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HOW TO MASS PRODUCE RELIABLE CRYOSTATS FOR LARGE PARTICLE ACCELERATORS*

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Abstract

Accelerators such as the Fermilab Energy Doubler/Saver require large numbers of reliable cryostats which can be mass produced. Successful production of these devices is an extremely exacting business, requiring great attention to detail. A method has been developed and adopted at Fermilab which provides the precise control of the manufacturing process, necessary whether the cryostats are manufactured in-house or purchased from industry. This paper describes the system in detail, showing the integration of the engineering specifications, the quality assurance program including the high vacuum leak testing methods, and the manufacturing and materials specifications. To date over one hundred reliable cryostats have been produced using this method; experience and results are discussed.

Introduction

The Fermilab Energy Doubler/Saver Project requires approximately 1,000 high-tolerance, unique design, superconducting magnets. The cryostats for these magnets provide the insulating vacuum and cryogenic liquid volumes for the superconducting coils. The support system and cryogenic characteristics of these cryostats were previously reported.[1] This paper describes the manufacturing plan and the specific, successful quality control methods used to obtain the first 100 of the required cryostats.

Cryostat Characteristics

The cryostat is a complex device comprised of several hundred parts. It must fit underneath our existing conventional magnet strings and permit the maximum packing of magnetic field into the available circumference. Figure 1 shows a cross section. A photograph of a cutaway of the cryostat including the steel yokes and coil is included in Figure 2. The Fermilab developed design is unique and the assembly sequence is not readily apparent by simply viewing an assembly drawing.

To produce these cryostats, a potential vendor must have good manufacturing and heliarc welding capability with stainless steel and a good quality control department, well versed in the art of helium mass spectrometer leak detection.

Manufacturing Plan

The procurement of cryostats has been taking place over a number of years by a series of independent bidding procedures involving many vendors. All vendors were completely unfamiliar with the methods of assembly of these cryostats. We found that simple mechanical drawings were inadequate and conventional bid specifications too cumbersome to convey the necessary manufacturing detail. We decided that a comprehensive, universal set of specific assembly instructions and quality assurance requirements was necessary to guarantee a defect free final product.

The vendors were to fill out and follow our production and quality assurance documents rather than go by the more traditional method of allowing them to make up their own per some generalized performance specification. This standardized the product and tests among vendors and assured that the experience gained early in the project would be transferred to later procurements with a minimum of cost. With this method, Fermilab took on the responsibility for the proper functioning of the final product. A description of this documentation and an analysis of its effectiveness follows.

The Assembly Procedure-Quality Assurance Traveller

The document included in our bid packages is called the Assembly Procedure-Quality Assurance Traveller and can be thought of as a greatly expanded "notes" portion of the assembly drawings. At the prototype

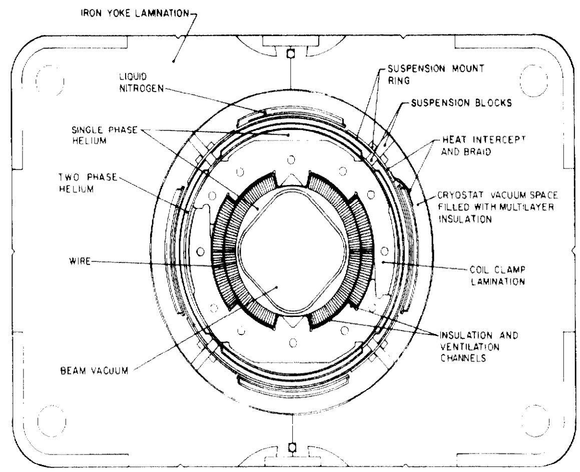

Fig. 1 Energy Doubler/Saver Dipole Cross Section

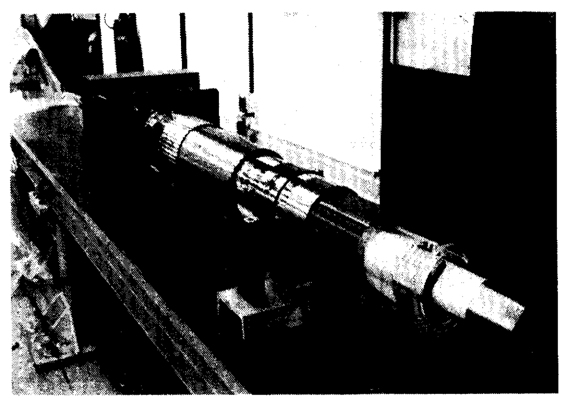

Fig. 2 Cutaway of Dipole Cryostat

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stage, it was written in a cooperative effort by design, inspection and production groups and is maintained as an integral part of the engineering package.

