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TRIP REPORT
VISIT TO SOLAR DIVISION, INTERNATIONAL HARVESTER COMPANY
SAN DIEGO, CALIFORNIA

R. C. Juergens

November 14-15, 1968

Relative to development contract for ceramic insulation selection and application techniques for use on magnet coils.

Persons Visited:

Solar Division

A. R. Stetson, Chief, Process Research Department

J. R. Long, Director of Research

E. G. Rolwing, Contract Specialist

Solar Division of the International Harvester Company has been in the business of developing and selling cermic materials and methods for their application for many years. They have gained special prominence in the field with the evolution of jet aircraft engine manufacturing technology. Their ceramic coatings are widely used in jet aircraft engines at the present time. Solar ceramic coatings have helped make possible the evolution of the gas turbine to its present state. Apart from the manufacture and sale of gas turbines, they make and sell a wide variety of ceramic frit materials used by a great many porcelain enameling firms throughout the country.

The development of a ceramic insulation system for use on accelerator magnet coils is not, at this writing, a matter of dire need. Rather, it represents an anticipated predicament we may one day find ourselves in at some location in the accelerator complex which deserves anticipation and action at this time. Insulation systems for the main-accelerator ring magnets and for the booster-accelerator ring magnets have been tentatively selected. The situation in the beam-transfer area and throughout the experimental facilities complex, especially proximate to targets, has not as yet been established. It is not unreasonable to assume however that at one location or another or at one point in time a "radiation hard" insulation system may be badly needed and it is toward that end that we propose to undertake a "State-of-the-Art" development effort.

Main Accelerator Section scientific and engineering personnel are generally familiar with the initial Project Suggestion received from Solar in June 1968, the scope of which was far beyond the needs of our Laboratory. Following a critique by the writer, which included an evaluation of the Solar ceramic coating samples which were irradiated in the ANL Gamma facility and reported on in a memorandum from Argonne indicating that any and all of the coatings evaluated would be satisfactory from a radiation-resistance standpoint, we received a revised Project Suggestion from Solar. This was dated August 16, 1968, following a visit to NAL, Oak Brook, by Mr. A. R. Stetson of Solar.

The present conversations with Solar in effect validated the revised Project Suggestion, a copy of which is attached.

Solar was requested to submit a proposal for the conduct of this development work. A few of the cogent points relative to its prosecution are as follows:

In order to minimize the time requirements, NAL is to supply all copper samples and uninsulated copper magnet coils to be utilized in the development program.

The coatings tentatively selected by Solar for this development effort are proprietary in composition and are designated by Solar as 71J-3 (containing significant amounts of lead oxide) and S5-8A, having a lower melting point than the material previously mentioned. The 71J-3 material is regarded as a likely conductor coating material. S5-8A may be useful either as an adhesive only or as a coating material as well as an adhesive. Both of these formulations have been radiation tested (to ~ 2×10^{10} rads) as mentioned above and seem to be satisfactory. These findings will be validated.

The amount and type of copper surface preparation required for satisfactory adherence of the ceramic coating must be established. Normal practice would involve the utilization of nitric acid to etch the copper surface. This is not considered, by me at least, to be a satisfactory answer for our purpose, especially when 10 to 20-ft long coils are contemplated. Hopefully, light sanding or sand blasting will be adequate and probably about as much as we would want to contemplate at this time.

Incidentally, the coating formulation, S5-8A is presently being sold to jet engine manufacturers as a compressor housing coating, also used on compressor blades and vanes.

These coatings can be had either as clear or in various colors. The standard color is green although creams, blue and various shades of red are also available. Reds are relatively unstable. At this time, it is thought that we can have almost any color, however, coating function must necessarily be the governing consideration.

The use of steel strapping or other coil peripheral wrapping material was discussed. This wrapping would hopefully be removed after firing of the ceramic, however, a suitable wrapping material and pattern could be left in place and would contribute to the structural strength of the coil. The use of non-magnetic stainless steel as a strapping material was discussed along with the possible use of glass unidirectional fibre or glass fabric. Mr. Stetson point out, however, that the glass would react with the coating and the physical properties of the glass per se would be lost.

Present thinking would have coils fired twice. Initially they would be fired open, that is, with the conductors close together but not touching one another so as to permit fusion of the coating which had been applied as turn insulation. Following the initial firing, additional uncured ceramic would be applied to function as adhesive material upon subsequent firing. Prior to the second firing, the coil would be strapped with ceramic or glass spacers to control turn-to-turn insulation spacing.

