FERMILAB-EN-0099

MISCELLANEOUS NOTES ON STEEL AND LAMINATIONS FOR THE MAIN RING MAGNETS

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February 5, 1968

The following notes will summarize some of the preliminary contacts with industry regarding laminations for the fabrication of the main ring magnets. The information contained herein is of a tentative nature and will most surely change as model studies are made. But perhaps the notes will be a useful background for the model work and for further negotiations with industry.

Magnet steels

We are looking for a steel that will go to high induction and will also have a low and uniform coercive force. It would be highly desirable to choose a steel which is a standard product for which production techniques are well established. One would expect that such a choice would hold down the cost and would assure an adequate production rate.

During the latter half of October, 1967, we discussed the availability of various steels with representatives from several steel companies. At the end of October we also held a meeting on magnets, at which Mssrs. Doles and Kilpatrick from LRL reported that their studies had led to trying decarburized steel for the prototype magnets. From the discussions at this meeting and with the steel vendors we concluded that we should look at the low carbon steels and in particular at the decarburized product.

A listing of our meetings with steel vendors is given in Table I. From these discussions we obtained the following information:

1. The high-field capability of low carbon steel is not increased appreciably by reducing the carbon content below about 0.05%, provided an optimum anneal is performed. Proper annealing can also reduce the coercive force to about one oersted but the steel may age through the migration of the residual carbon to the grain boundaries, resulting in an increase in H_c to 2 or even 3 oersteds. (However see the later comments on the steel in the CERN PS and the Argonne PS)

2. Silicon steels would provide low coercive force but the addition of enough silicon to go to $H_c = 1$ oersted (about 1.5% silicon) would involve a small but significant reduction in the high field capability. In addition the cost of this steel would be about 30% higher than that of standard low-carbon or decarburized steel.

3. *Decarburized steel runs about 0.002-0.005% carbon and costs about* the same as low carbon steel having about 0.05% carbon. The process of removing the carbon in the open hearth is nearly as costly as the extra open-coil anneal which is used in the decarburizing process. Decarburizing is limited to a thickness of 0.062 inch or less. This is probably the limit on stamping also. The use of heavy plate construction will not be discussed here.

4. Decarburized steel should not age. The initial value of H_c depends on the anneal and can be made somewhat less than 1 oersted. Working the steel beyond its elastic limit will tend to increase H_c, but there is not much information on this property. Armco reported that they had bent a sheet of 16 gauge decarburized steel to a radius of about one foot and then straightened it without anneal. The effect on H_c was small, less than 20%.

5. Other impurity elements in the decarburized steel should be kept below about 0.03%, except manganese which will be about 0.3%.

6. Most vendors agreed on the amount of crown to be expected on 16 gauge sheets. The variation of thickness ocross the entire width of the sheet would be about 0.0015 inch. If 1-1/2 inches is removed from each side of the roll, the remaining crown is about 0.0005 inch.

7. A C-5 core plate (10 ohms cm^2 at 500 psi) can be applied by Armco, USS and Allegheny-Ludlum at a cost of $12 per ton. Armco may want an extra for this since they do the core plating and decarburizing at different plants. C-5 core plate would add about 0.0001" to the total thickness if applied to both surfaces.

8. The C-5 core plate provides more insulation than is required for the main ring magnet cycle. Another interesting possibility is the use of a steam blue oxidation (about 0.1-0.2 ohm cm^2). USS can apply to low carbon steel but not to decarburized steel. At least one stamping company (Tempel) is equiped to apply this oxide layer after stamping. Armco and USS suggested that normal mill oxidation may provide sufficient insulation. Very little is known about the control of such a layer.

9. The steel can be supplied in cut sheets instead of coils to reduce the amount of working after the anneal. Armco estimated an extra of $4 per ton.

To obtain some representative samples of steel for model magnets, proposals were sought from all major steel companies by sending out NAL Request for Proposal No. 1114-671. Separate proposals were requested for 5 tons of decarburized steel and 25 tons of low carbon steel (0.06-0.08% C), annealed to develope fully their magnetic capabilities. Proposals were also requested for an inorganic core plate and/or a controlled oxide surface layer. No other specifications were written but the vendors were informed that low coercive force, low crown, and flat laminations were required. The main features of the proposals which were submitted are given in Table. 2.

From these proposals the steels listed in Table 3 were ordered. They represent a good sampling of what is commercially available and of interest to us. The 25 ton lot will provide enough steel to fabricate a full length magnet and several 3-foot models for magnetic studies. The 5-ton lots will each provide enough laminations to make two 3-foot models. Additional quantities of any of these products can be obtained in about six weeks.