The Traveller consists of a series of sequential steps keyed to the assembly drawings and describes precisely what should be done, in the correct order. Assemblers, welders and inspectors are required to fill in and sign off the Traveller to provide a record of work at every step to provide accountability. Interspersed with the assembly steps are inspection steps to be completed by a separate quality assurance group. This provides the necessary control. Many of the crucial details have been flagged with an interrogation such as "Are all standoffs in Place? Yes _____ No _____." This provides a specific method that prevents repeated errors.

The first few pages of the document consists of a graphical PERT style diagram which acts as a tree like index to the steps. A portion of this diagram is shown in Fig. 3.

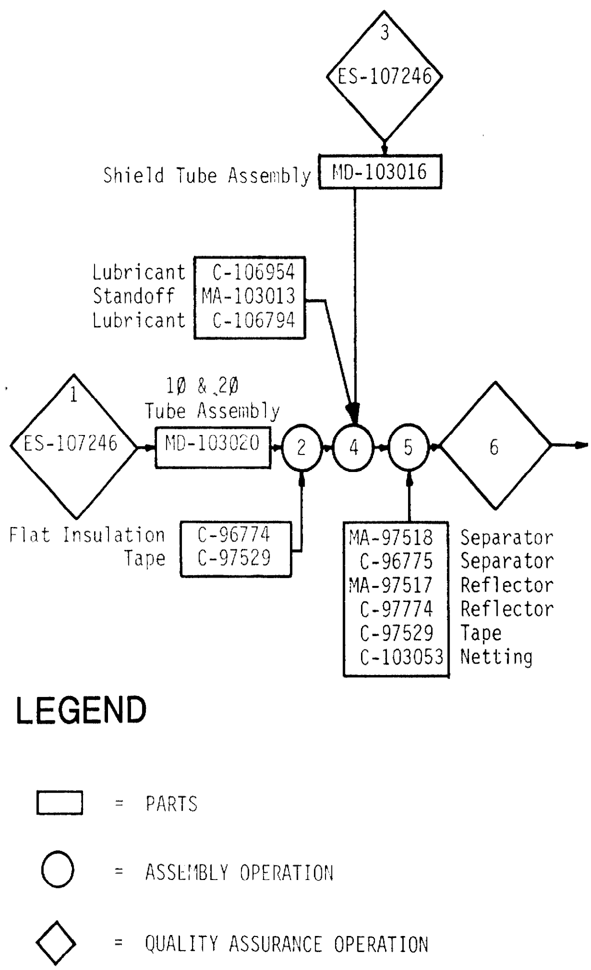

Fig. 3 Portion of Assembly Diagram

Each step is numbered, titled and indicated by a circle for an assembly operation or a diamond for an inspection operation. The part numbers are placed in rectangles and form branches on the tree.

This graphical method was the catalyst for the analysis of our complicated assembly sequence. It enabled us to adapt the quality assurance philosophy that was forced on us by failures during early prototyping. This philosophy requires that only fully tested sub-assemblies and parts be used in the final assembly. Additionally, during this buildup, leak tests or other appropriate tests are performed before any new weld or part is covered by subsequent parts. Before we adopted this method we were plagued by helium leaks showing up in our completed products with no indication of where they were buried. Now, after adoption of this methodical method, we have run up to 25 magnet strings with no leak problems from our weld joints.

We solved the problem of storing and transferring piece part, off-line test information by using preprinted pressure sensitive labels which are filled out by inspectors and inserted into the part package. Then, at the time of use, without any intervening logs or paper work, the label is simply pasted into the Traveller.

It is noteworthy that we have integrated both the manufacturing knowledge and the quality assurance into one document and it has worked very well. A feature is that all of the records for a particular unit are kept in one volume. This system has become the vehicle to first analyze and then convey the sometimes complicated assembly sequence. It is the primary method of technology transfer to vendors and our own technicians. This has led to low bid prices and a fast learning curve.

Standards

Where possible, our quality control system utilized national industrial standards so that additional specification preparation could be avoided. We found that for materials, the ASTM standrds for metals were quite satisfactory. In the case of insulating materials, we used the NEMA specifications. For fiberglass reinforced plastic used as a thermal insulator and structural support, we used a new cryogenic grade known as G-11CR. The standard for this material is published by the National Bureau of Standards and has been partially characterized by their tests.

Individual Part Specifications

We developed our own specifications for helium mass spectrometer leak detection, heliarc welding, and cleaning and handling. We issued them on a drawing format to insure that they reach the production floor. We aimed the language at the technician level, making it short, direct and simple.

We found the American Vacuum Society's tentative Standard 2.1 was the most satisfactory existing standard for helium mass spectrometer leak detector calibration. It requires calibration of detectors not only on the basis of sensitivity, but also on the basis of the most sensitive scale's signal-to-noise ratio. This standard provides a method of calculating one numerical value to express the two qualities. It forced the use of adequate leak detection equipment on our program by vendors. It further standardized nomenclature and the method of calculation and reporting of leak values so that comparisons could readily be made throughout the program.

