Construction Review of DSA321

This report is a summary of a series of meetings which took place between 1-2-91 and 1-9-91. All problems and concerns involving the construction of magnet DSA321 (the first 50mm short model) were discussed. They are listed in the approximate chronological order in which they arise during magnet assembly.

Attendees in whole or part were Rodger Bossert, Jeff Brandt, Kerry Ewald, Howard Fulton, Imre Gonczy, Mike Gordon, Alan Koca, Wayne Koska, Ray Pace, Jim Strait, Masayoshi Wake and Mike Winters.

1.) Cable:

a.) One outer coil developed a turn-to-turn short. The strand had come out of lay apparently during cabling. It was completely severed and "folded back" in the opposite direction over the face of the cable. This problem clearly existed before winding began, and was consequently not due to winding tension. The coil was replaced. The damaged section is being sent to the SSCL for observation.

b.) The damaged cable was not detected by the "lump detector" on the FNAL cable insulating machine. Reasons for this need to be studied. Redesign is taking place.

2.) Preforms:

a.) Preform shape was better than 40mm, but still inconsistent. Preformed cable was wider in some areas than the untinned bare cable by as much as .030 inches.

b.) There is no traveller related to making preforms.

c.) Preforms for both inner and outer coils were made successfully but were difficult with the present fixtures. New fixtures have been designed by Nancy Bartlett under Kerry Potter's supervision. The new fixtures will make the preform as a developed two dimensional shape. The preform will be bent into it's final three dimensional shape after the soldering is complete. Bending the preform after soldering causes a potential problem which will need to be closely monitored.

If the preform shape is made before the cable is soldered, strands are allowed to move longitudinally with respect to each other when the bend is made. This minimizes the local stretching of strands. If the preform is soldered before bending, thus preventing strand movement, the bend will cause the strands to stretch. This could result in an unknown amount of filiment damage and therefore conductor degredation.

To check for this type of damage a sample of cable sections has been tinned and bent to radii as small or smaller than the radii which will be used in the preform. They will be etched in the Materials Development Lab and inspected for filament damage. If none is found, preforms made by this method will be used in short magnets. The quench behavior of the preformed area will be observed in these magnets.

d.) Splice shape could be improved to make the bend more evenly distributed and thereby reduce the stress on the cable in this area. Solutions are being developed by Howard Fulton and Joe Cook. Complications to the end clamp and curing tooling due to the changes in preform shape are being considered by Howard Fulton.

3.) Winding:

a.) Winding tension was 85 to 87 lbs. for inner coils and 85 to 90 lbs. for outers. These tensions worked well. Tensions for future short coils will be set at 85 to 90 lbs. for inner and 88 to 90 lbs. for outer. The winding tensioner has an accuracy of +/- 2 or 3 lbs.

40mm experience showed it to be difficult to transfer the winding tension used on short coils to that used on the long coils. 40mm short coils were wound with 80 lbs tension while the long coils were wound with 60-65 lbs on the inner and 55-60 lbs on the outer. There are at least two possible reasons for the difference between short and long coil winding tension requirements:

1.) High winding tension causes a large amount of longitudinal "springback" when the coil is removed from the curing mold. The amount of springback is proportional to coil length and is therefore much greater on long coils than on short ones. This limits the maximum amount of winding tension for long coils. Short coil winding tension is limited only by the structural integrity of the cable.

2.) Low winding tension causes the cable to sag along the straight section while winding. Excessive sag can make the coil impossible to pack into the curing mold. One would intuitively expect this effect to be much worse for long coils because the span over which the cable must stretch is greater. In fact it is worse for short coils. This is because:

- The long coils are supported azimuthally on the winding mandrel at regular intervals along their length, effectively negating the difference in span.

• Sag is naturally worse near the ends because the coil is directed downward as it comes around the turn. This effect is worse for short coils because the entire straight length of short coils is affected by both ends.

The difference in winding tension needed is a problem which requires more study.

b.) Winding direction seems to be acceptable. The 50mm coils are wound in the opposite direction from the 40mm coils.

c.) During winding, a metal fixture is bolted to the pole keys on the winding mandrel as shown in Figure 1. It is used to hold the G-10 end parts down during winding. The fixture is so large that it interferes at times with the cable path. The operator must be careful not to nick the cable during the winding. Kerry Ewald will look into ways to reduce the size of the fixture without compromising it's function.

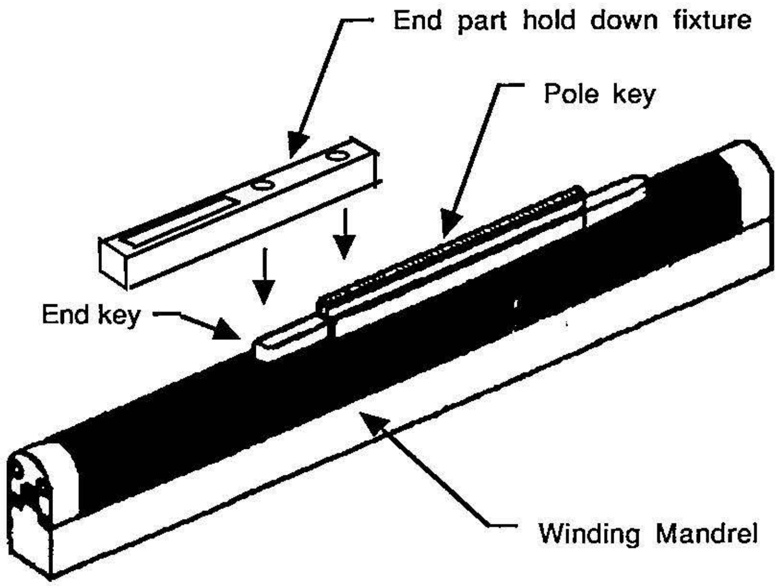

Figure 1.

