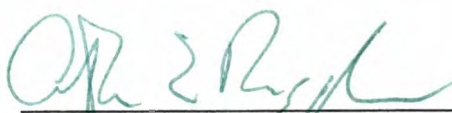


To the Graduate Council:

I am submitting herewith a thesis written by Ryan S. Brame entitled "Technical and Procedural Initiation/Implementation of Predictive Maintenance at the High Flux Isotope Reactor." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.



Arthur Ruggles, Major Professor

We have read this thesis
And recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

**TECHNICAL AND PROCEDURAL
INITIATION/IMPLEMENTATION OF
PREDICTIVE MAINTENANCE AT THE
HIGH FLUX ISOTOPE REACTOR**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ryan Scott Brame
December 1999

DEDICATION

For Hopper and Edda

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ABSTRACT

The High Flux Isotope Reactor (HFIR) provides a variety of research facilities for irradiation experiments, neutron scattering research, and a source for transuranic isotopes used in medicine and industry. In support of the HFIR maintenance organization's desire to continuously evaluate and improve maintenance practices, a strategy was developed for augmenting current practices with a predictive maintenance program. The specific steps accomplished include the following: selection of appropriate monitoring techniques, identification of components to be monitored, collection and centralization of equipment documentation, setup and configuration of monitoring equipment, initiation of data collection and analysis, and development of a technical basis document designed to serve as the foundation for the development of a predictive maintenance program at HFIR.

TABLE OF CONTENTS

Chapter	Page
1. INTRODUCTION	1
1.0 Purpose and Scope	1
1.1 Definition and Tasks	3
1.2 Contributions of the Report	4
2. REVIEW OF MAINTENANCE AND MAINTENANCE MANAGEMENT	6
2.0 Introduction	6
2.1 Objectives and Functions of Maintenance	8
2.2 Organization of Maintenance	9
2.3 Maintenance Operating Policies	11
2.3.1 Work Allocation Policy	11
2.3.2 Work Force Policy	12
2.3.3 Intraplant Relations Policy	13
2.3.4 Work Control Policy	14
2.4 Maintenance Techniques	16
2.4.1 Breakdown Maintenance	16
2.4.2 Preventive Maintenance	17
2.4.3 Corrective Maintenance	18
2.5 Maintenance Improvement Strategies	18
2.5.1 Predictive Maintenance	19
2.5.1.1 Introduction	19
2.5.1.2 Vibration Analysis	20
2.5.1.3 Thermography	22
2.5.1.4 Tribology	24
2.5.1.5 Motor Current and Flux Coil Signature Analysis	25
2.5.2 Reliability-Centered Maintenance	26
2.5.3 Total Productive Maintenance	28
3. EVOLUTION OF THE HIGH FLUX ISOTOPE REACTOR (HFIR) PREDICTIVE MAINTENANCE INITIATIVE	29
3.0 Introduction	29
3.1 Facility Description	29
3.2 Organization	32

3.2.1	Objectives of the Maintenance Organization.....	32
3.2.1.1	Safety.....	32
3.2.1.2	Availability.....	34
3.2.2	Roles and Responsibilities.....	34
3.2.3	Current Operating Practices.....	36
3.3	Origin of the HFIR Predictive Maintenance Initiative.....	36
3.3.1	History.....	37
3.3.1.1	HFIR Reactor Component Monitoring System.....	37
3.3.1.2	HFIR Reliability-Centered Maintenance Program.....	38
3.3.2	Objectives of the HFIR Predictive Maintenance Initiative.....	40
4.	PROGRAM DESIGN AND IMPLEMENTATION STRATEGY.....	42
4.0	Introduction.....	42
4.1	General Design and Implementation Considerations.....	42
4.2	HFIR-Specific Design and Implementation Considerations.....	45
4.3	Program Design and Implementation Strategy.....	46
4.3.1	Selection of Appropriate Monitoring Techniques.....	47
4.3.2	Selection of Equipment.....	48
4.3.3	Implementation and Execution.....	49
4.3.3.1	Setup and Configuration of Monitoring Equipment.....	50
4.3.3.2	Data Collection.....	50
5.	RESULTS AND DISCUSSION.....	51
5.0	Introduction.....	51
5.1	Results of Monitoring Technique Selection Process.....	51
5.1.1	Techniques Selected.....	51
5.1.2	Description.....	52
5.2	Results of Equipment Selection Process.....	57
5.2.1	Equipment Selected.....	57
5.2.1.1	Primary Coolant Pumps.....	57
5.2.1.2	Special Building Hot Exhaust Fans.....	58
5.2.1.3	Pressurizer Pumps.....	59
5.2.1.4	Auxiliary Pressurizer Pump.....	59
5.2.1.5	Primary Cleanup Pumps.....	62
5.2.1.6	Secondary Coolant Pumps.....	62
5.2.1.7	Cooling Tower Fans.....	64
5.2.1.8	Emergency Secondary Coolant Pump.....	64
5.2.1.9	Pool Coolant Pumps.....	64
5.2.1.10	Pool Cleanup Pumps.....	66
5.2.1.11	Hot Off-Gas Fans.....	66
5.2.1.12	Chilled Water Pumps.....	69
5.2.1.13	Demineralizer Pumps.....	70

5.3 Results of Implementation.....	71
5.3.1 RBMware™.....	72
5.3.1.1 Description.....	72
5.3.1.2 Organization.....	73
5.3.1.3 Discussion.....	83
5.3.2 Monitoring Hardware.....	85
5.3.3 Data Collection Strategy.....	85
5.3.4 Analysis Strategy.....	86
5.3.4.1 Description.....	88
5.3.5 Case Studies Demonstrating the Analysis Strategy.....	91
5.3.5.1 Analysis of Chilled Water Pump PU-1.....	99
5.3.5.2 Analysis of Hot Off-Gas Fan FN-5.....	116
5.3.5.3 Discussion.....	137
 6. CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK.....	 138
6.0 Introduction.....	138
6.1 Recommendations for Future Work.....	139
6.1.1 Initial Implementation (Phase 1)	140
6.1.2 Establish Comprehensive Condition Monitoring Program (Phase 2).....	140
6.1.3 Establish Comprehensive Predictive Maintenance Program (Phase 3).....	141
 REFERENCES.....	 142
 APPENDIXES.....	 148
Appendix A: Tables A1-A5.....	149
Appendix B: HFIR Technical Basis Document.....	180
 VITA.....	 227

LIST OF TABLES

Table 1: Common Sources of Vibration In Rotating Equipment.....	56
Table 2: Primary Coolant Pump Technical Specifications.....	58
Table 3: Special Building Hot Exhaust Fans Technical Specifications.....	61
Table 4: Pressurizer Pumps Technical Specifications.....	61
Table 5: Auxiliary Pressurizer Pump Technical Specifications.....	61
Table 6: Primary Cleanup Pumps Technical Specifications.....	63
Table 7: Secondary Coolant Pumps Technical Specifications.....	63
Table 8: Cooling Tower Fans Technical Specifications.....	65
Table 9: Emergency Secondary Coolant Pump Technical Specifications.....	65
Table 10: Pool Coolant Pumps Technical Specifications.....	67
Table 11: Pool Cleanup Pumps Technical Specifications.....	67
Table 12: Hot Off-Gas Fans Technical Specifications.....	68
Table 13: Chilled Water Pumps Technical Specifications.....	69
Table 14: Demineralizer Pumps Technical Specifications.....	70
Table 15: Alarm Codes Used By RBMware™.....	82

LIST OF FIGURES

Figure 1: HFIR Layout (Vertical Section).....	31
Figure 2: HFIR Facility Organization Chart.....	33
Figure 3: Amplitude Descriptors Commonly Used In Vibration Analysis ¹⁶	54
Figure 4: Organizational Hierarchy of RBMware™ ⁹	74
Figure 5: Measuring Point Location and Designation ⁴⁶	76
Figure 6: Typical Analysis Parameter Set ⁹	77
Figure 7: Vibration Severity Index ⁴⁴	79
Figure 8: Dual Upper Level and Delta Alarm Description ¹⁰	81
Figure 9: Typical Fault Frequency Set ¹⁰	84
Figure 10: Measurement Exception Analysis Report.....	89
Figure 11: Fault Frequency Report.....	92
Figure 12: Aug. 20, 1999 Measurement Exception Analysis Report.....	94
Figure 13: Vibration Data Collected from the MOV measuring Point of PU-1.....	100
Figure 14: Fault Frequency Report for MOV Measuring Point on PU-1.....	102
Figure 15: Data Collected from MOH Measuring Point on PU-1.....	103
Figure 16: Fault Frequency Report for MOH Measuring Point on PU-1.....	104
Figure 17: Data Collected from PIV Measuring Point on PU-1.....	106
Figure 18: Fault Frequency Report for PIV Measuring Point on PU-1.....	107
Figure 19: Data Collected from PIH Measuring Point on PU-1.....	109
Figure 20: Fault Frequency Report for PIH Measuring Point on PU-1.....	110
Figure 21: Data Collected from POV Measuring Point on PU-1.....	111

