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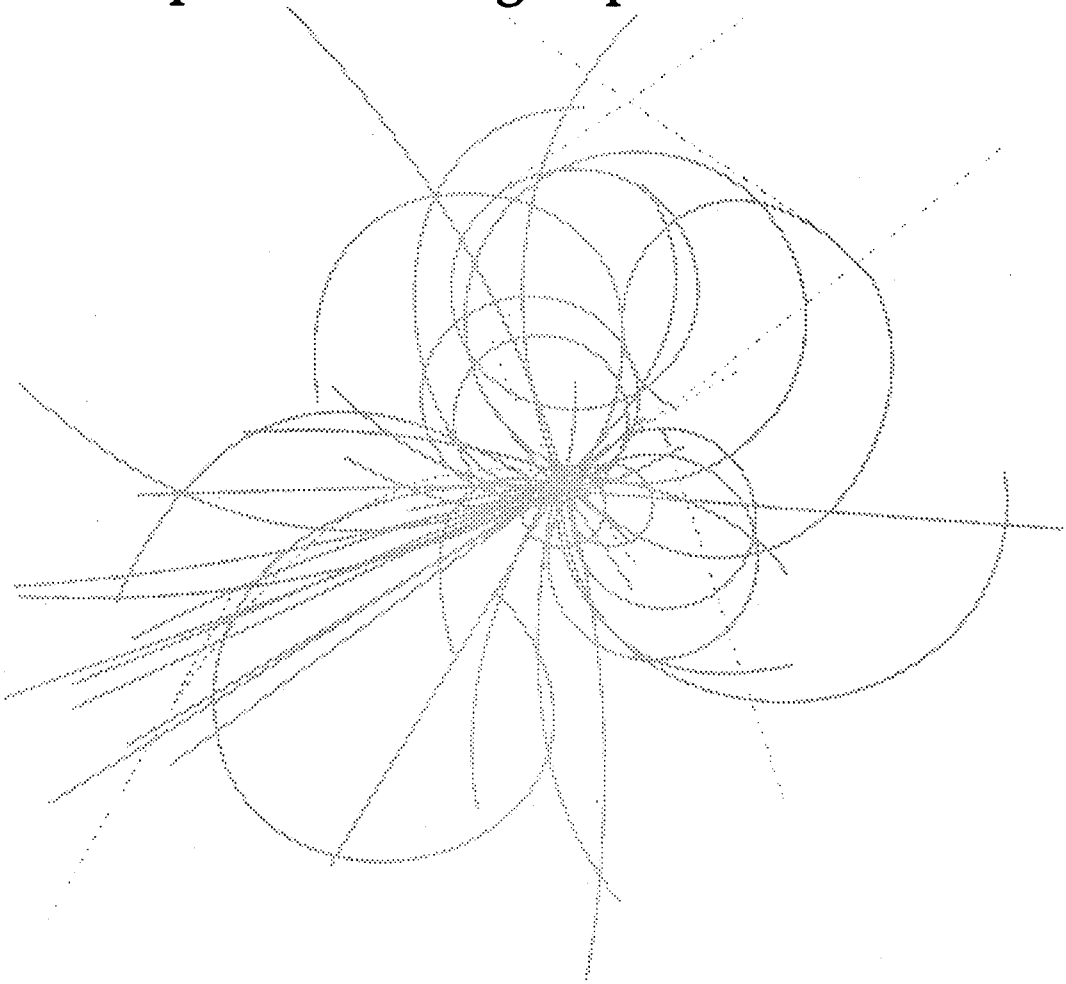

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IMPLEMENTING CORRECTIVE ACTIONS FROM THE FAILURE REPORTING, ANALYSIS AND CORRECTIVE ACTION SYSTEM (FRACAS) TO ACHIEVE MAGNET RELIABILITY AND AVAILABILITY GOALS

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ABSTRACT

Implementing corrective actions from the Failure Reporting, Analysis and Corrective Action System (FRACAS) is one of the methods from the reliability integrity approach used to ensure that magnets can achieve reliability and availability goals.