d.) A problem developed while packaging the ends. The end retainers are very difficult to push over the coils. This problem also had occured on the 40mm, and was solved by using fixures which screw into the bottom of the mandrel and drive the retainers onto the coil. The 50mm retainers are a slightly different design, so these fixtures will have to be designed a little differently. They will be designed by Kerry Ewald.

4.) End Parts:

a.) Coil ends are each approximately 3/16 inch too long. This results in poor and inconsistent conductor support. It also causes longitudinal gaps between wedges and end parts (as shown in Figure 2) to be excessively large.

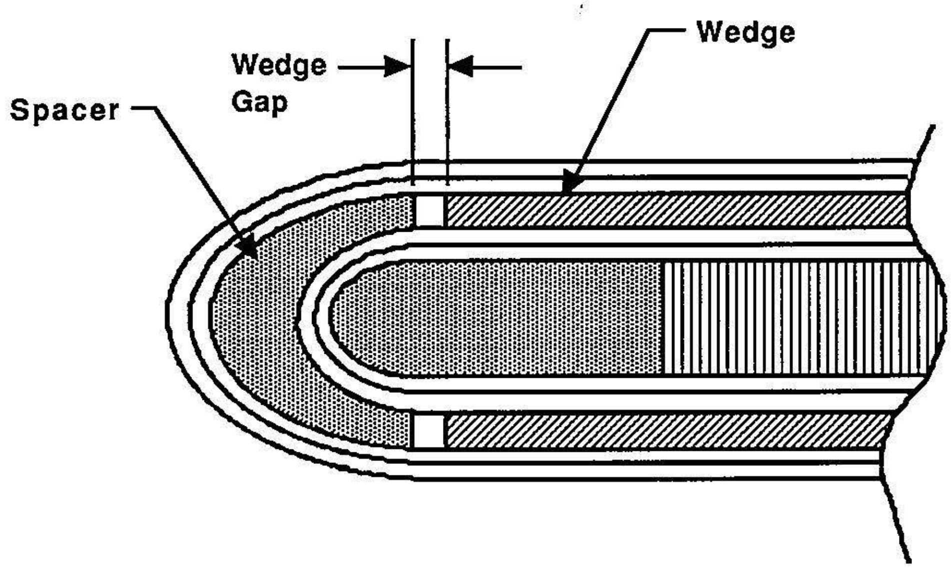

Figure 2.

There are several possible causes for this problem. Cable paths on end parts could be allowing too little space. Poor end preloading could also be contributing. The parts, being thicker than their 40mm counterparts, are much stiffer. As a result they are much more difficult to push into position. Friction between the parts and the glass tape on the cable is very high, impeding end preloading.

The temporary solution for DSA321 was to live with the unmodified end parts and increase the wedge length by an appropriate amount to fill the gaps between wedges and end parts. The long term solution will involve four steps:

I.) Experiments with end preloading. End preloading techniques will be improved as much as possible. This can be done by manipulating several variables:

a.) Pressure on mandrel cylinders
b.) Pressure on sizing bar cylinders
c.) Pressure on end cylinders
d.) Heating of coil.
e.) Adding or not adding slots to end parts.
f.) Activation or non-activation of last set of sizing bar cylinders.
g.) Use of alternate mold releases.

Several coils will be cured while manipulating the press sequence and the other variables stated above. The "ideal" preloading sequence and methods will be established.

II.) Special fixtures to preload each end part while winding will be tried.
III.) After the ideal preloading sequence has been tried, coils made with this method will be potted and sectioned. Conductor placement in the ends will be observed and measured.
IV.) Cable paths will be changed based on measurements of the potted and sectioned ends. A new iteration of end parts will be designed and manufactured.

The effort to solve the end part support/cable path problem is being coordinated by Jeff Brandt.

b.) Use of steel winding keys causes assembly problems. They must be removed after curing and replaced with G-10 keys. This causes insulation to sometimes be scraped away from the cable. It also causes the pole turn on the lead end (which must pass through the key) to be torn away from the rest of the coil for a few inches beyond the key. This section is never recured to the rest of the coil. The alternative is to use the G-10 keys during curing. This may cause dimensional problems. The G-10 keys may not be strong enough to withstand the combination of pressure and temperature to which they are subjected during the curing cycle.