Figure 22: Fault Frequency Report for POV Measuring Point on PU-1	112
Figure 23: Data Collected from POA Measuring Point on PU-1	114
Figure 24: Fault Frequency Report for POA Measuring Point on PU-1	115
Figure 25: Data Collected from MOH Measuring Point on FN-5	117
Figure 26: Fault Frequency Report for MOH Measuring Point on FN-5	119
Figure 27: Data Collected from MIH Measuring Point on FN-5	120
Figure 28: Fault Frequency Report for MIH Measuring Point on FN-5	121
Figure 29: Data Collected from FIV Measuring Point on FN-5	123
Figure 30: Fault Frequency Report for FIV Measuring Point on FN-5	124
Figure 31: Data Collected from FIH Measuring Point on FN-5	125
Figure 32: Fault Frequency Report for FIH Measuring Point on FN-5	126
Figure 33: Data Collected from FIA Measuring Point on FN-5	128
Figure 34: Fault Frequency Report for FIA Measuring Point on FN-5	129
Figure 35: Data Collected from FOV Measuring Point on FN-5	130
Figure 36: Fault Frequency Report for FOV Measuring Point on FN-5	131
Figure 37: Data Collected from FOH Measuring Point on FN-5	133
Figure 38: Fault Frequency Report for FOH Measuring Point on FN-5	134
Figure 39: Data Collected from FOA Measuring Point on FN-5	135
Figure 40: Fault Frequency Report for FOA Measuring Point on FN-5	136

Chapter 1

INTRODUCTION

1.0 Introduction and Scope

Built in 1966, the High Flux Isotope Reactor (HFIR) has long been one of the world's most powerful research reactors. Located at the Oak Ridge National Laboratories in Oak Ridge, Tennessee, the HFIR provides a variety of research facilities for irradiation experiments, neutron scattering research, and a source for transuranic isotopes used in medicine and industry. The scarcity of such facilities has lead to renewed interest in maintaining the operational status of the facility. Several recommendations have been made for augmenting current maintenance practices with a predictive maintenance program. In response to these recommendations, this project has initiated and developed a predictive maintenance program at HFIR.

A literature review was conducted which served to establish the common terminology and principles associated with maintenance and maintenance management. The literature review emphasized that successful implementation of maintenance improvement strategies such as predictive maintenance can be accomplished only by considering both technical and organizational issues. The technical aspects of the project were addressed by review of applicable documentation such as component technical specifications and equipment training manuals. The organizational issues required a thorough review of the current maintenance organization with respect to objectives,

operating practices and policies, and the history of previous maintenance improvement initiatives.

With this background, and with the assistance of the HFIR maintenance staff, a strategy was developed for augmenting current practices with a predictive maintenance program. The specific steps delineated in the resulting strategy include the following: selection of appropriate monitoring techniques, identification of components to be monitored, collection and centralization of equipment documentation, setup and configuration of monitoring equipment, initiation of data collection and analysis, and development of a technical basis document designed to serve as the foundation for the development of a predictive maintenance program at HFIR.

Based on several factors including the potential benefit in HFIR applications, the availability of resources, and the experience of maintenance personnel, the decision was made to implement vibration analysis on forty rotating components such as pumps, motors, and fans. Data are collected from these components at an established interval of every thirty days. The program is administered through a Computational Systems Incorporated (CSI) software package known as RBMwareTM, which was setup and configured in support of this project.

Recommendations were also made for a course of programmatic development involving three phases. This graded approach is necessary due to the disparity between the objectives of the HFIR and typical programs that employ predictive maintenance strategies. Namely, the HFIR is a nonprofit government facility. As such, the connection between the success and longevity of the facility and overall cost efficiency is necessarily ambiguous. The HFIR maintenance organization will have to carefully evaluate

appropriateness of a financially based strategy at a facility concerned primarily with safety and regulatory compliance. Introduction of a typical predictive maintenance strategy will require HFIR management to implement a comprehensive strategy for detailed monitoring of investment and return on investment.

Phase 1 of the recommended programmatic development consists of maintaining and evaluating the current condition monitoring activities. This will provide the HFIR maintenance organization with a reliable source of information regarding the operational integrity of monitored equipment as well as allow for the development of proficiency in data collection and analysis. Phase 2 involves expanding the scope of condition monitoring activities in terms of the number and type of components monitored as well as the number and type of monitoring technique employed. This expansion should be accompanied by increased effectiveness in work allocation procedures precipitated by evaluation in the context of quantifiable performance metrics. Phases 1 and 2 serve to provide the elements necessary for the HFIR maintenance organization to evaluate the benefits of a comprehensive predictive maintenance program.

1.1 Definition of Tasks

The objectives of this project were accomplished by completion of the following tasks:

- A literature review of strategies for maintenance and maintenance management
- Familiarization with HFIR systems and equipment
- Familiarization with current maintenance policies and practices

- Familiarization with equipment operating histories and documentation
- Review of previous maintenance improvement initiatives
- Review and selection of appropriate monitoring techniques
- Selection of equipment for monitoring
- Setup and configuration of monitoring equipment
- Recommendation of appropriate monitoring strategy
- Recommendation of appropriate analysis strategy
- Execution of monitoring and analysis activities
- Creation of a technical basis document which provides the procedural foundation for the program

1.2 Contributions of the Effort

The significant contributions of this effort are summarized as follows:

- A thorough literature review of strategies for maintenance and maintenance management
- Identification of issues regarding the design and implementation of a predictive maintenance program
- Identification of HFIR-specific issues regarding the design and implementation of a predictive maintenance program
- Selection of equipment for initial implementation
- Instrumentation of equipment and initial data acquisition

- Description and demonstration of the proposed analysis strategy
- Delineation of the stages of development that the HFIR maintenance organization must undergo in the process of establishing a comprehensive predictive maintenance program
- A technical basis document that provides the foundation for the development of a predictive maintenance program at HFIR

Chapter 2

REVIEW OF MAINTENANCE AND MAINTENANCE MANAGEMENT

2.0 Introduction

The traditional view of maintenance has been that of a technical discipline and as such, the realm of engineers and technicians. Increasing global competition and more complex operations have necessitated consideration of the managerial side of maintenance⁵⁴. It is not uncommon for costs associated with maintenance to comprise up to thirty percent of a facility's total operating expenses, making effective management of maintenance assets a financial must⁵¹. Effective maintenance management begins with the realization that maintenance is about minimizing the costs associated with maintaining and operating facility assets and ensuring that the assets are available for use when needed.

The basic principles used for managing maintenance activities are the same as those used to manage any activity. They include the following²¹:

1. **Establish Objectives:** The objectives of the maintenance function must be clearly understood. A clear statement must be made of what maintenance is expected to do in support of facility operations.
2. **Identify Roles and Responsibilities Necessary for Accomplishing Objectives:** Clear lines of authority must be established and should contain a minimum of overlap. It is essential that all personnel are aware of the role they play in the success of the maintenance program and ultimately, the success of the entire facility. This

awareness can be further facilitated by limiting the length of vertical lines of authority.

3. **Develop a Plan for Accomplishing Objectives:** An overview of the maintenance organization should be developed detailing policies that will govern practices such as how work is requested, planned, scheduled, accomplished, documented, and assessed.
4. **Select the Proper Personnel to Assume the Roles and Responsibilities:** Ensure that the responsibilities associated with a position are commensurate with the abilities of the personnel selected to occupy it. When evaluating personnel for maintenance positions, the selection criteria are often associated with technical competency alone²⁵. While this is acceptable at technician levels of the organization, many maintenance positions are primarily management positions. The communication and managerial skills of those considered are of key importance.
5. **Establish Procedural Guidelines for Organizational Activities:** Procedures should be generated for all significant maintenance activities. These should detail how tasks are performed as well as how performance is evaluated. This is especially important in maintenance organizations where quality control and worker safety are of the utmost importance.

Adherence to these general principles must be accomplished while considering factors such as the type of industry, the size of the plant, training and availability of maintenance personnel.

2.1 Objectives and Functions of Maintenance

The general objective sought by all maintenance organizations is to support the operation of a facility by solving the day-to-day problems inherent in sustained operations^{20, 54}. There are both primary and secondary functions that maintenance is expected to perform in support of obtaining this objective, the type and scope of which will vary greatly from facility to facility. The terms “primary” and “secondary” are used to establish priority, an essential element in any effective maintenance management organization.

The primary function performed by all maintenance organizations is the support of operations with maintenance and repair of existing equipment²⁵. In addition to repair of malfunctioning components, this also includes preventive maintenance activities such as visual inspection and lubricant inspection/change⁵⁶.

A secondary function common to all maintenance organizations is the installation of new equipment and modification of existing equipment. The size of the plant and the complexity of the tasks determine to what extent maintenance personnel perform work of this nature.

Another secondary function common to all maintenance organizations is that of the jack-of-all-trades. Tasks that do not clearly fall into any specific department are often placed on the maintenance organization’s schedule. Therefore, it is essential that the primary responsibilities of maintenance are clearly defined and prioritized.

