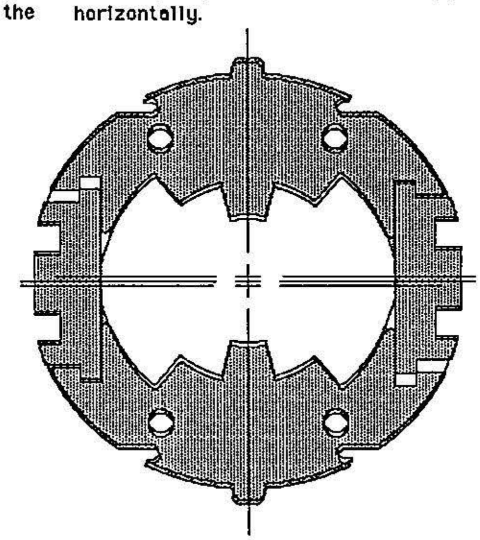
Two prefectly registered pairs: Key slot just the right size, clearance groove is .012 back from bearing surface and there is a .014 gap for the tabs.



Top in -to-top in: Right side key slot is larger by the amount of misregistration of the upper pair. Left side key slot is larger by the amount of misregistration of the lower pair. Clearance surface is closer to the bearing surface in both cases by the same amount as the misregistration. Tab gaps are unchanged in two quadrants and reduced by the sum of the misregistrations in the other two quadrants.

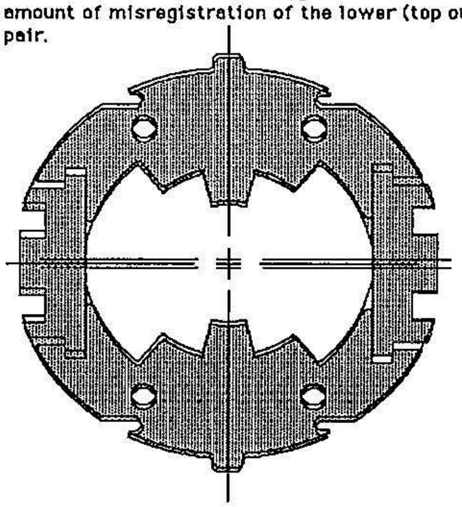
Top out-to-top out. All effects are exactly the same as a top in-to-top in but reversed about the vertical axis. A top out-to-top out pair is in fact identical to a top in-to-top in pair which has been flipped horizontally.





Top in -to-top out. Key slot is exactly the correct size on the left side and increased in size by the sum of the two misregistrations on the right side. Clearance surface is closer to the bearing surface on the right side by the sum of the misregistrations. Tab gaps on the upper left and lower right are smaller by the amount of misregistraion of the upper (top in) pair. Tab gaps on the lower left and upper right are smaller by the amount of misregistration of the lower (top out) pair.

Top out-to-top in. A top out-to-top in pair is identical to a top in-to-top out pair which has been flipped horizontally. All effects are identical but reversed about the vertical axis.



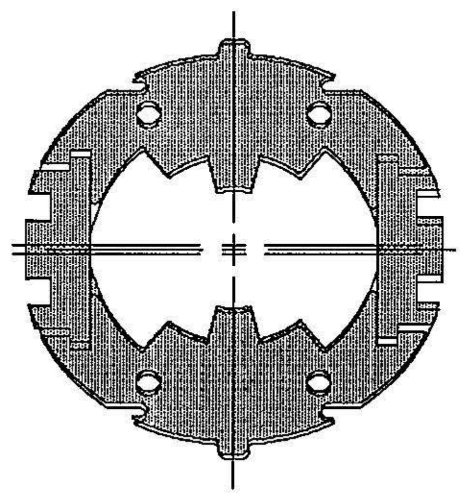


Figure 10.

In all cases, the misregistration causes the key slot to grow larger while the clearance for the back surface of the tapered key gets smaller. This indicates that misregistration of lamination pairs does not contribute to the collaring problem. It probably does not make the key slot appear significantly larger, though (a reverse effect), because there are still a large number of well registered pairs intermixed with the poorly registered ones.

7.) The collars are "overclosed" causing the keys to contact the "back end" or clearance surface of the key slot and consequently not be able to insert without force.

The openings in the collars which accept the keys have a .012 inch clearance by design. Inspection reports on actual laminations used in 40mm magnets show this clearance to be closer to .014.