Magnetic data on samples of these steels have been obtained by E. Rowe at PSL, using their null-gap permeameter. Some representative results are given in Table 4. It must be remembered that these are preliminary results from single samples and cannot be taken seriously until more results are available.

Not much can be said about a choice of steel until results of field plots on model magnets are available. But from the information available to us now, the USS Vitrenamel 1 appears to be the best buy. If the more expensive Armco product looks good enough in the model tests to warrant the extra cost, then one or more of the low-silicon steels should be investigated, since they are in a similar price range. But the models will provide the answer.

Several puzzles are presented by the magnets in the PS and the ZGS. The PS magnets are made of 16 gage laminations of 0.06% carbon steel. The mean coercive force is about 0.9 oersted with 90% of the steel between 0.75 and 0.95 oersted. Evidently no appreciable increase in coercive force has taken place. The steel in the ZGS magnets is in the form of 1/2 inch plates of 0.08% carbon steel. The residual field in the magnet is about 20 gauss, corresponding to an H_c of about one oersted. The variation in the residual field among the magnet blocks is about 0.5 gauss. Perhaps more information should be obtained concerning these steels.

Dies and Laminations

Before asking for bids on dies and stamping for laminations for model bending magnets, we discussed the general problem with a number of industrial representatives who are listed in Table 5. After the bids were received we made a four of the plant of Northern Metal Products Company. We had earlier visited the plant of Tempel Steel Company. Discussions were based on stamping 16 gage.low-carbon steel having a hardness of about Rockwell B 40, but other gages were also considered. The following comments are those on which there was general agreement among the potential suppliers:

1. To stamp out one half-lamination for the bending magnet, a force of about 70 tons is required. A press rated at least twice this force, and preferably three times this force, should be used.

2. Standard practice for precision stamping is to use a die clearance that is 5% of the gage. Cut edge should then show 1/3 shear and 2/3 break with a burr about equal to the clearance - for 16 gage this means a 3 mil burr. As the die clearance is reduced the shear surface should get larger and the burr smaller, but the die will wear more rapidly. Low carbon steel with a soft anneal may not behave this way. Hydrocam reported the results of some trials with Armco decarburized steel and varying die clearances, the values of which were not reported:

Trial	Shear	Break	Burr
1	75%	25%	.001"
2	50	50	.0007
3	40	60	.0005

After making these tests they recommended a die clearance of 2 mils and were willing to accept a burr specification of .001" maximum. Carbidex stated they were able to hold 0.0003" burr tolerance on LRL stampings but we can see much larger burrs, peaks up to 0.004", on one sample.

3. It is considered good practice to round off corners with a radius equal to the thickness of the lamination. Opinions varied on the amount of excess die wear at sharper corners.

4. There is a general preference for stamping directly from coils if this can be done without impairing magnetic properties. We would probably have to add 25% to cost of stamping if we use sheets instead of coils. Pay-off arbors generally go up to 24" diameter, although for such a large job no significant cost extra should arise by using a larger arbor.

5. Dry stamping may cause excessive burrs. It may be possible to use an air-drying lubricant.

6. Most stampers would use a compound carbide die for the production run although Hydrocam recommended a progressive die in which a thin shave on the cortical edges could be performed as the last step. Coenelation could be easily handled in a progressive die.

7. Estimates of stamping rates varied from 700 hits/hour to 100 hits/min. The slower rate was suggested by Northern Metal Products, who recommended that B1 and B2 laminations be stamped simutaneously in a 500 ton press. At this rate we would need a little more than 200

working days of 20 hours stamping time to produce the magnets without spares. A somewhat higher rate would be desirable - perhaps 1200 double hits per hour. We believe it would be highly desirable to avoid duplicate dies, although spare dies would be required to avoid a delay if a production die suffered major damage.

8. Annealing after stamping should be avoided. Tempel tried several samples and found that critical dimensions changed beyond tolerance limits.

9. In general stampers do not apply insulating layer to laminations. They prefer to have this done at the mill. However, Tempel has excellent facilities for steam bluing which involves heating the laminations to 1000°F. This has been done with no warping. A sample of Armco decarburized steel, which was stamped then blued, has been sent to PSL to check the magnetic properties.

10. Standard flatness tolerance for finished laminations seems to be about 0.005" per inch. I doubt that there is any reason to try to improve on this.

11. Carbidex recommended that we consider using a hot rolled steel to take advantage of the mill scale as an insulating layer. It seems unlikely that such a product would have magnetic properties comparable to those of the decarburized steel, but they submitted a sample from National Steel and this has been sent to PSL for measurements. Carbidex claims they could stamp this material in a thickness of 0.097".