2.2 Organization of Maintenance

The top level in most maintenance organizations is occupied by a senior member of the facility management⁵⁶. These maintenance program managers must be cognizant of not only maintenance objectives, but overall plant objectives as well. Under the program manager will be various numbers of supervisors and craft personnel such as machinists, electricians, welders, and carpenters. The appropriate number of maintenance personnel is dependent on factors such as the size of the operation and the overall complexity of maintenance activities.

There are several criteria upon which these determinations are usually made, including the ratio of the number of maintenance personnel to the number of operations personnel and the percentage of total operating costs comprised by maintenance activities. While the ratio of the number of maintenance personnel to the number of operations personnel is a widely used metric, its successful use depends on factors such as the complexity of plant equipment²⁵. The same caveat holds true for use of the percentage of operations cost metric. Experience can assist in the decision-making process, but the uniqueness of each maintenance organization requires prudence when selecting such criteria.

There are three arrangements typically employed for organizing maintenance personnel including the craft, the area, and the team organizational arrangements⁵⁶. In a craft organization, one supervisor typically controls a group comprised of one craft. This type of organization is quickly becoming obsolete due to its inherent rigidity. The area organization is based on geographic considerations. A supervisor is assigned all of the

equipment in a specific area of the facility and is supported by all the crafts. In recent years, many maintenance organizations have begun using the team concept that relies on consensus among team members for work assignments. The team leader is typically an operations or maintenance supervisor, while the team members comprise a diverse craft base. The team and area organizations are more flexible in terms of shifting demands due to use of diversified craft pools. Most modern maintenance organizational structures possess elements from both.

Another organizational issue that has received a great deal of attention in recent years is that of centralized maintenance structure versus decentralized maintenance structure. Centralized maintenance structures are characterized by diversified resources, specialized supervision, and improved training, while decentralized maintenance structures are characterized by familiarity with equipment, a sense of ownership among the maintenance personnel, and expediency³⁹. Large tasks that require more coordination and attention to detail are well suited for centralization, while smaller tasks that arise in day-to-day operations are better served with a decentralized approach.

No matter what organizational structure is employed, it is imperative that adequate flexibility exists to adapt to changes in the future. The only constant in industry is change, and all organizations should be constructed with this in mind.

2.3 Maintenance Operating Policies

If selected properly, successful implementation and execution of operating policies will ensure that the maintenance organization accomplishes its stated objectives. These policies are typically classified into four general categories³⁹:

1. Work allocation policies
2. Work force policies
3. Intraplant relations policies
4. Control policies

2.3.1 Work Allocation Policy

Demand for work will always exceed the availability of maintenance resources in efficiently manned maintenance organizations²⁵. For this reason, the methods used to prioritize and subsequently schedule maintenance activities must be carefully selected and based on quantifiable metrics. Work allocation policy deals with the scheduling of maintenance activities³⁹. The degree of formality present in scheduling activities should be commensurate with the size and complexity of maintenance tasks²⁰. It is determined by an organization's policies regarding the minimum size of jobs that are scheduled, the percentage of the total workload that is scheduled, or the lead-time for scheduling³⁹.

One particular dilemma faced by many facilities is the amount of reconfiguration/installation work performed by maintenance personnel. In aging facilities where installations of new components or modifications of existing components are frequent, maintenance departments may devote more than half of their time to such work⁴⁸. The reality of limited resources is that the completion of any task incurs the expense of forgoing other tasks. The cost of forgoing component maintenance for installation/reconfiguration work is the inevitable decline in the performance of the component. This often results in a movement toward exclusive reliance on breakdown maintenance. The additional workload incurred in performing such work must be factored in to work allocation decisions to preclude this occurrence.

2.3.2 Work Force Policy

Work force policies address such issues as the use of outside contractors and training of maintenance personnel³⁹. The amount of outside contracting purchased by a maintenance organization will depend on several factors including the complexity of the task relative to the skills of in-house personnel and maintenance workload. For example, the use of outside contractors during peak work periods such as outages provides maintenance organizations with great flexibility, but usually at a high price. Other short-term activities such as installation of new equipment are often less expensive when outside contractors are utilized. The experience gained in previous implementations allows

contractor personnel to accomplish the task with more expediency and quality. The potential costs associated with trial and error learning are often overlooked when considering this issue.

The alternative to employing subcontractors is to develop and maintain expertise "in-house". This entails a commitment to continuous training and retraining of maintenance personnel. Considerations such as the complexity and criticality of facility operations should be used to determine what level of formality is appropriate in the training program. The highest level of formality is the apprentice-training regime. Personnel are trained to common standards with consistent techniques, thus minimizing the effects of individual ability and maximizing the consistency in maintenance practices. Plants with no formal training programs rely on experience and association with more experienced personnel for their training. The success of such programs depends on many factors, including the willingness of experienced personnel to coach the inexperienced.

2.3.3 Intraplant Relations Policy

Intraplant relations policies address the role that maintenance personnel have in the overall organization. In most organizations the procurement of new equipment or construction of additional facilities is directed by operations or production personnel, even though the costs associated with maintenance often constitute the majority of equipment lifetime operating costs³⁹. Disregard of

maintenance issues inherent in the change inevitably leads to conflict between operations personnel and maintenance personnel. The maintenance department will ultimately be responsible for the new equipment or facilities; their input must be sought during the early stages of such decision-making processes.

Poor relations between operations and maintenance personnel are prevalent at many facilities⁸. Although both parties have the same primary goal of supporting continued facility operations, differences in background and philosophy tend to inhibit effective cooperation. Both organizations contribute to the problem by promoting from within, with little consideration for anything but the technical expertise of candidates. Maintenance organizations must recognize the managerial abilities needed for supervisory positions and select personnel accordingly.

2.3.4 Work Control Policy

Work control policies delineate how maintenance activities are identified, planned, scheduled, executed, and reviewed for adequacy. There are several organizational components that are essential to the success of work control policy, including procedures, standardized units of measure, and performance evaluation criteria³⁹. Procedures serve to provide consistency in maintenance activities and assign organizational responsibility for the proper completion of these activities. Not only must technical tasks be clearly delineated, but also organizational ones such as reporting and documentation. Standardized units of measure allow

maintenance managers to compare and evaluate the performance of personnel and departments. Typical examples include the number of man-hours or the materials and labor costs associated with completing an activity. These two elements establish how work is done and measured, while the final element establishes how performance is judged. It is imperative that the performance criteria are within the control of those being evaluated. In many instances, maintenance organizations are evaluated based on overall objectives that they have little control over⁵⁶. Proper identification of objectives for each organizational level is the key to selection of proper performance criteria, which requires that they be defined in the context of overall facility goals. The techniques used to accomplish work control are based on control of either cost or time and include schedules, tracking of labor costs, and budgets.

The costs and benefits of maintenance are difficult to quantify. Direct costs such as labor and parts are calculated easily enough, but others such as the cost of running at reduced speed or poor product quality defy precise quantification⁵¹. There is no perfect technique for quantifying the influence of maintenance on breakdowns, unnecessary stoppages, or excessive calibrations or adjustments. Numerous economic models have been created that attempt to capture this information, all with limited success²¹. Care in selection of cost tracking and performance-monitoring techniques is crucial since they provide the windows from which maintenance performance is viewed and subsequently evaluated.

2.4 Maintenance Techniques

As stated earlier, the primary function of maintenance activities is the repair and maintenance of existing equipment. There are three types of maintenance techniques that are used in the execution of this function. They are breakdown maintenance, preventive maintenance, and corrective maintenance⁴².

2.4.1 Breakdown Maintenance

Breakdown maintenance consists of repairing components as they fail. This type of maintenance is reactive in nature and seeks only to maintain equipment operability at some minimum acceptable level. It is usually the most inefficient and expensive option available and contributes to poor planning and a lack of quality repair work⁴². Poor maintenance planning leads to inefficient use of maintenance resources and higher costs. The need for expediting repairs incurs expense not only in terms of an inability to effectively schedule activities, but also in terms of hurried maintenance work and incomplete repairs. Repairs are initiated to correct a problem, typically with no examination of whether the problem is a cause or an effect. Organizations that rely heavily on breakdown maintenance techniques are characterized by high maintenance costs and heavy maintenance workloads. However, certain situations exist that make the practice of breakdown maintenance the most cost-effective option²⁰. When dealing with components that are relatively unimportant or inexpensive, the inherent expense

associated with implementing more advanced maintenance methods may be excessive in comparison to the replacement costs.

2.4.2 Preventive Maintenance

The objective of preventive maintenance is to minimize or eliminate unanticipated equipment failures^{38, 42}. Many facilities confuse preventive maintenance with time-driven maintenance, called periodic maintenance. Typical periodic maintenance tasks include lubrication and calibration of equipment based on either manufacturer's recommendations or actual failure history. While such activities are the first step towards accomplishing the objective of preventive maintenance, they are insufficient alone. Periodic maintenance activities must be complemented with predictive techniques and incorporated into an overall maintenance strategy to achieve the goal of preventive maintenance⁴². Predictive techniques such as vibration analysis and tribology seek to ascertain the condition of equipment by monitoring the magnitudes of key operating parameters. Information gleaned from analysis of these parameters allows the maintenance organization to schedule maintenance based on need and facilitates the attainment of preventive maintenance goals.