Probably two approaches will be employed to control this spacing. One would be to try to fabricate the coil without using spacers of a different material, instead making spacers of the 71J-3 material, controlling its thickness in fabrication, and utilizing the S5-8A material as adhesive. A second approach to the spacing problem would be to use the glass spacers mentioned earlier with 71J-3 self bonded; also trying S5-8A on the spacers self bonded. The bond strength of satisfactory coatings applied with manageable procedures should be determined.

The use of inorganic cements, which are attractive from the standpoint that they offer what is essentially a room termperature cure, merit consideration as adhesives only. They might, however, be valuable from the standpoint of field repair procedures.

The effect of 100% relative humidity on all these coatings needs to be evaluated.

The compatibility of various brazing alloys with the coating in question must be established. Mr. Stetson predicted that Sil-fos and E-Z Flo would be compatible only with the S5-8A material. 71J-3 firing temperature is greater than the brazing temperature of these solders. In phase 2 of the proposed development contract, it seems sensible to me and the Solar people agreed, that when we had arrived at a point where we were contemplating insulating and evaluating a 3-ft long model coil, it would be best to have this coil made by others in bare copper with the turns properly spaced. This could be done in a minimum time by coil makers familiar with forming and brazing techniques. It would also save us from the need to buy another set of tooling and have Solar become familiar with coil manufacture. This coil could then be sent to Solar for application of the insulating coatings, to be followed by shipment to NAL for installation in a magnet iron structure probably already on hand. It was suggested that NAL plan to supply about four complete bare copper coils. The coil geometry to be insulated by Solar should be determined as soon as possible and drawings of this coil supplied to Solar so that jigs and other tools for applying the ceramic coatings and for firing them can be made up, thereby avoiding unnecessary delay.

It was felt that the revised Project Suggestion was otherwise satisfactory, including the portion thereof relative to reports. It was agreed that in addition to the progress letters and the final report mentioned in the Project Suggestion, we would be in frequent touch with Solar as to their status and the progress they were making and that this information would be disseminated promptly to interested NAL sections.

As stated in the Project Suggestion, phase 1 of the program would be completed approximately four months after receipt by Solar of the NAL purchase order and the copper bar material. Phase 2 would be completed at Solar approximately 3 months after completing phase 1, after receipt of the bare copper coils from whomever builds them for NAL.

9% but on AEC contracts was about 10%. Mr. Rolwing also pointed out that Solar has a resident Government auditor, a Mr. R. W. Harris, of the Defense Contract Auditing Agency.

Potting coils in their respective magnet structures was discussed briefly. The use of calcium aluminum silicate as a grout was suggested. I mentioned the possible use of concrete and this, of course, could be used if the inherent porosity of concrete can be tolerated.

Solar's production facilities for firing ceramic coatings are somewhat limited. They can fire a coil which will fit within an 8-ft diameter x 10-ft long, right circular cylinder. Firing ceramic insulating coatings on larger coils would require a search of porcelain enamelers, having furnace equipment of appropriate size with good temperature control in the firing temperature range. Furnaces having forced air circulation are preferable.

Discussion of the commercial and contractual aspects of this development program with Mr. Rolwing revealed that they are developing cost reporting procedures which will supply labor cost data on a project within about one week of the current date. Material cost reporting procedures, at present, are delayed by about five weeks from the current date. A budget estimate is prepared monthly by the engineer responsible for the project which incidentally does not report the percent complete but rather the estimated cost to complete, a far more meaningful figure.

Our present intent is to develop a cost-plus-fixed-fee, i.e., a CPFF contract, which stipulates a dollar ceiling. A definition of our cost ceiling must be made and be satisfactory to Solar, of course. Mr. Rolwing mentioned that the typical fee percentage requested by Solar was about

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19 August 1968

In reply please
refer to 6-3153

National Accelerator Laboratory
1301 West 22nd Street
Oakbrook, Illinois 60521

Attention: Mr. Richard C. Juergens

Subject: Project Suggestion for "Development of Electrical Insulation for the Quadrupole and Bending-Magnet Coils of the 200 BeV Synchrotron Proton Accelerator" Revision 1

Enclosure: Solar RDUP-6818-1 dated August 16, 1968 (two copies)

Gentlemen:

Solar is pleased to present the enclosed project suggestion.