A purchase order contract is being given to Northern to make the ~~laminations for the models of the bending magnets~~. Their bid was ~~the~~ lowest and they seem to have good facilities for doing the job. Consideration was given to splitting the work between two companies, giving the coated material to Northern and the uncoated to Tempel to look at the steam blue process, but the high tooling charge submitted by Tempel discouraged us. For the model work the uncoated laminations can be coated by technicians. The steam blued USS steel will be available to study the effectiveness of such a layer.

Perhaps another stamping company should be involved in the model program. For instance the quadrupole laminations could be stamped elsewhere by re-shipping some of the steel from Northern or by purchasing more steel.

Perhaps a few numbers relative to quantities of stampings would be useful. The quantities of steel on hand for the first models are a bit low, because we increased the model length from 2 to 3 feet after the steel was ordered.

For a 36" model we need (for 34" of laminations) 1088 stampings. For a 239" model (237" of laminations), 7584 stampings. To allow for gage variation we should obtain 1150 stampings for a 36" model and 8000 stampings for a 239" model.

Assume a density of 0.284 lb/cu. in. for the steel and a blank size of 7-1/2" x 27" for each stamping, then:

1150 stampings require 4100 lbs of steel

8000 stampings require 28500 lbs of steel

We can obtain two 36" models from a 5 ton roll with nearly 2 tons left.

A suggested partial allocation of the steel follows:

Armco	5 tons coil 36" B1 and B2 models (1150 stamping each)
	5 tons sheets 36" B1, save rest for quad model.
USS Vitrenamel 1.	5 tons coil 36" B1 plus quad
USS	.08C 25 tons coil 36" B1, 239" B1, plus full quad.

Inamel		5 tons coil	Perhaps 36" Bl.
Inland	.08C	5 tons coil	?

I am sure this allocation can be improved.

Miscellaneous Comments

While talking to steel suppliers we discussed steel shapes for the magnet structures. Of particular interest to us were the welded shapes produced by Inland Steel. Wilson and I visited their mill and were impressed by the quality of the finished products and the flexibility of the production facilities. Standard dimensional tolerance is about 1/4 inch for 20 foot lengths. This could be reduced to 1/8 inch with a modest premium in cost. Mr. Arthur Westrich is their structural engineer (Chicago Office) who should be contacted about these shapes. Ryerson is a subsidiary of Inland and has a major fabricating plant in Melrose Park.

American Bridge Division of U.S. Steel also expressed an interest in the magnet structures and submitted a schematic design for the bending magnets. Mr. C. N. Ludman, their assistant district engineer in the Chicago Office, can be contacted concerning their future involvement.

Table 1

A list of representatives from various steel companies, with whom we discussed steel for main ring magnets.

Jones and Laughlin — 19 October 1967

A. M. Goodman, Metallurgical Engineer, Chicago

Bethlehem — 19 October 1967 , by telephone

W. McArdle, Bethlehem Office

Inland — 20 October 1967

F. W. Robbins, Sales)
P. A. Speer, Quality Control) — Chicago

Armco — 26 October 1967

D. Dieterly, Research)
R. W. Easton, Research)
J. R. Trimble, Product Supervisor)
T. Pyle, Sales, Chicago) — Middletown, Ohio

USS

D. E. Coass, Sheet and Strip Products)
P.D. Ohrman, Metallurgical Engineer) — Pittsburgh

L. Brunner)
J. D. Bradley) — Chicago Office

Republic

J. S. Watso, Technical Service — Warren, Ohio

L. L. Anderson, Sheet & Strip Division — Cleveland

W. C. Hatch, Sales, — Chicago

Allegheny Ludlum

G. P. Seitanakis, Devel. Engr. — Brankenridge, Pa.

C. F. Plazak, Sales — Chicago

Table 2

Summary of bids received for model magnet iron

Vendor and type of steel	Price per ton	Core plate Price per ton	Freight per ton	Coil ID
USS				
Vitrenamel 1 (Decarburized)	$158.50	C-5, $12	$13.60	20"
Spec. Vitrenamel 1	184.50	No	"	?
CR Sheet	150.50	C-5, $12	"	20"
(.08% C)		Steam blue		24"
CR Sheet	152.50	C-5, $12	"	20"
(0.06% C)		Steam blue		24"
Armco				
Decarburized	220.00	No offer	?	24"
Inland				
Inamel (Decarburized)	159.50	No	6.80	24"
CR Sheet (0.08% C)	145.50	No	"	24"
CR Sheet (0.10% C)	142.50	No	"	24"
Allegheny Ludlum				
CR Sheet (0.015% C)	331.00	C-5, $12	?	?
CR Sheet (0.08% C)	243.00	C-5, $12	?	?
Jones and Laughlin				
CR Sheet (0.06% C)	157.30	No	Incl.	24"

Notes: 1. The USS Special Vitrenamel 1 is an extra coil of the steel made for the LRL prototype magnet.