2.4.3 Corrective Maintenance

Corrective maintenance is distinguished from breakdown maintenance by its timing⁴². Breakdown maintenance is initiated upon failure; corrective maintenance upon identification of degradation. There is less urgency associated with corrective maintenance, thus providing maintenance personnel with the opportunity to determine the root cause of the problem. The difference between corrective and preventive maintenance is that a problem must exist before corrective maintenance is performed. This is primarily a semantic difference since the information provided by preventive techniques is used to schedule corrective maintenance activities. The two must be operated in unison for either type to provide any benefit^{38, 42}.

2.5 Maintenance Improvement Strategies

The growing recognition of the role that maintenance can play in the overall success of a facility has lead to the emergence of numerous maintenance improvement strategies²³. The general goal of these strategies is to improve the management and conduct of maintenance activities through the quantification, evaluation, and optimization of maintenance work in the context of overall facility goals. Three of the more commonly used strategies are Predictive Maintenance, Reliability-Centered Maintenance, and Total Productive Maintenance.

2.5.1 Predictive Maintenance (PdM)

2.5.1.1 Introduction- Condition monitoring is the process of evaluating the relative health of a component through the use of technologies such as vibration analysis, tribology, thermography, motor current signature analysis, flux coil signature analysis and others. The information provided by condition monitoring may be used by a maintenance organization to perform certification, diagnostic analysis, and predictive maintenance¹⁸.

Certification, also known as post maintenance testing, is the use of predictive technologies to provide functional verification of proper component operation. Certification is performed after corrective maintenance or when a new component is placed in service.

Diagnostic analysis is the use of predictive technologies to identify the cause of component faults. Assuming that an appropriate technique is employed, characteristics of the data collected from a failing component will provide indication of the underlying cause of failure. This type of analysis is reactive in nature since it is performed only after a fault has occurred.

Predictive maintenance, also known as potential fault analysis, is the systematic use of the data provided by condition monitoring to optimize the allocation of maintenance resources. To support the implementation of a predictive maintenance strategy, data reflecting the values of key component parameters are collected at established intervals using one or more predictive techniques. Significant deviation in the magnitudes of one or more of the

monitored parameters from normal levels is indicative of changing component condition. Once a deviation has been identified, further analysis is performed to determine the underlying cause. Routine performance of this process provides a maintenance organization with the ability to predict which components are most likely to fail and approximately how long these components may remain in service before failure occurs. The goal of predictive maintenance is to use this information to enhance the quality of maintenance decisions in regard to both effectiveness and efficiency.

In spite of the large number of available technologies, most predictive maintenance programs rely solely on vibration monitoring for ascertaining the health of rotating machinery^{43, 44}. This is because the vibration signal produced by a piece of rotating machinery contains a wealth of information about its condition. However, there are numerous faults that may be more readily visible with the use of other predictive techniques. Fully developed predictive maintenance programs utilize a variety of predictive techniques, depending on the type of component. The techniques usually considered include vibration analysis, thermography, tribology, motor current and flux coil signature analysis, and monitoring of process parameters.

2.5.1.2 Vibration Analysis- Vibration analysis is the process of ascertaining the condition of a mechanical component by careful inspection of various characteristics of the vibrations it produces during operation. Recent advances in technology have made vibration analysis cost-effective for use in

most facilities with large numbers of rotating components⁴³. The emergence of handheld data collectors and sophisticated program software has greatly reduced the amount of time required to administer the program, requiring little more than consistent data collection from maintenance technicians for comprehensive monitoring and reporting.

Most modern vibration monitoring programs are administered through commercially available maintenance software packages⁴³. These packages provide maintenance organizations with resources for collection, analysis, and storage of data, as well as automated reporting features. They also provide an excellent means of consolidating and tracking component history and technical information. Analysis of the vibration data is performed using broadband trending, narrowband trending, signature analysis, or some combination of the three⁴³.

Broadband trending correlates machinery operating condition to overall vibration levels collected from various points on the machine. The magnitude of the vibration reading is compared to either baseline data collected from new equipment or published vibration severity indexes. This technique alerts the analyst of changing component condition, but does not provide any information regarding the actual cause of the problem.

Narrowband trending allows identification of specific component problems by determining the magnitudes of specific frequency bands within the overall vibration signature. These narrow frequency bands are associated with specific modes of degradation, allowing the analyst to make specific diagnoses.

The magnitude of the frequency bands is evaluated by comparison to either baseline data or past magnitudes of data collected from the same measurement point.

Signature analysis evaluates the condition of a component based on comparison of the magnitudes of various components of the signal. For example, some fault modes are distinguishable by the presence of small peaks around a larger central peak. The presence of these smaller peaks, known as sidebands, allows the analyst to differentiate between potential fault modes. As stated earlier, most vibration analysis programs will use a combination of all three techniques. It is important to note that many characteristics of vibration data are dependent on factors such as the operating speed, load, and other relevant parameters.

2.5.1.3 Thermography- Thermography uses instrumentation to measure the amount of infrared energy emitted from the surface of a component to ascertain component condition. The analyst looks for indication of abnormal temperatures, be they higher or lower than the expected value. The location and magnitude of these temperature anomalies are used to locate and diagnose equipment problems.

Thermography is based on the scientific principle that all bodies possessing a temperature above absolute zero emit electromagnetic energy^{37, 43}. In particular, thermography examines the amount of energy emitted at the infrared wavelengths. The intensity of the infrared radiation emitted from an object is

directly dependent on the surface temperature of the object. It is important to note that other factors may influence the amount of thermal radiation emitted from the surface³⁷. The emissivity of the surface, variations in the surface condition, and the atmosphere between the instrument and the monitored surface will all have an effect on the intensity of the emitted radiation^{37, 43}. Most infrared monitoring equipment has various filters to minimize the effects of such phenomena. Thermographic data is typically collected using one of two tools: infrared thermometers and infrared imaging equipment¹¹.

Infrared thermometers are designed to determine the temperature at a specific location on the surface of a component. These tools are typically used in predictive maintenance programs to monitor the temperature of bearing housing and motor winding temperature. The output of infrared thermometers is specific to a relatively small point on the surface of the component, limiting their usefulness in periodic monitoring activities.

Infrared imaging allows the analyst to view the infrared emissions of an entire component. In a manner similar to operating a handheld video recorder, infrared imaging equipment is used to collect images of components. These images provide a view of the thermal emission profile of the component, allowing the analyst to identify any thermal anomalies. Increased microprocessor speed and availability has influenced the use of thermography by making the acquisition and retention of thermal images fast and economical⁴³.

2.5.1.4 Tribology- Tribology refers to the activities associated with collection and analysis of data regarding the condition of machine lubricants. The basic functions of lubricants in mechanical equipment are to reduce friction between moving parts, reduce wear, control temperature rise, and minimize corrosion⁵. There is a great deal of confusion regarding the different techniques employed under the guise of tribology, especially in terms of the predictive merit of the analyses⁴⁷. The confusion centers primarily on the different benefits that can be derived from lubricating oil analysis and wear particle analysis.

Lubricating oil analysis consists of analyzing the physical characteristics and contents of a lubricant sample⁵. The sample is usually tested for attributes such as viscosity, contamination, and oxidation⁴⁸. All mechanical components are designed to operate with specified lubricant characteristics. Lubricating oil analysis determines the ability of the lubricant to meet its design service, but does not provide insight into the condition of the component from which the sample was drawn¹. The primary benefit of lubricating oil analysis to a maintenance organization is to allow periodic oil changes to be scheduled on the condition of the lubricant and not the calendar⁴⁷. As a result, it is expected that the frequency of oil changes will diminish.

Wear particle analysis differs from lubricating oil analysis in its ability to provide information about the condition of the component from which the sample was collected^{2, 5}. The shape, composition, and quantity of particles entrained in the lubricant sample are analyzed, the result being an understanding of how the component is wearing. The analysis is typically accomplished in two steps². The

first step is the trending of the size and quantity of the particulate matter found in oil samples. Changes in the operating characteristics of the component will result in an increase in one or more of the trended quantities, prompting the analyst to initiate the second step in the wear particle analysis process. The next step consists of a more detailed analysis of the composition and shape of the particles. This analysis allows the identification of the source and severity of the wear responsible for the particles.

Most facilities collect lubricant samples on a routine basis, usually specified by the component manufacturer. The samples are typically sent to a commercial laboratory for analysis due to expense of analysis equipment and the expertise required to make effective use of such equipment⁴⁸. Maintenance personnel have the responsibility of recording and trending the results produced by the laboratories.