A coherent plan to determine the solution to this problem needs to be developed. This plan needs to include:

I. Curing of coils with G-10 keys. Measurements of the G-10 keys before and after curing to see if dimensional changes are taking place.
II. Consideration of alternate materials for keys if the G-10 is not dimensionally stable.

c.) End parts, being thicker than the 40mm parts, are much stiffer as stated above in 4a. They are difficult to place over the coils during winding. Slots in the parts might also relieve this problem.

d.) Keys and end clamps are both relieved by a small amount to allow the kapton ground wrap to extend beyond the collar laminations longitudinally (into the area which is covered by the end keys and end clamps). A relieved key is shown in Figure 3. This is done to prevent the possibility of a ground short between collars and coil. The relief in the key is only 3/8 inch while end clamp relief is 1/2. The key needs to be changed to 1/2 inch to conform to the end clamp. This will be done by Jeff Brandt.

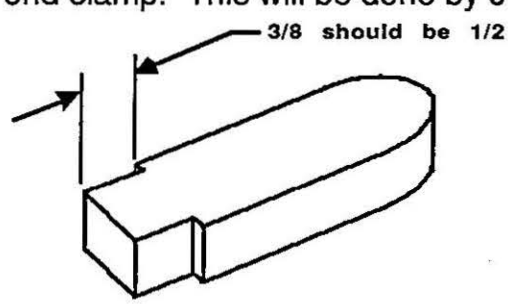

Figure 3.

e.) The key relief referred to in 4d creates an inconvenient situation for the magnet assembly crew. The key must be placed into the coil before ground wrapping takes place. The technician assembling the ground wrap must therefore force the ground wrap into the small space provided between the key and coil pole turn. The solution may be to separate the relieved area of the key from the rest of the key as shown in figure 4. The relieved area would be a 1/2 inch long straight section of G-10 key and could be put in place after the ground wrap is completed. This and other solutions should be considered.

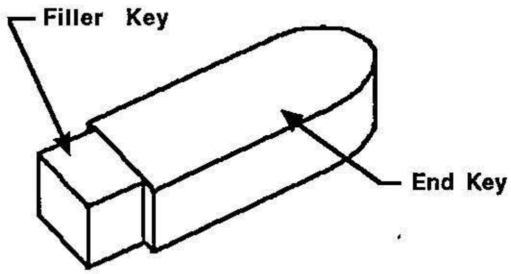

Figure 4.

f.) The long SSC magnets need to have an extra piece of "copper only" cable soldered to the parting plane lead of each coil as it passes through the saddle. This is done for thermal stability. This should also be incorporated into the short magnets for the purpose of learning what difficulties this lead may present. It was not used on DSA321. It will be incorporated on future short models (probably beginning with DSA324). The saddles on both inner and outer coils need to be modified to accept the extra piece of cable.

g.) Shoulder bolts will be used to attach the bullet preload plate to the end clamp. (Refer to 12h). Holes need to be placed in ends of the saddles to allow clearance for these shoulder bolts (probably just the outer saddle).

5.) Curing:

a.) Even with improved end parts, end preloading techniques and consistency in winding tension, there is still likely to be some inconsistency in the length of coils. As a result it is necessary to have a tool to trim the backs of saddles after curing the coils. This will allow all coils to be physically the same length. This tool needs to be designed.

b.) The wedge closest to the parting plane on the inner coil often scrapes against the retainer as the coil is compressed into the mold. This scraping causes the glass tape and insulation to come off the wedge.

This is likely a cross section problem. The wedge has a very large angle and must rotate significantly in the mold to be pushed into position. Improved low friction mold release might relieve the problem somewhat. We will experiment with different mold releases. It is not likely that this problem can be completely eliminated without a change in the cross section.

c.) Coil size varies by as much as .005 inches within a coil. Many factors can be contributing to these size variances. A study of consistency of tooling parts and all factors related to coil size variances is being coordinated by Dick Sims.

d.) Discrepancies exist between the curing mold size as measured and the coil size measurements. Coils measure at 12000 psi about 10 mils larger than curing mold measured size. This problem needs to be studied in detail.

e.) Temperature/ pressure sequence for curing is still unresolved. This will be determined by a combination of the results of the end part study (4a), The coil size variance study (5c) and the coil size measurement study (5c and 6b).

<u>6.) Coil Measurements</u>

a.) Measurement of one short coil takes about a day. Meaurements are very labor intensive. A new automatic measuring fixture is being developed which will dramatically reduce measuring times.

b.) Discrepancies exist between the curing mold size and coil measurements as stated above in 5d. Coil masters are inconsistent in size. Differences in hysteresis between coil and master may be related to excessive fixture deflections. This problem is being studied by Dick Sims. New masters have been ordered with more tightly held tolerances.

c.) Radial measurements are done by hand with a micrometer. A new method needs to be developed which takes less time and is less dependent on the individual taking the measurements.

<u>7.) Ground Insulation:</u>

a.) All ground insulation was, by design, supposed to end 1/2 inch into the end clamp as shown on Figure 5. This does not allow for the outer coil caps to extend through the end clamp, causing an upper-to-lower coil short possibility to exist on the ends (although this same situation exists on the

Tevatron without any problems). The outer coil caps on DSA321 were extended all the way to the end of the coil as shown on Figure 6. The extra radial space at the poles was filled in by .005 kapton. This creates a .005 inch interference fit radially inside the end clamp area. This is not thought to be a problem because preload in this area is traditionally too low. Kapton also provides a slip plane for the coils and end parts against the end clamps.