The program contemplated would be performed on a cost-plus-fixed-fee contract. The amount estimated for the task proposed is $33,920.00 including fee.

After you have had a chance to review this suggestion, we would be happy to discuss the technical approaches with you at your facility or here in San Diego.

A formal cost proposal can be compiled and submitted within one week from finalization of the statement of work.

We shall look forward to hearing your comments.

Very truly yours,

E. G. Rolwing, Contract Specialist

EGR:sd

CC: A. R. Stetson
R. H. Essig

SOLAR
DIVISION OF INTERNATIONAL HARVESTER COMPANY
2200 PACIFIC HIGHWAY, SAN DIEGO, CALIFORNIA 92112

RESEARCH LABORATORIES

REVISION 1

PROJECT SUGGESTION

DEVELOPMENT OF ELECTRICAL INSULATION FOR THE QUADRUPOLE- AND BENDING-MAGNET COILS OF THE 200 BeV SYNCHROTRON PROTON ACCELERATOR

REF NO. RDUP-6818-1
QR 6-3153

ISSUED August 16, 1968

SUBMITTED TO

Mr. Richard C. Juergens
National Accelerator Laboratory
1301 West 22nd Street
Oakbrook, Illinois 60521

PREPARED BY
A. R. Stetson
A. R. Stetson
Chief - Process Research Department

APPROVED BY
John V. Long
John V. Long
Director of Research

Based upon Mr. R. C. Juergens' critique (dated June 28, 1968) of Solar's original Project Suggestion (Ref. 1), the evaluation of Solar's ceramic coatings by Mr. R. N. Woll (Ref. 2) and a visit to the National Accelerator Laboratory by Mr. A. R. Stetson, a revised scope of work is proposed for the development of a process to insulate the focusing and bending magnets of the 200 BeV Synchrotron with inorganic vitreous coatings. The significant changes that will be made from the formerly presented Project Suggestion are:

- A de-emphasis on physical property measurements prior to undertaking the evaluation of current coating systems for coating potting the coils.
- The elimination of sheet copper as a substrate material. Material 1/2 inch to 1 inch thick will be used in all experimental work.
- Emphasis will be placed from the initiation of the program on the specific details of the assembly rather than individual components.
- Two available inorganic coatings, Solar 71J-3 and Solar S5-8A will form the basis of the proposed program. These will be used separately and in combination to effect both coating and potting. Modifications to these coatings will be made only if weaknesses are observed in the systems.
- The initial electrical breakdown voltage goal will be 1900 volts minimum instead of 1200 volts.
- Radiation exposure tests will be minimized at least until a process is perfected since both basic coating compositions have been evaluated at 10^{10} rad exposure and found to have adequate voltage breakdown if at least 10 mil coatings are applied (>2000 volts breakdown).
- Braze alloy systems will be evaluated that are capable of joining the copper conductors to determine compatibility with each of the coating systems.
- After demonstration of the concept, Solar will, at the option of the NAL project monitor, contact several large porcelain enameling organizations, e.g., Pfaudler, A. O. Smith, etc., to elicit their interest in coating the magnet coil using the process demonstrated on subassemblies by Solar.

The proposed program will develop sufficient process data to make the transition to production status a routine operation.

STATEMENT OF WORK

The program at Solar will demonstrate the feasibility of coating copper magnet turns up to 1 inch x 1 inch in cross sections and potting them in an array similar to that currently being considered for the bending and quadrupole magnet coils for the 200 BeV Synchrotron Proton Accelerator. The program will be divided into two phases as follows:

Phase I - Specimen Demonstration

Phase II - Subscale Coil Demonstration

Solar will supply all manpower and materials excepting the 3/8 inch x 3/8 inch or 1 inch x 1 inch copper bar, which will be supplied by NAL.