FRACAS achieves early feedback by monitoring magnets from assembly through operation, thereby saving time and reducing the number of items that may have a particular design or manufacturing process defect.

This paper will discuss the FRACAS program as it has developed in the Magnet Systems Division of the Superconducting Super Collider Laboratory, the type of information FRACAS has accumulated on the magnets, and corrective actions implemented to help achieve the reliability and availability goals.

INTRODUCTION

The Collider Dipole Magnet (CDM) reliability goal is to design for failure-free life during the operation of the collider. This is an enormous technical challenge, as minimum reliability data exist for the present design or for the specified operation conditions.

As a result, a conventional reliability approach that uses historical data from equipment already operating in understood environments would not be applicable. At the Magnet Division, the reliability program is an Integrity Methodology that emphasizes the product.

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Because the available reliability data for CDM are minimal, a strong effort went into the development and execution of the Failure Reporting Analysis and Corrective Action System (FRACAS).

The subject of problems/failures is a sensitive issue. It is not the intent of this paper to identify the faults but to give credit for the openness of information from each of the associate labs. In fact, each lab is considered to be a stronger supporter by the number of FRACAS reports generated.

FRACAS

FRACAS is a closed-loop problem reporting system that ensures that corrective action is taken. When a FRACAS program is utilized on a product such as the CDM, it can optimize the program by addressing product problems early in the schedule and providing refinement and reproducibility of the production process. The results are a cost-effective program and a better product.

FRACAS programs are usually initiated during the testing and qualification phase of the product development. However, due to the stringent reliability goals and minimum magnet testing presently being performed, it was decided to initiate FRACAS during the manufacture process of the magnet. Magnet Reliability is highly dependent on the production process. This effort has resulted in tight process controls and product improvements of which the entire lab is aware and proud.

FRACAS generates a discrepancy report upon discovery of a problem with procedures, test equipment, manufacture equipment, or the product. The discrepancy report must then be addressed by the cognizant engineer or physicist for problem classification, disposition, and possible corrective action.

Problem classifications are defined as Class 1 and Class 2 discrepancies. Normally, Class 1 problems are product discrepancies that affect either the function, fit, reliability, or safety. Class 2 problems are simply defined as not Class 1 discrepancies (*e.g.*, process documentation).

All discrepancy reports are provided to the Magnet Reliability Group for tracking, data recording, information dispersion, and Class 1 close-out meetings. A Failure Review Board (FRB) has been developed to address critical and timely problems requiring Magnet Division action. The FRB also has the responsibility to review each Class 1 discrepancy report for corrective action prior to its close-out of the report.

A FRACAS Report is considered closed when the discrepant item's disposition is successfully completed and the corrective action identified is implemented for prevention on subsequent units. At this time the FRACAS Report is presented to the FRB for close-out concurrence. However, some items are not so clear-cut. In these cases all the applicable information is obtained and reviewed and the best disposition and corrective actions, if any, are determined. Again, the FRACAS Report is presented to the FRB for close-out concurrence.

Data

As of January 15, 1992, there had been 538 Discrepancy Reports logged. Table 1, FRACAS Discrepancy Report Summary, shows the breakdown of the Class 1 and Class 2 reports generated. Approximately 15% of the reports are Class 1. Table 1 also lists the number of Class 1 closed reports and the number of discrepancy reports suggested for close-out. Suggested reports are those that will be presented to the FRB at the next close-out forum.

Table 1. FRACAS Discrepancy Report Summary.

	Total DRs Received	Closed	Suggested for FRB Closure
Class 1	83	37	21
Class 2	455	N/A	N/A
Total	538	37	21

The breakdown of the total number of FRACAS Reports received from each of the associated labs is shown in Table 2, National Lab Discrepancy Report Summary. It is important not to misinterpret this table. The most important item to remember is that the number of reports recorded is a positive value, as more impact can be made when more problems are identified and corrected. Each of the associated labs does not have the same number of magnets or the same manpower available, which may affect the number of discrepancy reports identified.