This system will continue to be used on SSC short magnets until heater strips are incorporated. At that time the entire end ground wrap system will be changed.

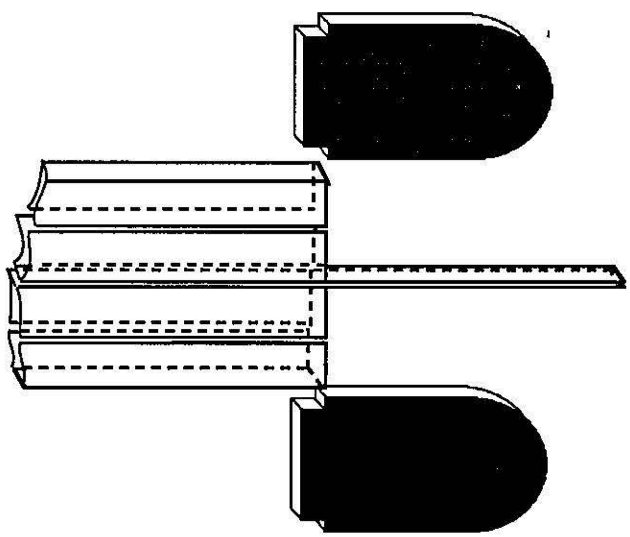

Figure 5.

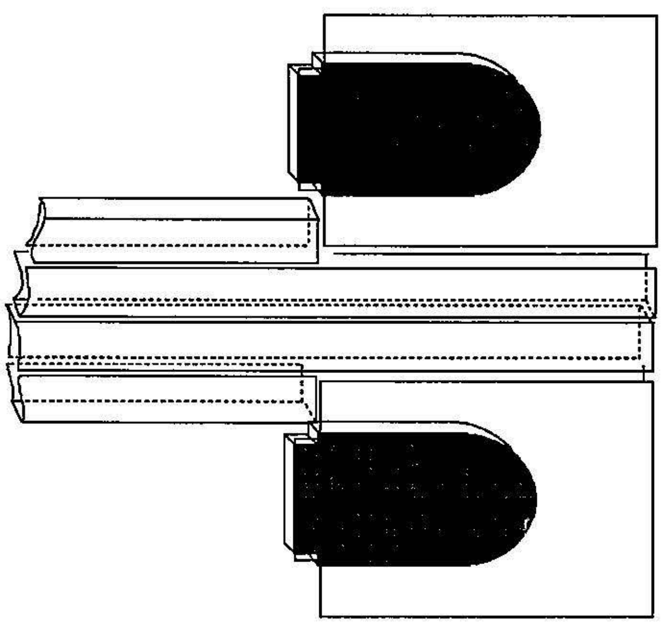

Figure 6.

b.) The short magnet does not provide for heater strips. Even though they are not necessary for the operation of short magnets, they should be incorporated for two reasons.

- To test heater strip operation.
- To learn about any assembly problems associated with heater strips before the long magnet program begins.

Heater strips will be included in short magnets, probably beginning with DSA324. Heater strip design is being done by Howard Fulton in consultation with Chris Haddock of the SSCL. End clamp and ground wrap modifications necessary to allow the heater strip to be included are being done by Howard Fulton.

c.) The collaring shoe, although it did not cause any obvious problems during assembly, does have drawbacks. It's use should be discussed and determined. Several factors should be considered when discussing the relative merit of the collaring shoe.

- Is the shoe an assembly aid or a hindrance? Consider both long and short magnets.
- Is protection for the kapton from the collar laminations really necessary? Look at corrugations of kapton under the brass shoe in DSA322.
- Is the shoe necessary to prevent kapton failure in case of a quench? A magnet without shoes should be built with spot heaters at critical areas to induce quenches. Collar laminations are being designed for 50mm magnets without collaring shoes.
- Can the collaring shoe cause quenches, as in 7d?

d.) The collaring shoes in DSA320 and DSA321 are shorter than they should be azimuthally. The shoe was purposely left short to avoid the excess buildup of kapton at the corners where the shoe ends. It appears from looking at the DSA320 cross sections that it is so short that the pole turn of the outer coil can be left partially unsupported. DSA321 had it's first training quench in the outer coil pole turn. Could it be related to the short collaring shoe? In any case the shoe width needs to be changed.

e.) Kapton ground wrap layers are all .005 thick. Thinner kapton would allow less thermal contraction. .003 is available and reportedly has a resistance to mechanical punch through about equivalent to .005. It's incorporation into the magnet should be considered. The collar lamination which does not use collaring shoes (7c) could also provide for the thinner kapton layers. The insulating properties of the .003 kapton also need to be verified.

8.) Collaring

a.) The "overcompression spike" was very large on DSA321. This is the difference between the coil preload at maximum press pressure during collaring and the preload in the final keyed assembly in the free state. A large overcompression spike is expected with the square key method of collaring. Nevertheless, it is always desirable to reduce it. Methods of reducing the amount of overcompression will be considered by Masayoshi Wake.

b.) The lower half of the collaring tooling was unavailable for DSA321. The upper half was split into two sections and used on both the top and bottom of the magnet as shown in Figure 7. The collaring tooling, after being split in two pieces, was only 36 inches long. As a result, the magnet had to be collared in two sections (incrementally).