The specific work items to be accomplished in the program are listed in the following sections:

Phase I - Specimen Demonstration

- Apply both S5-8A and 71J-3 to copper bars, 1 inch x 1 inch x 3 inches or 3/8 inch x 3/8 inch x 1 inch in thicknesses of 10 and 20 mils. Determine best processing conditions, i.e., atmosphere, firing temperature and time, thickness per coat, and surface preparation.
- Modify coatings as required to assure adherence.
- Damage coating by falling ball impact. Demonstrate localized repair and furnace repair.
- Using high expansion glass spacers, pot six each of the coated copper bars using both of the frits in the 71-J-3 and S5-8A coatings. Ideally, the coils coated with 71-J-3 can be potted with the S5-8A frit. This will enable the assembly to be steel strapped together and fired below the softening temperature of the 71-J-3 coating. If potting proves best by use of identical frits to those in the coatings, then glass separators will be used under the steel straps.
- The potted assemblies will be bonded to a swiveled assembly using an epoxy resin/catalyst system. The coating bond will be pulled in tension to failure of the resin or coating bond.
- Coatings or surface preparation will be modified as required to increase the adherence.
- Other separators will be investigated as required to minimize stress concentration.
- Consideration will be given to the use of inorganic cements, e.g., aluminum phosphate, calcium aluminate, sodium silicate, colloidal silica, etc., if the vitreous bond exhibits processing difficulties.
- On the optimized composition, the voltage breakdown will be determined during and after exposure to 100 percent humidity.
- The compatibility of the selected coatings with braze alloys and solders will be determined. One inch x one inch x one inch specimens will be joined with various commercial silver solders (Sil-foz, EZ-Flo, etc.), the silver-copper eutectic, and other braze alloys

as applicable. These joined specimens will then be coated and subjected to the previously determined processing cycle. The single most compatible system will be used in all subsequent work.

- The breakdown potential will be determined over the coated brazed joint.
- A single six-element rectangular array containing brazed elements will be prepared, the voltage breakdown will be determined, and the unit will be sent to NAL for radiation exposure testing.

Phase II - Subscale Coil Demonstration

Based on the parameters evolved in Phase I, four subscale assemblies will be prepared -- two of the bending magnets and two of the focusing magnet coil configurations. Each will be approximately 3 feet in length and will contain all turn ends. The units will be built at Solar using NAL copper and design drawings. Each coil will have at least five braze joints in the straight length of the turns. Parameters to be investigated in Phase II are:

- Jigging techniques to assure retention of shape after potting
- Permissible heating and cooling rates and any requirements for adjustment of the atmospheric conditions determined in Phase I as a result of the more massive size of the coils.
- Breakdown potential will be determined on the single best unit of each configuration in the "as coated" and 100 percent humidity conditions
- The single best coil assembly of each configuration will be shipped to NAL at the conclusion of the program.
- A process specification will be prepared covering in detail the recommended coating and potting techniques and all other necessary steps to assure successful processing of the larger coils.

REPORTS

Monthly progress letters will be furnished. The final report will consist of a brief summary of the significant data generated on the program and a detailed process specification.

SCHEDULE

Phase I will be completed within four months after receipt of the purchase order and copper bars from NAL. Phase II will be completed three months after completion of Phase I.

MATERIAL REQUIREMENTS FROM NAL

For Phase I -- 30 feet of typical copper bar that will be used in the bending magnet coils, and the same quantity of copper bar to be used in the focusing magnets.

For Phase II -- sufficient copper bar must be furnished to construct two 3-foot lengths of each of the full size bending and focusing magnet coils. These subassemblies will be constructed with the turn ends.

MANPOWER REQUIREMENTS

Phase I	
Engineers	350 hours
Technicians	680 hours
Phase II	
Engineers	510 hours
Technicians	765 hours
Total Manhours	2305

PERSONNEL ASSIGNMENTS

The program will be performed in the Process Research Department of the Research Laboratories. Program Director will be Mr. A. R. Stetson and the principal engineering personnel will be Mr. F. J. Hodnick, Mr. C. G. Root, Mr. V. S. Moore, and Mr. H. A. Cook. Biographical sketches of these personnel were submitted in the previous Project Suggestion (Ref. 1).

TRAVEL

Three trips to NAL will be made in the program: One after two months; one after Phase I; and one after Phase IV.

ARS:jr

REFERENCES

1. A. R. Stetson, "Project Suggestion - Development of Electrical Insulation for the Quadrupole- and Bending-Magnet Coils of the 200 BeV Synchrotron Proton Accelerator", RDUP-6818, June 10, 1968.

2. Robert N. Woll, "Preliminary Report - Radiation Induced Degradation of the Dielectric Strength of Various Ceramic Insulators", RNW-1 (May 24, 1968).