2. All vendors can supply products at the rate of 2000 tons/month, except for Inland's Inamel which cannot be produced at this rate.

3. The steam blue on the USS CR Sheet was offered at no extra cost.

4. It is assumed that the Allegheny Ludlum 0.015% C steel is a decarburized product.

Table 3

Quantities of steel on order

Mfg.	Type	Tons	Coating	Form
USS	Vitrenamel 1	5	C55	Coil, 20" ID
USS	CR Sheet (0.08% C)	25	Blue steam	Coil, 24" ID
Armco	Decarburized	5	None	Coil, 24" ID
Armco	Decarburized	5	None	Sheets
Inland	CR Sheet (0.08% C)	5	None	Coil, 24" ID

Notes: 1. All steel is to be delivered to Northern Metal Products Company, Franklin Park, Illinois.

2. All coils and sheets are to be 27" wide.

3. Sheets are to be cut in 109" lengths.

Table 4

Preliminary results from B-H plots on single samples of various steels. The coercive force is given for the cycle between H = $\pm$ 150 oersted. B is given in kilogauss, H in oersteds.

Supplier	Type	Hc	B			
			H = 10	100	200	350
Armco	Decarburized	1.0	14.6	17.8	19.4	21.1
USS	LRL	1.0	14.0	16.9	18.6	20.2
"	Vitrenamel 1	1.5	15.0	17.8	19.4	21.0
"	Vitrenamel 2	3.0	13.2	16.9	18.7	20.0
"	0.06% C	2.6	13.9	17.2	18.9	20.7
Inland	Inamel	5.5	12.3	18.0	19.8	21.5
"	0.05% C	1.3	14.2	18.1	19.7	21.3
"	Intorq A-1	3.2	13.2	17.4	19.2	21.1
Tempel	Tempcore	0.7	13.6	16.6	17.9	19.8

Notes: 1. The Inland Inamel sample, a decarburized steel, was found to have been improperly annealed. Another sample has been submitted.

2. The Tempel steel has been annealed and steam blued after cutting to reduce the carbon content.

Table 5

List of stamping companies and representatives who discussed dies and laminations with us.

Tempel Steel Co., Chicago

Tempel Smith, Pres.

J. H. Ihrig, V. P., Sales

L. E. Medlin, Mgr. E.E.

E. B. Sperling, Mgr, Tool Engr.

Harig Mfg. Corp., Chicago (Dies only)

A. Rasmussen, Sales

R. Nutting, Chief Engr.

Hydrocan Engr. Co., Troy, Mich.

Mr. Pape, Pres.

E. J. Pratt, Sales

Carbidex Corp., Southgate, Mich.

A. E. Chambers, Pres.

Northern Metal Products Co., Franklin Park

A. N. Bendoff, V.P., Sales

L. LaScola

Controls Company of America (Dies only)

Andrick Tool Mfg. Div.

K. A. Anderson, Gen. Mgr.

W. B. Dahlgren, Plant Supt.

~~A. L.~~ Leone, Sales

Table 6

Summary of proposals for dies and laminations for model bending magnets.

Vendor	Die Cost	Other Tooling Etc.	Stamping Cost per lamination	Press Capacity
Hydrocam	$17,150	$120 per run	$0.0404 plus freight	125 tons
Carbidex	21,750	none	0.1108 - 0.315 incl. freight	440
Northern	9,680	none	0.102 incl. freight	165
Tempel	12,950	16,500	0.1493 - .3495 plus freight	250
Demmer	10,450	1,480	0.375 - 1.325 plus freight	200
Lansing	7,300	none	0.111 - 0.22 plus freight	Not given

Notes: 1. Where a spread of stamping costs is shown, the lower figure applies to lots of 20000, the upper to lots of 1000.

2. Carbidex and Demmer quoted on applying an inorganic insulating coating after stamping, but the prices were too high to be considered - comparable or greater than the stamping costs. Tempel's price included a blue steam oxide layer.

3. Northern gave a verbal statement that they would use a heavier press if they had problems with the 165 tons press.

4. Best schedule for making the die was 8-10 weeks, submitted by Northern and Hydrocam.

5. Tempel's added tooling charge included the cost of a ~~roller leveler to handle the 16 gage material~~.

6. Northern's die would be made by Andrick; Tempel's die by Harig.