The keys, instead of being pushed in by hydraulic cylinders, were placed in by hand. No problems resulted from the altered collaring procedure. Future magnets will be collared with the regular collaring tooling.

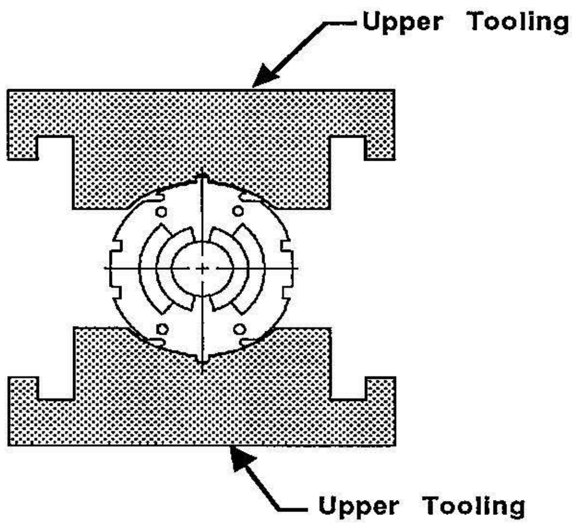

Figure 7.

c.) The regular collaring press was unavailable for DSA321. The Tevatron collaring press was used. No problems resulted. The regular press will be used on all future magnets.

d.) There is a groove in the collars for the strain gage wires. It was too small. Yokes had to be chamfered to avoid pinching the wires. They were chamfered at the yoke parting plane (coil pole) by approximately 1/8 inch by 45 degrees. This will have some small effect on the magnetic field. Future magnet yokes will also need to be chamfered until the collar laminations are modified. It is likely these modifications will be incorporated by magnet DSA325.

e.) Collar and tooling deflections during the collaring process are unknown. These measurements are usually taken but were bypassed on DSA321 to save time. They will be taken on future magnets.

f.) Clearance between the collar pack pin and the hole in the collar lamination is very tight (.000 minimum thru .012 maximum by design). When the pins are manufactured the diameter near the flared end becomes slightly larger due to the flaring operation on the end as shown in Figure 8. This creates an interference fit between the pin and the collar for the last three or four spot welded pairs. The temporary solution has been to drill the holes in these pairs out slightly larger to fit the pins. A long term solution needs to be determined. Either the manufacturing process on the pin will need to be modified to prevent the pin from flaring or the collar lamination hole clearance will need to be increased.

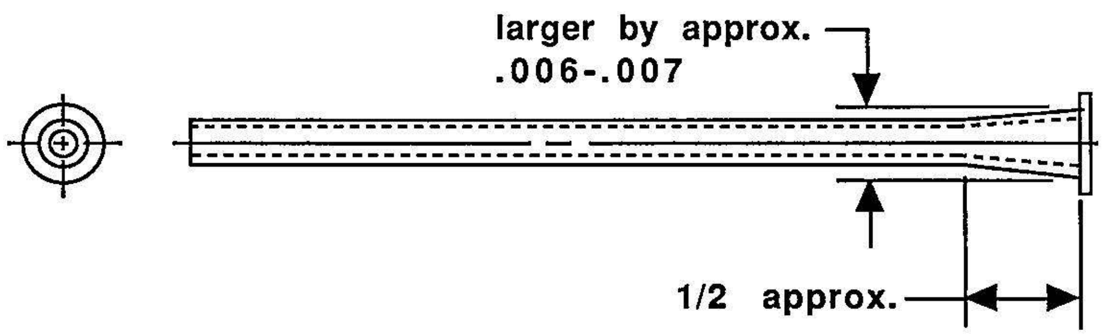

Figure 8.

g.) The collar lamination manufacturer says that there are several places on the collar lamination in which the corners are too sharp. Excessive die wear is the result. Several radii will be changed on the collar lamination drawing #1012-ME-292059 to reduce die wear.

9.) Strain Gage Pack

a.) A 1/8 inch thick by 1/2 inch diameter spacer is used to separate laminations in the center of the strain gage pack. This space provides an area for the strain gage wires to exit the pack. There is a hole in the center of the spacer for the collar pack pin. The part is the same as was used on the 40mm magnets. It's hole needs to be increased in size for the larger 50mm collar pins.

b.) When the collared coil was disassembled due to the turn-to-turn short, a serious amount of damage to the ground wrap was observed in the strain gage area. The sharp corner of the outer coil transducer block (as shown in Figure 9) had cut into the kapton ground wrap layers. Two of the three layers were completely severed. This problem did not exist on the 40mm magnets because the transducer block, due to the different geometry, did not directly contact the ground wrap. The solution on DSA321 was to round the corners on the transducer block before reassembling the magnet. This may or may not be an acceptable long term solution. Two steps need to be taken:

- Collar DSA322 with the rounded corner outer transducers. Dissasemble and inspect for damage.
- Calibrate some transducers both with and without the rounded corners to see if the calibration is affected by the rework.