2.5.1.5 Motor Current and Flux Coil Signature Analysis- Motor current and flux coil signature analysis rely on the collection and analysis of motor electrical signatures. Both techniques offer a better view of many electrical faults experienced by motors than vibration monitoring. The underlying science behind vibration analysis is the same as that behind motor current and flux coil signature analysis. Both rely on time and frequency domain analysis of time series data for ascertaining component condition. For this reason, the emergence of technological advances has influenced the use of these techniques in the same manner as it influenced the use of vibration analysis. The analysis techniques

used for motor current and flux coil signature analysis are virtually identical to those used for vibration monitoring.

2.5.2 Reliability-Centered Maintenance (RCM)

RCM is a strategy used to assist in the allocation of resources for preventive maintenance. It is based on the idea that the reliability of a component is determined solely by the quality of design and installation⁴⁸. Effective preventive maintenance ensures that the design reliability and performance of a component is attained. Improvements in the design reliability or performance of a component can only be realized by modification of the existing design or installation configuration. Maintenance organizations typically believe that more is necessarily better when it comes to preventive maintenance⁴⁸. In fact, excessive preventive maintenance has the opposite effect due to the frequency of maintenance-induced faults. In other words, fixing a component that isn't broken often results in one that is. RCM is a well-designed plan for determining the optimal amount of preventive maintenance in terms of cost-effectiveness and proper resource allocation⁴⁵.

The RCM strategy known as Failure Modes and Effect Analysis (FMEA) is the most frequently employed strategy for plant equipment⁴⁸. FMEA systematically identifies a component's functions, functional failure modes, and probable failure modes. An analysis is then performed to assess the significance of the potential effects of each failure mode. Preventive maintenance activities

are then scheduled based on the relative severity of the potential effects associated with failure of the component in question. There are several categories of preventive maintenance activities that are typically recommended, including on-condition tasks, rework tasks, redesign tasks, and no preventive maintenance^{45, 48}.

On-condition tasks are those preventive activities associated with the determination of a component's condition. This type of task is often confused with the collection of predictive data, but actually entails the implementation of a complete predictive maintenance program. On-condition tasks are usually recommended for equipment possessing failure modes that have a large potential for impacting the safety or reliability of a facility.

Rework tasks are often referred to as overhaul or recondition tasks. If a component is operating significantly below the design standards, preventive maintenance may entail overhauling the component. Rework tasks are typically less expensive than on-condition tasks, so they should be considered first.

Redesign tasks are performed when a significant failure mode exists which cannot be monitored or controlled through the use of preventive techniques. In such situations, it is necessary to redesign the component or its configuration.

Most importantly, no preventive maintenance is a valid recommendation. Relatively unimportant components with entirely financial failure consequences may be better served with a replacement strategy⁴⁸. In such cases, the inherent costs associated with more stringent preventive maintenance tasks are not justified by the possible benefits of maintaining component operability.

2.5.3 Total Productive Maintenance (TPM)

TPM is a comprehensive strategy for optimizing the effectiveness of maintenance activities in the context of overall facility objectives. The principle of the strategy is that maximizing the efficiency and quality of machinery operations will allow a maintenance organization to substantially impact the overall profitability of a facility⁵⁸. Such programs rely on the formality introduced during previous implementations of PdM and RCM programs for the ability to identify and correct deficiencies in the organization.

TPM is comprehensive in that it encourages the cooperation of all business units in accomplishing overall goals. In particular, maintenance and production or operations personnel are expected to work as a cohesive unit with the goal of enhancing profitability. An effectively implemented TPM strategy will include procedures for data collection and analysis as well as problem identification and solution⁵⁸.

In essence, a TPM program is an organizational commitment to optimizing and evaluating all business unit objectives in the light of overall facility goals. Effective implementation requires that the benefits of PdM and RCM are fully available. In particular, the ability to quantify and track the benefits associated with improved maintenance in the context of overall objectives is essential to the success of such programs.

Chapter 3

EVOLUTION OF THE HFIR PREDICTIVE MAINTENANCE INITIATIVE

3.0 Introduction

The foundation of any maintenance improvement strategy is an understanding of the objectives and working environment of an organization. Issues such as the complexity, the criticality, and cost and time constraints associated with facility operations must be considered before the appropriate improvement strategy can be developed. This is especially important at the HFIR because it is unique in many ways.

3.1 Facility Description

The HFIR has been one of the world's most powerful research reactors since beginning full power operations in 1966. While the HFIR presently provides experimental irradiation facilities to the research community, its primary purpose has always been the production of transuranic isotopes for use in medical and industrial applications. In response to a growing awareness of the limited availability of such resources, the HFIR is being upgraded in preparation for an additional 30 to 35 years of operation.

The HFIR was originally designed to operate at 100 MW, but irradiation tests conducted in 1986 indicated that the reactor vessel was becoming embrittled at a faster pace than expected. Subsequent to this finding, the maximum operating power of the

reactor was limited to 85 MW. At this power level, the reactor produces a maximum neutron flux of 3×10^{15} neutrons/cm²/sec. This is the highest steady state neutron flux available in the world, making the HFIR a unique resource for irradiation experiments.

The HFIR uses 93% enriched ²³⁵U, which is placed in individual aluminum-clad plates. The reactor is beryllium-reflected and uses light water as a moderator and a coolant. The reactor core assembly is contained in an 8-ft. diameter pressure vessel located in a pool of water. Primary coolant enters the reactor pressure vessel through two 16-in. diameter pipes. The coolant then flows down through the core and exits out through an 18-in. diameter pipe located at the bottom of the reactor vessel. The average flow rate is approximately 16,000 gpm, of which approximately 13,000 gpm flows through the fuel region. The remainder flows through the target, the reflector, and control regions. Under normal operating conditions, the inlet pressure is 468 psig and the inlet temperature is 120 °F. The corresponding pressure and temperature on the outlet are approximately 358 psig and 156 °F. From the reactor, coolant flow is distributed to three of four primary heat exchangers. These heat exchangers transfer the heat in the primary to secondary coolant. The secondary coolant is then circulated through a cooling tower, releasing the heat to the atmosphere. Figure 1³ shows the layout of the reactor building.

The fuel cycle of the HFIR consists of full power operations at 85 MW for approximately 22 days. At the end of this period, the reactor is shutdown and refueled. The typical outage lasts from 4 to 6 days, but may be extended to perform more complex maintenance work.

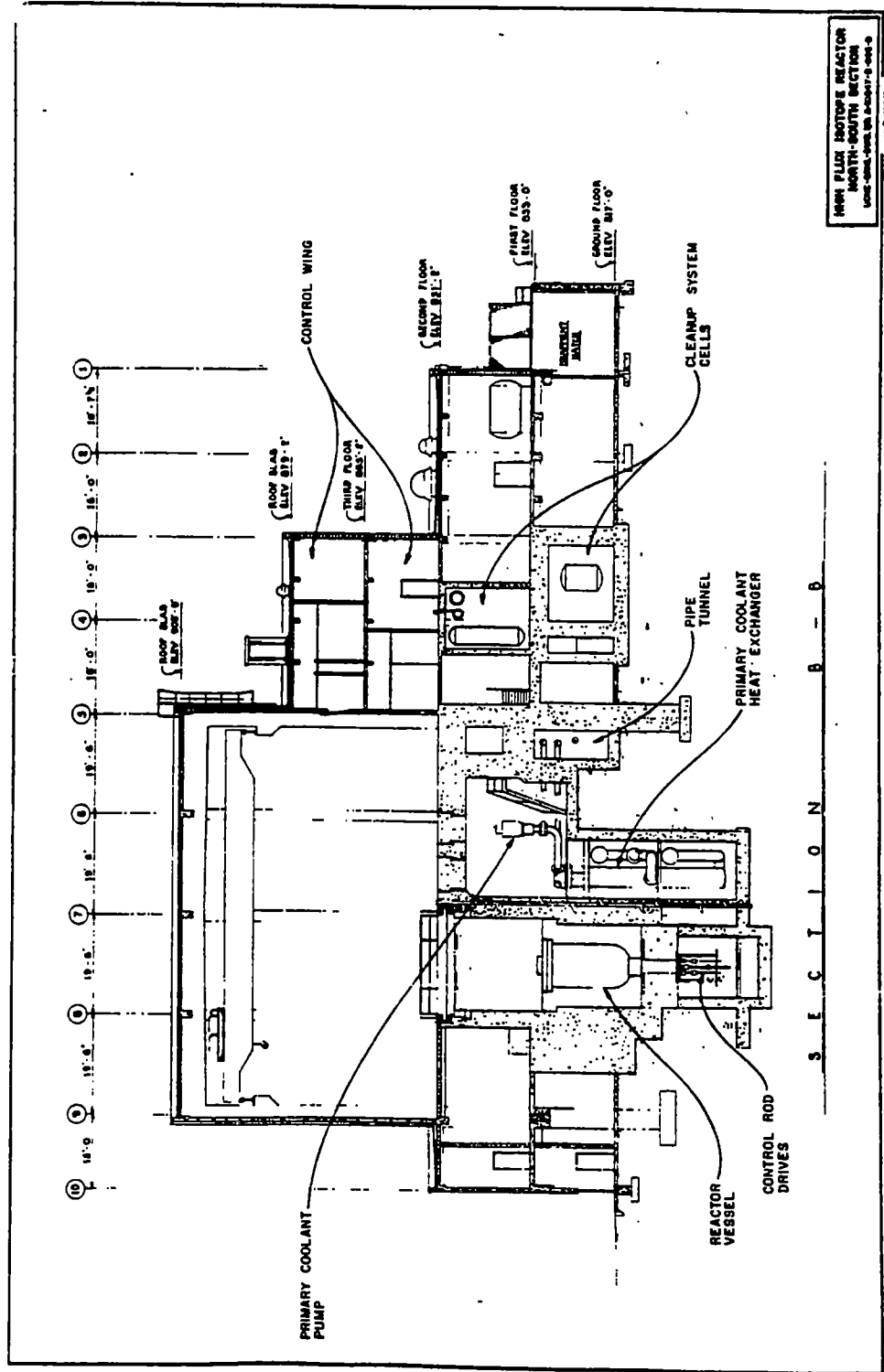


Figure 1: HFIR Main Building Layout (Vertical Section)

3.2 Organization

The HFIR is operated and maintained by Lockheed Martin Energy Systems (LMES) under contract to the U.S. Department of Energy (DOE). Figure 2 shows the lines of authority and responsibility for the operation and maintenance of the facility.