The misregistered pairs, as discussed above, cause the clearance on the back end of the key slot to be decreased by a few mils. This suggests that if the overcompression is too large the laminations would begin scoring the back of the keys. This has not been evident even with vertical shims as large as 20 mils. Overclosing does not appear to be a problem. Collar deflections of some kind are obviously taking place, however, because 20 mils would certainly be enough overcompression to score the back of the keys if deflections are disregarded. 20 mils also exceeds the clearance for the tabs.

8.) Laminations in tooling are curving under the press load.

Both the collaring tooling and the collared coil assembly, being laminated structures, have very little resistance to shear. As a result they can curve as shown in Figure 11 under the loads applied by the platten.

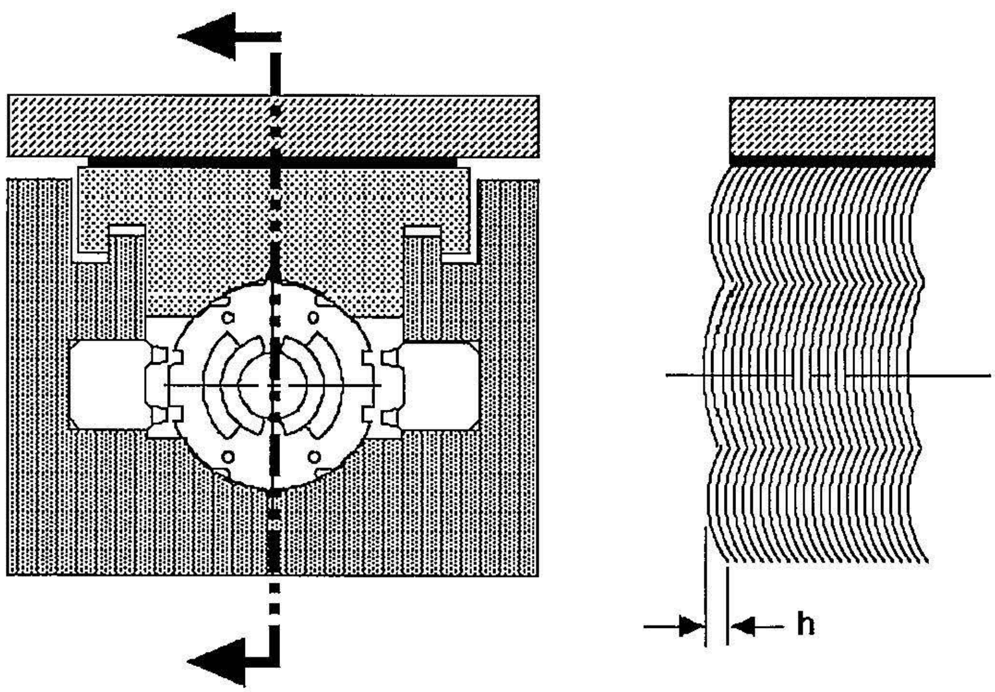


Figure 11.

If we assume the maximum longitudinal deflection (h in Figures 11 and 12) is .030 and the shape of curvature is circular, we can calculate the vertical deflection.

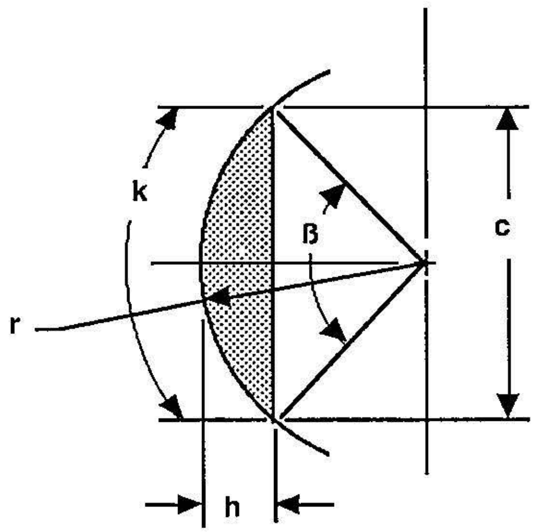


Figure 12.

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h = .030

c ≈ 2

$r = [c^2 + 4h^2] / 8h = [2^2 + 4(.03^2)] / 8(.03) = 16.681$

$ß = 2\{\tan^{-1}[(c/2)/(r-h)]\} = 2\{\tan^{-1}[1/(16.681-.030)]\} = 6.874$ degrees

$k = (r \times ß \times 3.1417) / 180 = (16.681 \times 6.874 \times 3.1417) / 180 = 2.0014$

k- c = .0014 at .030. for both upper and lower tooling laminations.