The results will determine whether this solution is acceptable for the 50mm magnets.

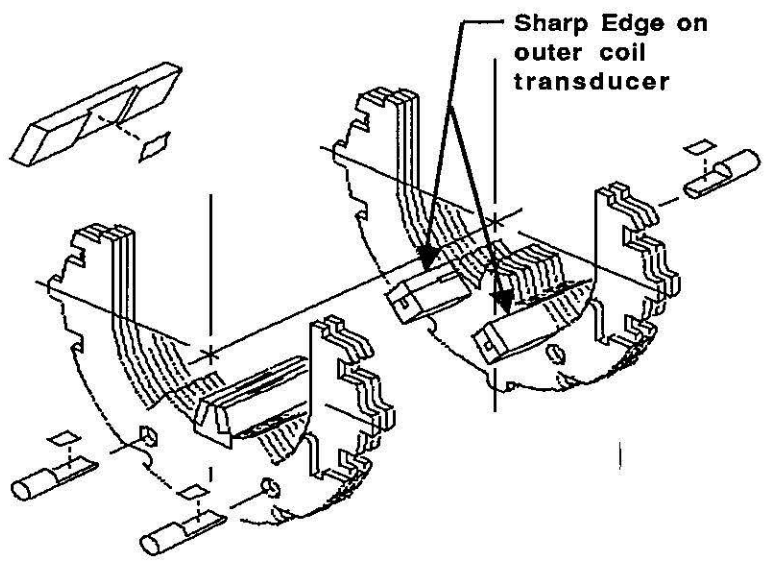

Figure 9.

c.) The placement of the strain gage wires between the strain gage pack and their exit from the magnet is not documented on any drawing. This should be included on the collared coil assembly drawings.

d.) There is nothing in the design to provide an exit for the strain gage wires at the point where the collars end and the end clamps begin. The temporary solution has been to grind grooves in the last few yoke laminations at assembly. On future magnets the end clamp end plate will be grooved by the manufacturer. This groove will be added to the end clamp drawings.

e.) The inner transducer backing block was made to be used with laminations that include collaring shims. As a result a .025 brass shim must be placed beneath the transducer at assembly (.025 is the collaring shim thickness). This is inconvenient and invloves the risk of losing or misplacement of the brass shim. A new inner transducer backing block is being ordered which is made for laminations without shims. It should be available by magnet DSA323.

f.) The outer transducers are consistently high azimuthally by approximately .003 inches according to measurements. The program which makes the groove in the lamination in the Village Machine Shop needs to be changed slightly.

10.) Voltage Taps

a.) Two voltage taps are connected to each inner-to-outer coil splice. The present end clamp design provides no exit route for them. The end clamp drawings will be modified to add this provision.

b.) The physical position of the voltage taps and the routes their wires take as they exit the magnet is not shown on the assembly drawings, although a separate voltage tap drawing is available. This information must be added to the collared coil drawings.

11.) End Clamps

a.) Azimuthal fiber G-10 was used for the collet end clamp pieces for DSA321 due to the immediate unavailability of other materials. The material should be changed and parts should be molded in the long term. Manufacturing of molds and discussions of alternate materials are taking place.

b.) Magnet leads interfere physically with the hydraulic fixture which is used to drive on the end clamps. The fixture will be modified.

c.) There is currently no provision for heater strips in the end clamps. The drawings must be modified to accept the heater strips as soon as they are available. The inclusion of heater strips is discussed in 7b.

d.) The end clamp "collet" pieces need to be changed to accept added ground wrap. This will be needed when the heater strips are included as discussed in 7b.

e.) As discussed in 4e, filler keys need to be added to the magnet. It may be possible to incorporate these filler keys into the end clamp design. Possible changes to the end clamp collet pieces need to be discussed.

f.) The large exterior can of the end clamp must be driven onto the collet pieces from the inside "collared' area of the magnet toward the ends as shown in Figure 10. It is therefore necessary to slide this part onto the collared area of the coil before installation begins. When sliding the can onto the coil, there is a physical interference between the end clamp can and the inner-to-outer coil splice. The face plate of the end can must be slotted to allow the can to slide over the end without excessive bending of the splice