3.2.1 Objectives of the HFIR Maintenance Organization

Government-owned nuclear research facilities are not profit-driven organizations; they are compliance-driven. The desired product at such facilities is the availability of research facilities, the benefit of which is evaluated at higher levels of government. The general objective of the HFIR maintenance organization is to facilitate the safe and continued operation of the HFIR. The vagueness of this objective is necessitated by the wide variety of potential tasks that must be performed in the course of maintaining an aging nuclear facility such as the HFIR. The performance of the maintenance organization is evaluated relative to the safety and availability of the facility^{48, 49}.

3.2.1.1 Safety- All nuclear facilities are subjected to regulations, requiring compliance to ensure safe operation and to minimize the possibility of an accident that could result in public harm. In government-owned facilities, the lack of a profit objective and the intensity of oversight make compliance the ultimate objective of any maintenance organization. The redundancy and stringent procurement requirements that exist in nuclear facilities serve no purpose if

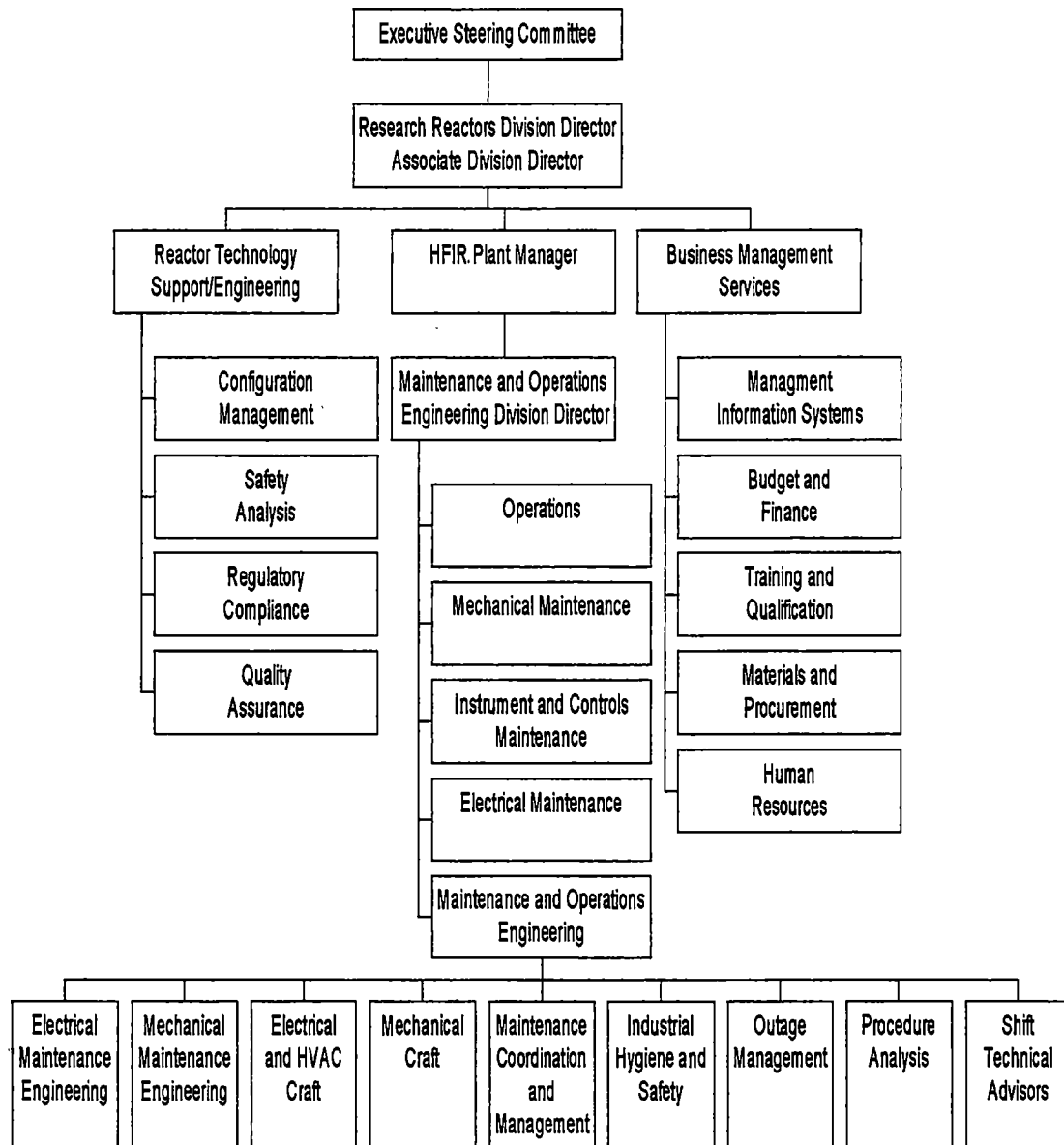


Figure 2: HFIR Facility Organization Chart

the facility is shut down for non-compliance. The safety of HFIR operations are evaluated in reference to previous assessments of the potential for various reactor accidents and the equipment required to safely shutdown the reactor^{48, 49}.

Fortunately for the HFIR maintenance organization, the HFIR is a particularly safe reactor design, requiring a relatively small number of components for safe shutdown and possessing redundancy at these key positions. It is important to note that the safety assessments performed at the HFIR to ensure safe shutdown did not consider operation with one or more redundant components out of service for maintenance.

3.2.1.2 Availability- The availability goals of the HFIR are based on minimizing the occurrence of lost operational time due to unanticipated shutdowns or delayed startups^{48, 49}. The relatively short fuel cycle of the HFIR and the redundancy in the design of systems critical to operations or safety help the maintenance organization to achieve availability goals.

3.2.2 Roles and Responsibilities

DOE personnel operate primarily in an oversight capacity at the HFIR, providing recommendations based on periodic reviews of operational and maintenance practices. The maintenance organization is provided guidance on the standards for maintenance activities in the form of numerous DOE orders. DOE Order 4330.4B, "Guidelines for the Conduct of Maintenance at DOE

Facilities” is the primary order referred to by HFIR maintenance personnel⁴⁹.

Unlike many regulatory documents issued by DOE, the language of Order 4330.4B does not require the performance of certain activities through the use of “shall”. Instead, the order states that the level of analysis, documentation, and action necessary to be in compliance with its recommendations, or “Performance Objectives”, be commensurate with the following:

1. The relative importance to safety, safeguards, and security
2. The magnitude of any hazard involved
3. The stage of the facility’s lifecycle
4. The programmatic mission of the facility
5. The particular characteristics of the facility
6. Any other relevant factor

The intent of writing the order with such language is to highlight the importance of tailoring maintenance organizations to the specific facility, a practice referred to as the “graded approach” in DOE 4330.4B. There are so many facility-specific issues that must be considered when deciding what maintenance practices are acceptable that DOE 4330.4B avoids the requirement of any. Unfortunately, the effect of this language is an absence of clear guidance on critical maintenance management issues such as scheduling or estimating. This is in stark contrast to the regulatory demands placed on other business units such as operations due to nuclear safety concerns.

3.2.3 Current Operating Practices

There is a great deal of work inherent in operating an aging nuclear facility such as the HFIR; the list of potential improvements and modifications is endless. Currently, the HFIR maintenance organization practices breakdown maintenance almost exclusively^{48, 49}. The age of the facility and many of its components requires that the maintenance organization also perform a great deal of new installation or reconfiguration work. Maintenance supervisors currently prioritize and schedule work based on their workload and perception of importance⁴⁸.

3.3 Origin of HFIR PdM Initiative

Several DOE reviews in the 1990's identified a need for the implementation of a maintenance improvement strategy at HFIR. It is the opinion of the reviewers that some improvement strategy must be integrated into routine maintenance activities at the HFIR before considering the maintenance organization in compliance with DOE 4330.4B recommendations such as the following:

“A predictive maintenance program should be established and utilized to monitor; determine trends; analyze parameters, properties, and performance characteristics or signatures of equipment in order to forecast equipment degradation so that “as-needed “ planned maintenance can be performed prior to equipment failure.”