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h = .030

c ≈ 4.5

therefore r = 84.39

therefore $ß = 2\{\tan^{-1}(2.25/84.39-.030) = 3.056$ degrees

$k = (84.39 \times 3.056 \times 3.1417) / 180 = 4.5007$

k- c = .0007 at .030. for collar laminations.

Lower tooling compressions would not contribute to the collaring problem. This means that the whole assembly (collared coil in tooling) would compress due to the lamination curving by .0014 + .0007 = .0021 inches. We do not know, of course, if the .030 figure for h is realistic or if the curvature is circular, but the figures show that this effect is at most a small contributor to the problem. If the curvature were some shape other than circular, the vertical deflection would be more severe for the same h value.

K - c, by the way, increases rapidly as h increases. For example, if h is increased to .060 on the tooling:

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h= .060
c=2
therefore $r = [2^2 + 4(.060^2)] / 8(.060) = 8.363$
therefore $ß = 2\{\tan^{-1}(1/(8.363-.060)\} = 13.735$ degrees
$k = (8.363 \times 13.735 \times 3.1417) / 180 = 2.0049$

k- c = .0049 at .060. for upper tooling alone

9.) Collar laminations are slanted because of the gaps between packs.

Collar packs are stacked very loosely. As a result the collar laminations tend to slant when the pressure is applied in the collaring press. The design gap between collar packs of 1/32 inch is frequently in excess of 1/16 inch at the poles while closing to zero at the parting plane as shown in Figure 13. This causes the height of the collar laminations to be locally smaller.

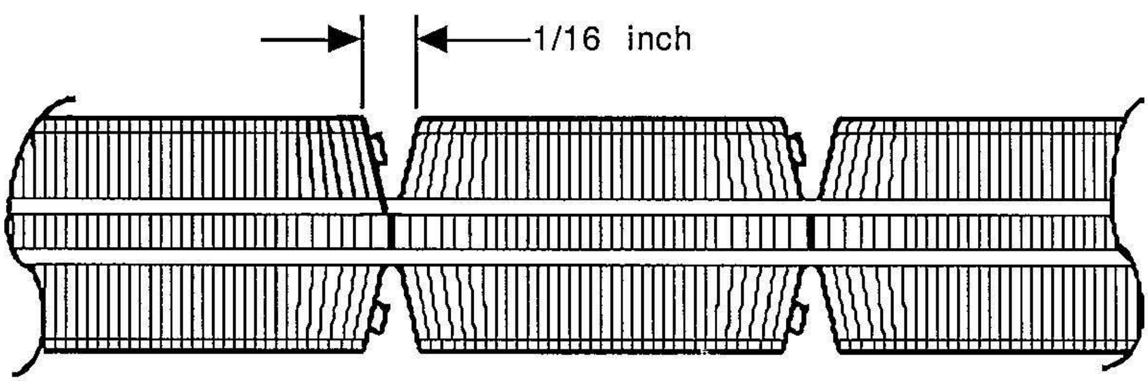

Figure 13.

$r_{collar} = 2.181$. Half the gap between laminations at the top = .03. $x^2 + .03^2 = 2.181^2$ x = 2.1808 2.181 - x = .0002. The total collared coil height is therefore smaller locally by .0004 due to this effect. This is not a significant contributor to the problem unless the laminations are taking a curved shape and bending much more near the top. This does not appear to be the case from observation. In any case it would probably occur only locally near the ends of the packs.

10.) The interface between the collar laminations and the tooling (lamination to lamination) is interlocking or yielding in a way which makes the tooling seem smaller than it is.

This question has not been addressed. Perhaps it could be in the 50mm project if it is deemed worthwhile. The 50mm short tooling has 2 inch EDM'd blocks instead of 1/16 inch thick stamped laminations. The long tooling uses conventional laminations. Cross calibration of these two otherwise identical types of tooling might answer this question.

Conclusion: All this information needs to be verified before any reasonable conclusions can be drawn. From the preliminary results shown it appears that only two of the effects mentioned above are contributing in any significant way to the collaring problem; collar lamination deflections and press platten deflections. Press platten deflections will soon be measured by use of the steel rod mentioned in Section 4. The collar lamination deflection will be verified by more measurements and by using the steel rod as a "control" to measure tooling deflections. When these measurements are complete their magnitudes can be compared with the collaring data.