Table 2. National Lab Discrepancy Report Summary.

	SSCL DRs Received	FNAL DRs Received	BNL DRs Received	LBL DRs Received
Class 1	12	59	9	3
Class 2	76	326	33	20
Total	88	385	42	23

After this CDM-specific reliability data has been generated and logged, it must be analyzed for trends. There are as many ways to look at this data as there are data records. One way to examine FRACAS Records is to group them by problem causes. This tells us which area is more susceptible to Class 1 problems and what type of problems may be expected. Table 3, FRACAS Class 1 Problem Cause Summary, lists "coil shorts" as a major heading, then lists specific causes of that problem. Prevention of coil shorts is critical to optimal functioning of the magnets. The remaining major headings are the result of a "best fit" categorization effort.

Table 3. FRACAS Class 1 Problem Cause Summary.

Problem Cause	FNAL	BNL	LBL	SSCL	Total
Coil Shorts					
Contamination	6	1	0	0	7
Over Pressure	3	0	0	0	3
Dimensional	1	0	0	0	1
Craftsmanship	1	2	0	0	3
Strand Fault	1	0	0	0	1
TBD	3	1	0	0	4
(Sub-Total)	(15)	(4)	(0)	(0)	(19)
Bus Hi-Pot	7	1	0	0	8
Coil Bonding	2	0	0	0	2
Heater Short	4	0	0	0	4
Dimensional	17	0	1	2	20
Workmanship	6	3	2	3	14
Certification	0	0	0	0	0
Cleanliness	1	0	0	0	1
Documentation	1	0	0	0	1
Configuration	3	0	0	1	4
Other/TBD	3	1	0	6	10
TOTAL	59	9	3	12	83

LESSONS LEARNED

Coil shorts are a primary concern during magnet manufacturing and testing. The primary cause of coil shorts was contamination. This information is significant because it shows that the feasibility of manufacturing is high and that cleanliness controls are significant during cable and coil processes. One could go a step further and evaluate the cost-effectiveness of a semi-clean room for cable insulation and coil winding processes. It is strongly believed that no magnet assembly should be initiated until the complete manufacturing area and tooling items are assembled and cleaned.

Coil shorts resulted also from overpressure of the coil, which occurred because of the breakdown of the insulation scheme due to high stresses. One way to address this issue is an engineering evaluation of the insulation scheme to minimize the stress or to increase the insulators' capability to handle high stress. A second way to maintain product integrity is by assembly process verification. This may include testing coils for turn-to-turn shorts during the curing process prior to unpackaging. It may also include loading the ends and the coil straight sections prior to the next higher level of assembly.

The next category of problem causes is dimensional. Again, this information is critical as it shows that strong emphasis on parts control and component inspection is significant in building the best product possible. This information also shows that manufacture of the magnets is very feasible using process controls.

Workmanship is the next most probable cause for a Class 1 problem with a magnet. This is a serious issue, as the producibility of the magnet is a direct function of the technician's capabilities and experience level and of the true manufacture of the magnet. While there have been a few isolated problems due to a lack of awareness by personnel, in the lab environment it is believed that the technician's skill levels are higher than what may be available during full production. This would then translate the cause from workmanship to engineering design for producibility. This effort is best performed by the magnet contractors, who iterate their present design for producibility and use the FRACAS data to determine which areas need to be analyzed. The need for experience and practice cannot be overemphasized at this point, especially in the cable insulating and coil winding processes. Presently there is a large effort to semi-automate the coil winding process, which can in large measure address this major identified cause of failure.

The Power Bus Hi-Pot problem is a specific failure, not a cause. The cause for the excessive current leakage during test was a flux containing Zinc-Chloride, which had a tendency to absorb moisture, causing an ionization reaction and resulting in current leakage/insulation breakdown. A process and material change to use a resin-based flux and a 60/40 tin/lead solder was incorporated quickly and effectively to minimize the schedule and cost impacts. This is a good example of the positive effects of the FRACAS program.