However, there has been some confusion regarding which maintenance improvement strategy should be implemented.

3.3.1 History

In the past ten years, several attempts have been made to implement both RCM and PdM programs at HFIR, none resulting in any lasting improvement to the HFIR maintenance organization. The methods in which these past maintenance improvement strategies were implemented and their lack of longevity have had a definite impact on the attitudes of HFIR personnel. There are two prior initiatives that are particularly relevant to the current effort: the HFIR Reactor Component Monitoring System (RECOM) and the HFIR RCM Program.

3.3.1.1 HFIR RECOM Program- The HFIR RECOM program was initiated in the early 1990's with the intent of establishing a condition monitoring program at HFIR. It was implemented by maintenance supervisors and craft personnel over a period of several years. The program purchased equipment for vibration monitoring, flux current signature analysis, motor current signature analysis, and tribology, as well as a comprehensive software support system. Routine data collection was initiated, consisting primarily of vibration data.

The HFIR RECOM program was a successful implementation of a condition-monitoring program. However, this program was unable to provide any tangible benefits to the maintenance management organization. In short, the

program succeeded in allowing the monitoring of component health, but failed to improve the ability of maintenance management to better schedule or plan maintenance work⁴⁹.

Maintenance management personnel originally believed in the potential of the program, but a change in the availability of resources resulted in termination of program funding. The isolated and technical nature of this program did not facilitate effective communication with maintenance managers, and as a result, the HFIR RECOM program was unable to provide cost-justification. The belief in the qualitative enhancements provided to maintenance work by this program could not stand up to the need for expense justification because the program was primarily technical and not implemented into an overall improvement strategy.

The failure of this initiative is typical of many programs that are implemented primarily by technical personnel. The tendency to focus on technical issues seems to necessitate disregard of organizational issues^{41, 43, 56}. The history of the nuclear industry, and government nuclear facilities in particular, is that changing public opinion can and will affect the availability of resources. Programs that do not effectively justify their existence will not survive periods of reduced resources⁴¹.

3.3.1.2 HFIR RCM Program- The most recent maintenance improvement attempt at HFIR was orchestrated by personnel in the Research Reactors Division (RRD) and intended to implement a RCM strategy at the HFIR. A subcontractor was hired to interact with operations personnel and establish data

collection techniques. There were several problems with the program including the use of informal data collection practices at the HFIR. While information such as the number of hours a component has operated is available, it is in notes and logbooks and not centrally located or easily retrieved. In addition, the limited size of HFIR requires the use of sparse data, greatly impacting the statistical significance of results. The maintenance organization felt the list of components that needed to be monitored was intuitive and the use of RCM techniques was unnecessary^{48, 49}. Ultimately, the funding for the project came from the HFIR maintenance organization, which decided that the lack of tangible benefits to their personnel was sufficient reason to end project funding.

The subcontractors had previous experience implementing such programs at commercial nuclear facilities and mistakenly assumed that the same approach would work at the HFIR. However, just because one situation was conducive to a certain improvement strategy does not mean that similar situations will be likewise. In the case of RCM strategies, there are a number of foundational elements that must exist before the data provided by the strategy are of use to the organization.

Maintenance objectives at the HFIR are directed towards compliance, not profit. The maintenance organization desired the ability to monitor safety-related equipment and the ability to identify degradation. They were interested in increased technical expertise, not the integration of these techniques into the overall maintenance strategy. Instead of addressing technical issues first, the subcontractor spent several years trying to establish the elements necessary to run

an efficient RCM program, focusing on record-keeping practices and selection of performance criteria. The result of such disparity in expectations was the failure of the program and a resistance to similar efforts in the future.

The failure of the HFIR RCM initiative also left the HFIR maintenance organization with the responsibility for development of a predictive maintenance program to comply with outstanding facility review recommendations.

3.3.2 Objectives of HFIR PdM Program

The past several years have seen several changes in the top levels of the HFIR management. This is particularly difficult for the HFIR maintenance organization, due to the subjectivity with which maintenance practices may be evaluated. For example, the impetus for this initiative was DOE recommendations for development of a predictive maintenance program. Specific, quantifiable inadequacies that the resulting program should be designed to address are, however, absent from their recommendations. The lack of stated deficiencies makes it difficult to identify objectives for the program or justify the expense of the program.

In the absence of quantified deficiencies, the stated objective of the HFIR maintenance organization for this implementation effort is the initiation of routine data collection and analysis and generation a technical basis document for the performance of predictive maintenance at the HFIR. With ability to collect data, early indication of degradation is available, thus meeting the primary objective of

maintenance by enhancing the safety of the plant through the mitigation of catastrophic or unanticipated failures. This is a valid step in the construction of a predictive maintenance program, but the program's success will eventually require the introduction of a maintenance objective with reference to quantified benefits such as cost or time savings, or the formal statement of an organization-wide improvement strategy based on a single quantifiable metric. The maintenance organization has little trouble in maintaining the plant in conditions safe for shutdown, so more stringent objectives should be established and conveyed to all personnel.

The initiative described herein is designed and implemented to promote the definition of performance objectives and to foster the modernization of maintenance practices at the HFIR.

Chapter 4

PROGRAM DESIGN AND IMPLEMENTATION STRATEGY

4.0 Introduction

The goal is to initiate the development of a predictive maintenance program at HFIR. In light of DOE recommendations for implementation of RCM practices and given the current standards for maintenance practices in the nuclear industry, this is considered to be the first step in a process of continuous development and improvement of HFIR maintenance practices. As such, the predictive maintenance program resulting from this initiative should address both the short-term goal of gaining compliance as well as a long-term goal of a process of continuous evaluation and improvement of the HFIR maintenance organization.

4.1 General Design and Implementation Considerations

Predictive maintenance is presently the most common maintenance improvement strategy employed by maintenance organizations^{36, 41, 43}. It is also the most frequently misunderstood and confused maintenance improvement strategy. Some maintenance organizations view predictive maintenance as a method for eliminating the occurrence of unanticipated equipment failures, while others view it as a maintenance management tool that assists in prioritizing and scheduling maintenance work⁴¹. Predictive maintenance is no different than maintenance in general; it will mean different things at different

facilities. In general, it is a strategy for making effective use of the information provided by condition monitoring. The manner in which these data are used to assist a maintenance organization is dependent on the objectives of the particular organization.

It is important to realize that predictive maintenance is not a panacea for all maintenance organization's ills. Many predictive maintenance programs fail due to unrealistic expectations fostered by equipment vendors and professionals in the field, who cite benefits for fully developed mature maintenance organizations^{21, 51}. This tendency leads to confusion regarding the requirements for, and the benefits of, predictive maintenance. A predictive maintenance program is nothing more than a procedural description of a maintenance management strategy that seeks to optimize performance with the assistance of condition monitoring information. It is not a stand-alone entity that possesses capabilities other than those already possessed by the overall maintenance organization. For example, root cause failure analysis and detailed tracking of component histories are unspoken prerequisites for eliciting substantial organizational benefits from predictive maintenance. In practice, many programs that seek to implement predictive maintenance do not have the capability to collect or effectively use the information.

Another reason often cited for the failure of predictive maintenance programs is upper management's inability to appreciate the benefits. As a result of this incomplete understanding, the expense of the program is often viewed as excessive and the program eventually dies due to a lack of funding. In response to this problem, vendors and professionals generate studies detailing how predictive maintenance can be used to increase the overall profitability of an organization. In cohesive organizations where

maintenance views itself as only one part of a larger unit working towards a common goal, the use of overall organizational goals is the obvious best course. Unfortunately, such facilities are the exception not the rule^{25, 56}. More frequently, each organizational component will be concerned first with the potential benefits to its personnel. In particular, maintenance personnel must believe that the extra effort entailed in performing predictive maintenance is providing them with a direct benefit⁴¹. If they do not, the predictive maintenance program loses its champions and fails.

It is impossible for an informal organization to realize the kind of benefits typically cited for predictive maintenance until formal planning and scheduling practices are developed. The decision to augment current maintenance practices with a predictive maintenance program should be made in response to the identification of quantified deficiencies or the potential for significant improvements in regards to a performance metric. Maintenance organizations that do not possess the formality required to quantify deficiencies are better served by first reviewing and amending the organization to establish performance metrics and more effective work allocation and work control policies.

The steps required for an initial implementation of a predictive maintenance strategy in an informal organization differ from those required to augment practices in a more formal organization.

4.2 HFIR-Specific Design and Implementation Considerations

The desire of the HFIR maintenance organization is to implement qualitatively better maintenance practices into their routine activities. They are not concerned with cost/benefit analyses or the ability to enhance scheduling at this time^{48, 49}. The DOE recommendations made for enhancements reinforce this position. There is no mention of deficiencies in efficiency or effectiveness in their recommendations, other than the absence of a predictive maintenance or RCM program. The failure of past initiatives to attain this objective provides a valuable source of information regarding potential pitfalls.