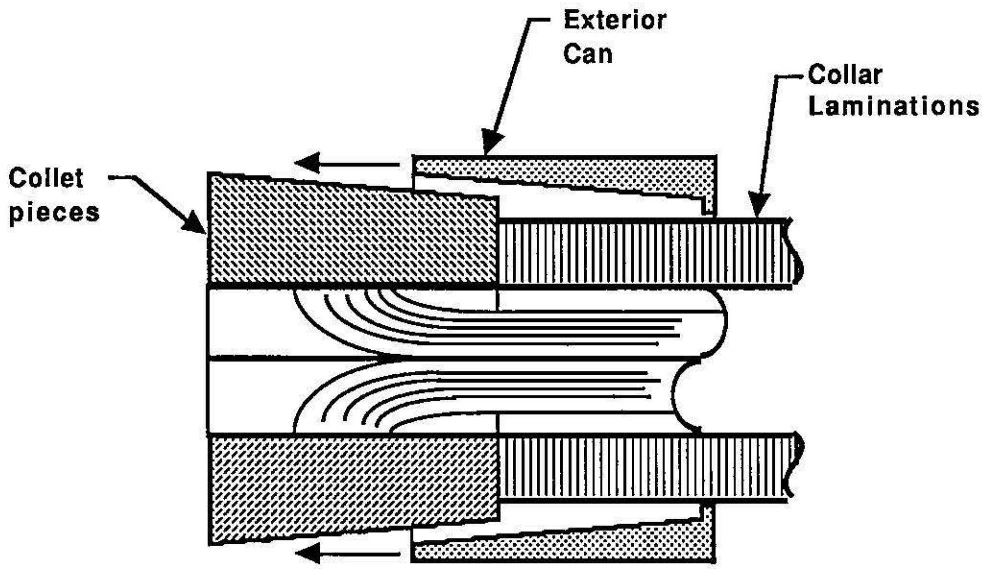

Figure 10.

g.) Grooves needs to be cut into the end clamp face plate to allow the strain gage wires to exit the collar coil assembly as discussed in 8d.

h.) On the lead end, the outer-to-outer coil splice (the U shaped splice) is pressed between two G-10 plates inside the end clamp. There are several screws which hold these two plates together. The holes for these screws are open both to the end clamp end cap and the collet end clamp pieces. Although there is very little chance that the screws could actually make electrical contact with the leads, voltage tap wires or heater strips, it seems prudent that any possible path be closed. The solution on DSA321 was to add a piece of .005 kapton to the face of the G-10 plate. A long term solution is needed. Making the screw holes blind (not drilling them all the way through the G-10) will accomplish this. The end clamp length may need to be increased for this purpose.

i.) The upper-to-lower splice was made as a single lead as discussed in 4f. End clamp parts need to be modified to accept the double lead.

j.) End clamp deflection on DSA321 was very small. It is impossible to predict the preload with deflections of this magnitude. It seems likely that the preload on the ends of DSA321 were small, although the magnet performed well. We want to consider changing end clamp exterior wall thickness and/or material. Supporting the end clamp with the iron at the coil parting plane is also an option. These matters need to be discussed and resolved.

k.) It is difficult to azimuthally align the exterior of the can with respect to the coil. It is necessary to achieve this alignment to take deflection measurements and for the bullet placement. A solution needs to be worked out.

l.) Lead end clamp on DSA321 was 3/8 inch longer than the design because the splicing fixture and parts did not match. This has been resolved and will not be a problem on future magnets.

12.) Yoke, Skin and Final Assembly

a.) The end plates were not recessed at the skin parting plane to accept the alignment keys. They need to be revised for DSA323.

b.) The weld preparation on the end plates has been modified since the end plates used on DSA321 were ordered. This will require a modification in the skin length. Assembly and detail drawings need to be changed to accept the new design. The new style should be incorporated by DSA324.

c.) Yoke filler laminations are used in the end plate area to support the skin when the magnet is cooled. They were not used in DSA321 because the material from which they are made (high manganese steel) was not available in time. They will be incorporated as soon as possible (probably around DSA324 or DSA325). Until they are used, the assembly procedure during the yoke and skinning must be altered.

Assembly procedure with filler laminations:

1.) Assemble yoke laminations, filler laminations, skins and alignment keys around collared coil.
2.) Put cold mass in press without end plates or bullets.
3.) Make longitudinal weld on alignment key.
4.) Remove cold mass from press.
5.) Cut skin to final length.
5.) Install bullets
6.) Install end plates.
7.) Weld end plates.
8.) Adjust bullet positions.
9.) Apply preload to bullets and lead end preload screws.

Assembly procedure without filler laminations:

1.) Cut skin to final length.
2.) Assemble yoke laminations, skins, alignment keys, bullets and end plates around collared coil.
3.) Put cold mass in press with end plates and bullets.
4.) Make longitudinal weld on alignment key.
5.) Remove cold mass from press.
6.) Weld end plates.
7.) Adjust bullet positions.
8.) Apply preload to bullets and lead end preload screws.

The alternate assembly procedure is required because the end plates must be installed before making the longitudinal weld if filler laminations are not used. If the longitudinal weld is made without filler laminations or end plates, the skin will distort too much to install the end plates. The end plates then cannot be removed after the longintudinal weld is made because the welding causes the skin to be pulled tight around the end plate. There are two disadvantages of the alternate procedure:

- The skin must be cut to size before welding, thereby making it hard to ensure that the skin end is perpendicular with the longitudinal plane of the magnet.
- The assembly of the bullets is slightly more involved, since they must be kept roughly in position during the entire cold mass welding procedure.

d.) SSC magnets, by design, have a "monolithic" yoke pack on each end. A monolithic pack is identical to a regular pack except that all laminations have been epoxied together. This is done to give the yoke assembly enough column stability so that it will not collapse under the pressure of the yoke and skinning press before welding. All yoke packs were mistakenly made as monolithic packs in DSA321. This will be corrected in future magnets. No problems resulted from this mistake.

e.) The screws which hold the yoke packs together were not strong enough. some failed during the individual pack assembly. A new screw design has been incorporated. It will be used on DSA323.

f.) The yoke packs, which presently have four pin holes, still do not retain a shape sufficiently parallel to meet the magnet requirements. Packs are "bellevilled" by as much as 1/8 inch on a 24 inch pack as shown in Figure 11. Several solutions are available. A fifth pin is possible. Welding of yoke packs is also being tried.