Three mass spectrometer leak test procedures were developed to accompany the AVS 2.1 calibration. We believe that they are an advance in the state of the art because they require both calibration of leak detectors in a consistent fashion, and a stringent test procedure. This concern over leak tightness is necescery because leaks below those detectable by the best mass Spectrometer Leak Detectors are still of the order that will cause a marginal insulation vacuum in our accelerator. The common stringency to all the procedures is to bag the tested part in helium for two minutes after the detector has reached pump down equilibrium. Compared to the industrial standard practice of a survey spray with helium while the part is still pumping down, our method enables the detection of the smallest leaks. Two of the procedures are used for large objects requiring auxiliary pump down. To assure the system has the required sensitivity, we require that it be calibrated per AVS 2.1 at the end of the test. We determine the sensitivity with a calibrated leak placed at the system point furthest from the leak detector.

A proper welding standard turned out to be a problem. The ASME standards did not cover the gauge thicknesses included in our product. The American Welding Society standards and Aerospace Materials Welding Standards were also reviewed and found to be unsatisfactory for this type of task. A Fermilab welding specification was written and submitted to the vendors. This specification requires the qualification of all welders working on the project to submit for review, work on the thinnest gauges of metals used in the device. This method has been successful throughout the program to date.

The procedures for cleaning and handling of parts were written to eliminate any trace ions which could cause corrosion failure with time, create better surfaces for welding and minimize pump down time. For instance, haloginated hydrocarbon solvents are not permitted to be used in the cleaning process. Water wash with chloride free detergents was substitued. These procedures are particularly important on thin gauge parts and near crevices. Pitting corrosion rates, which are involved here, are up to .250 inch per year and some failures in some uncontrolled parts occured over the transit time from the manufacturer to Fermilab.

Procurement

After producing a number of prototype units with this manufacturing plan, enough confidence was generated to allow an external procurement program. This program would not only evaluate the effectiveness of technology transfer, but would lead to higher confidence in overall budget and program planning for the project. Approximately 150 cryostats have been manufactured to date and it is now possible to evaluate some of the results of this program.

For the first outside procurement, Fermilab made use of its experience in obtaining the component parts for these cryostats. Fermilab decided to supply these component parts in a kit to outside fabricators who would then assemble the finished item. There were other reasons for this choice. Among these was the requirement for rapid delivery. The schedule called for deliveries which would not have allowed the vendors the turnaround time to order these parts on their own.

This approach requires Fermilab to develop an in-house material procurement and parts control organization. This function was only partially successful. Laboratories such as Fermilab are not basically production-oriented organizations. They are usually making "one of a kind" experimental devices. Their procurement and materials management departments are largely organized around this "one of a kind" concept and when faced with the task of procuring high quality materials in large quantities, it was difficult to respond while maintaining the schedule and quality requirements presented by the program. Because of the short time involved in these procurement operations and schedule requirements, it was impossible to add enough qualified personnel to insure that the material quality was satisfactory.

On the other hand, one benefit of this method of operation is that it permits evaluation of its organizational performance very early in the "game". Also, outside vendors can be quickly indoctrinated into the system and their evaluation becomes much easier.

Fermilab Procurement Experience

Experience indicates two important points. First, supplying the parts was not a workable technique and task to undertake at Fermilab. As previously mentioned, the procurement and material control systems and personnel were heavily over-taxed and product quality suffered because of this. Secondly, and most importantly, the manufacturing system itself worked very well in spite of this. Indeed, it was possible to transfer the engineering requirements and the quality control specifications and tests through the use of the flow charts and shop travellers.

It was found that all manufacturing organizations had a learning curve of about ten units. Assuming no problems with parts, time to fabricate at the end of ten units was very near a predicted value. Problems in the first few units were mainly of technology transfer, particularly in the vacuum testing and quality control areas.

Further along in the production process, it was found that continuing engineering or manufacturing defects required about ten units before the fault was corrected. This was due to two reasons: First, the limitation of sufficient permanent in-house inspectors; and second, transportation delays before subsequent inspection at Fermilab. The resident inspector is thus critical, particularly at the front end of the project to facilitate technology transfer and minimize the length of the learning curve. Later, a full time inspector minimized the defect "time constant".

Conclusion

Fermilab developed a unique design, complex cryostat by a long prototyping program. Simultaneously, we developed a manufacturing documentation system which conveyed to industry the exact requirements necessary to build a successful product. The system is based on a Fermilab imposed, specific assembly procedure and Quality Assurance Traveller. It relieves the vendor of ultimate product perforamnce responsibility as long as all intermediate and final inspection steps are passed. Over one hundred successful cryostats were produced using this Traveller, in a short time, using initially inexperienced vendors at an integrated cost below conventional style procurements.

References

(1) G. Biallas, et al., "The Support and Cryostat System for Doubler Magnets," IEEE Trans. Magnet. MAG-15, No. 1, Jan. 1979, pp.131-133.