Similar to the Power Bus Hi-Pot problem, the strip heater is also a specific failure and not a cause. The primary cause for strip heater problems is due to breakdown of the kapton insulation as a result of overstress or contamination. However, as a result of heater problems the issue of destructive testing, such as Hi-Potting versus megger testing strip heaters and coils, has been identified and is being addressed. This issue cannot be decided here, but it was FRACAS which has elevated the problem to be addressed by Magnet Systems, Engineering, Production, and Test.

Configuration is primarily aimed at parts, not to the proper or latest revision. This problem is a normal parts control and configuration function. Under true production and statistical controls, this type of issue is expected to be more closely monitored and controlled. However, once a change occurs, it is always possible for the incorrect part to be used, thus prolonging the problem.

The documentation heading is primarily for in-process control specifications, travellers, and/or manufacturing operational procedures. The number of these problems is due mainly to the incorporation of the need for such documentation during each magnet assembly step. A lesson well learned is to develop and evaluate these procedures prior to beginning any formal magnet assembly. The documentation control, such as revisions, is a serious issue that must be addressed to ensure smooth operation.

A few other items that have been identified during magnet assembly include, but are not limited to, the following: tooling break-in, proper cryostat pipe alignment, and torn kapton/B-stage during various processes. It has been learned that new tooling, primarily the coil winding mandrel and associated hardware, need to go through a few curing processes to get baked-in prior to producing high-quality, damage-free coils. Another problem still being analyzed is the cryogenic pipe locations. The present tolerance leaves little margin for error, while the design was well developed, and only reasonable design efforts were used to attempt to meet the tolerances. This is one producibility issue that may be best addressed by the CDM contractors. During coil winding, kapton problems were fairly common and showed signs of increasing when new winding crews/personnel performed the task. Again, producibility is the issue here, and the strong effort for semi-automated coil winders is a positive step.

The level of effort is much higher than anticipated because of the challenge of performing FRACAS during magnet assembly. The workload from maintaining and tracking all the appropriate documentation has a tendency to minimize the amount of involvement on the Class 1 problems that occurred. Additional manpower and computer automation are the principal solutions, both of which have been initiated. All FRACAS participants should be aware of the manpower needs upfront, or the system can become so unbearable that it may fail to achieve its full potential.

Summary

The lessons learned are based on the experience and work performed to date, and are limited to magnet assembly. There is minimal data on cryostating, and even less on interconnect work, short-term testing, and long-term life testing. New issues and new lessons learned will develop as the program moves further along the schedule. Using the FRACAS approach, these problems will be identified and corrected as effectively and efficiently as feasible.

The FRACAS program has also been a key instrument leading to engineering design changes, magnet assembly process changes, and magnet assembly test changes. Even in the short period of time that the FRACAS concept has been utilized, the amount of significant data for our specific and unique use is overwhelmingly high.

The amount of data accumulated in approximately one year could not have been possible without the support of each of the associated labs. The management support of such an effort is the fundamental reason for such success.

FUTURE

We plan to continue as we are through the remainder of the associated lab works. FRACAS is working, and we will continue a good thing. It is presently foreseen that once again the level of effort will increase if superconducting wire manufactures are brought into the FRACAS System. As the magnet contractors begin their model magnet programs, they, too, will use FRACAS.

In order to better handle the increased number of problem reports an effort has been initiated to develop an automated database between the Magnet Division and the many contractors. This system is scheduled to be in controlled use within six months and fully operational in one year. This effort will allow more time to work on the issues and to accurately analyze trends.

In the future, more single-magnet testing will occur, the SSCL string test will be operational, and possibly some reliability extended cycle testing will be in progress—and FRACAS will be there! It is expected that magnet autopsies will be performed on specific life-tested magnets to determine long-term wearout modes and corrective action, again using FRACAS.

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