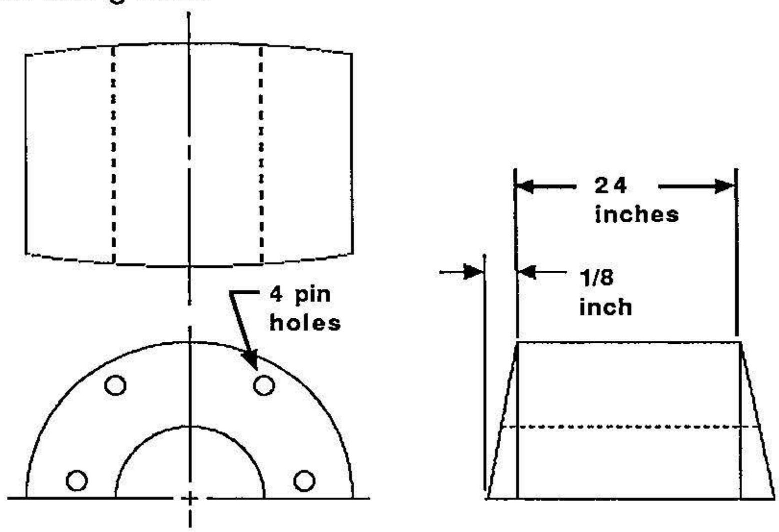

Figure 11.

g.) The end plate needs dowel pin holes to accept the harmonic probe that is used in Lab 2. Without these holes the harmonic probe cannot be aligned. They were put in the plates after from sketches for DSA321. They need to be incorporated into the official end plate drawing. These holes will not be needed for the long magnets.

h.) The bullets are held onto the end clamp by means of a plate (called the preload plate) with two screws. The holes are by design placed on the vertical axis. On the 40mm magnets, the bullet/preload plate assembly was bolted firmly onto the end clamp. Alignment between the bullets and the end plate was done by adjusting the end plate at final assembly. This method will not work on the 50mm design because the end plates are welded to the skin and consequently not adjustable.

The 50mm solution is to drill oversize holes into the bullet preload plate. It is loosely attached to the end clamp by shoulder bolts through these holes before the endplate is installed. The bullet preload plate position is then adjusted to conform to the end plate after the end plate has been welded. The holes in the preload plate must be changed to the horizontal plane to allow access through the end plate. The assembly is shown in Figure 12.

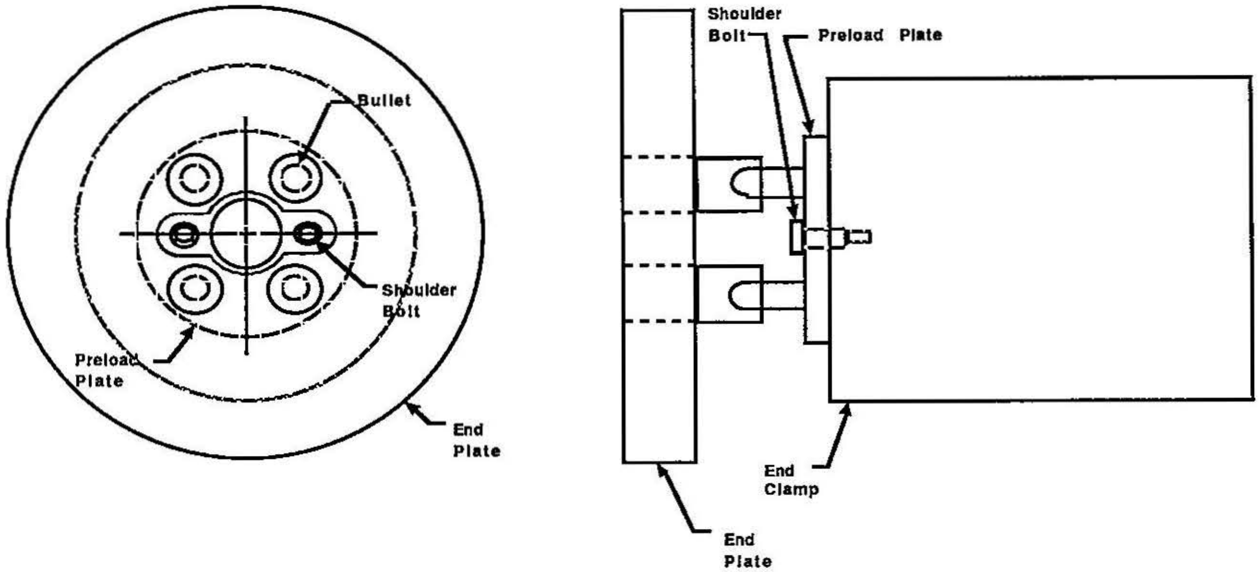
Bullet
Shoulder Bolt
Preload Plate
End Plate
Shoulder Bolt
Preload Plate
End Clamp
End Plate

Figure 12.