The HFIR RECOM program was a successful condition-monitoring program, and at a minimum, it provided a qualitative improvement in maintenance at HFIR. Unfortunately, that is all that condition monitoring programs can supply, especially when implemented and maintained solely by technical personnel. If the information provided by condition monitoring is not implemented into an overall strategy designed to increase the effectiveness and efficiency of maintenance management, it will provide only a means to mitigate catastrophic component failure and reduce periodic maintenance. These are valid short-term goals, but will not be sufficient to justify the investment of hundreds of thousands of dollars in equipment and training in most cases.

In contrast, the malady that afflicted the RCM initiative was too much formality too quickly. The importance of gaining the support of maintenance supervisors and craft personnel cannot be overstated. Spending maintenance department money on a program directed by subcontractors and designed to inform maintenance personnel how they can

best perform their job is unfeasible at a small facility such as the HFIR, particularly in the absence of support from maintenance supervisors and craft personnel.

The task of this initiative is to strike a balance between the two previous approaches. Sufficient formality must exist to ensure that the expense of the program can be justified, but must be developed in a manner supported by maintenance managers, supervisors, and craft personnel. This can only be accomplished by clearly defining the role of the initiative in facilitating the long-term goal of developing a comprehensive predictive maintenance program at the HFIR.

4.3 Program Design and Implementation Strategy

Since this is an initial implementation, the short-term goals of the HFIR PdM initiative are based on creating an atmosphere conducive to future growth and development. Designing the program with the expectation and anticipation of development cannot ensure program longevity, but neglecting the need for a growth in complexity will lead to failure of the program. This implementation develops the skills of maintenance supervisors and craft personnel, bolsters their belief in the merits of the program, and enhances the record-keeping practices of the maintenance organization. These elements are critical to any maintenance improvement strategy and must be in place before attempting to expand the program.

Maintenance improvement is as much about changing the attitudes of those performing the maintenance as it is about changing practices. Patience is required to create an atmosphere where the maintenance personnel believe in the merits of the

program and feel pride and a sense of ownership. During this development, gradual introduction to more complex analyses and augmented record keeping or work scheduling practices can occur. The following actions are taken in this initial implementation:

1. Selection of condition monitoring techniques
2. Identification of components to be monitored
3. Implementation and execution of the program

4.3.1 Selection of Appropriate Condition Monitoring Techniques

There are several factors considered in the selection of the appropriate condition monitoring technique including the experience of maintenance personnel and the potential benefits afforded by individual techniques.

The technical expertise of the personnel administering the program is the source from which all future benefits originate. The lifeblood of a predictive maintenance program is information, the consistency and reliability of which is dependent on the expertise of the analysts and the effectiveness of the particular monitoring strategy. With this in mind, the experience of maintenance personnel with the condition monitoring options available must be considered. The less training that has to be conducted, the lower the startup costs and the sooner benefits can be expected, assuming the technique is appropriate. All condition monitoring techniques require a familiarity that can only be attained through

training and experience. It is essential that the personnel using the techniques believe in the potential benefits.

The expense associated with purchasing and using condition-monitoring equipment is often prohibitive. The techniques chosen for this initial implementation must have the capacity to generate almost immediate benefits. This means that the technique should allow a comprehensive view of component health and be responsive to degradation. However, insistence on the most versatile and comprehensive tools creates the need for elaborate claims of potential benefits to justify the investment. As has been repeatedly stressed, substantial benefits are a long-term goal of this initiative; promising too much too soon has been the reason for the demise of more than one predictive maintenance program.

4.3.2 Selection of Equipment

The equipment chosen for monitoring are selected with simplicity in mind. Learning is facilitated by instilling practitioners with confidence, which is best accomplished by choosing a small number of components with well-known operating characteristics and histories. It is also important that the equipment selected for initial programmatic development is relatively simple to monitor. Applications requiring remote or continuous monitoring increase the initial expense and complexity of implementing the program, and should be avoided at this time. The equipment are selected from a list containing items with associated

periodic or preventive maintenance requirements. As the experience of the analysts grow, periodic maintenance can be reduced or eliminated, thus providing both tangible benefits and confidence to maintenance personnel.

The size and importance of the equipment considered for monitoring should also be significant enough to allow claiming reduction or elimination of unanticipated component failure as a short-term benefit. In general, equipment is classified into three categories depending on the factors such as function and redundancy. These three categories are critical equipment, necessary equipment, and utility equipment. Critical equipment is required for safe operation or shutdown of a facility. This equipment must be maintained at all times and is usually installed with redundant backups. Necessary equipment is vital to the operation of the facility, but has no impact on safety. Utility equipment has no impact on either the safety or the availability of a facility.

4.3.3 Implementation and Execution

Once the scope of the HFIR PdM initiative has been defined, the task of implementing and executing the program must be addressed. The most important consideration at this stage is the selection of the appropriate personnel. Predictive maintenance requires a desire to learn and a willingness to change, and personnel should be selected accordingly.

4.3.3.1 Setup and Configuration of Condition Monitoring Equipment-

The first step in configuring new equipment is to organize and update component technical information. This information will be used to configure the vendor-supplied program software, so its collection and organization is of the utmost importance. Most software programs provide automated features that can greatly simplify the actions required to analyze the data, but rely on the accuracy of technical specification information provided during the initial setup. It is essential that the personnel selected to perform the monitoring and analysis be involved in this process. In particular, they should be trained on the setup and configuration of equipment.

4.3.3.2 Data Collection- Data collection should begin immediately upon completion of the setup and configuration phase. Maintenance personnel should focus not only on proper data collection techniques, but also begin to inspect the data for signs of component degradation.

The evaluation of component condition is accomplished by comparing collected data to data from components known to operating properly. It is expected that many of the components monitored will have problems, based on the current breakdown maintenance practices. For this reason, the focus at this time must be on identifying and correcting the most severe problems. Only when the state of the monitored equipment has been stabilized can baseline data be established. To facilitate this process, all of the initial data collected will be analyzed for indication of problems.

Chapter 5

RESULTS AND DISCUSSION

5.0 Introduction

One of the primary objectives of an initial implementation of a predictive maintenance program is to gain the confidence and support of the maintenance supervisors and craft personnel. This was especially critical in this effort, due to the skepticism resulting from the failures of previous maintenance improvement attempts. To address this concern, the HFIR maintenance management organization decided that this implementation would be conducted under the direction of a maintenance supervisor. The immediate effect of this decision was the creation of a sense of responsibility and ownership among lower-level maintenance personnel. It also served to limit the scope of the implementation to the equipment in the maintenance supervisor's charge.

5.1 Results of Condition Monitoring Techniques Selection Process

5.1.1 Technique Selected

Vibration analysis is selected as the primary condition monitoring technique for use in the developmental stages of the HFIR predictive maintenance program. The use of vibration analysis is standard in nuclear maintenance organizations. In addition, it is the single most useful technique for condition

monitoring of rotating mechanical equipment, which are the only equipment considered in this initiative.

This decision to rely solely on vibration analysis is also influenced by the experience of HFIR maintenance personnel. Several maintenance personnel received extensive training on the techniques and tools used for vibration analysis under the HFIR RECOM program. The implications of this are twofold. First, using this prior experience greatly reduces the initial training costs, thus expediting the realization of tangible benefits. The less money that is invested initially, the less that must be justified. Second, while vibration analysis has become more accessible to maintenance personnel since the advent of the software support systems, it still requires expertise that can only be developed with experience. Analysts must strive to develop not only the ability to recognize degradation, but also the confidence to make recommendations based on their findings.

The use of other techniques is not rejected, only postponed. Each technique possesses unique capabilities; the attainment of a comprehensive predictive maintenance program will require HFIR maintenance personnel to employ a variety of condition monitoring techniques.

5.1.2 Description

The term vibration refers to oscillation about a reference point¹⁷. Such oscillations result from the dynamic forces generated during the operation of a

rotating component. A plot of the oscillations over time will reveal a wave pattern. The magnitude of the vibration is dependent on the units used for measurement, typically displacement, velocity, or acceleration. The units used to express these magnitudes are as follows¹⁷:

Displacement-mils (peak-to-peak)

Velocity-inches/second (peak)

Acceleration-G's (rms)

Most condition monitoring activities will use units of velocity, since they provide consistent response for both low and high frequencies⁴¹. Displacement emphasizes the magnitude of low frequency vibrations, while acceleration emphasizes the magnitudes of high frequency vibrations.

In addition to different units, different amplitude descriptors may also be used to characterize the magnitude of a vibration. Figure 3 provides a visual depiction of the different descriptors commonly used for vibration analysis¹⁶.

The average magnitude of a signal with a frequency of T^{-1} is calculated using Equation 1⁴⁴:

$$E_{ave} = \frac{1}{T} \int_0^T |E(t)| dt \quad (1)$$

The root mean square (rms) magnitude of the same signal is calculated using Equation 2⁴⁴:

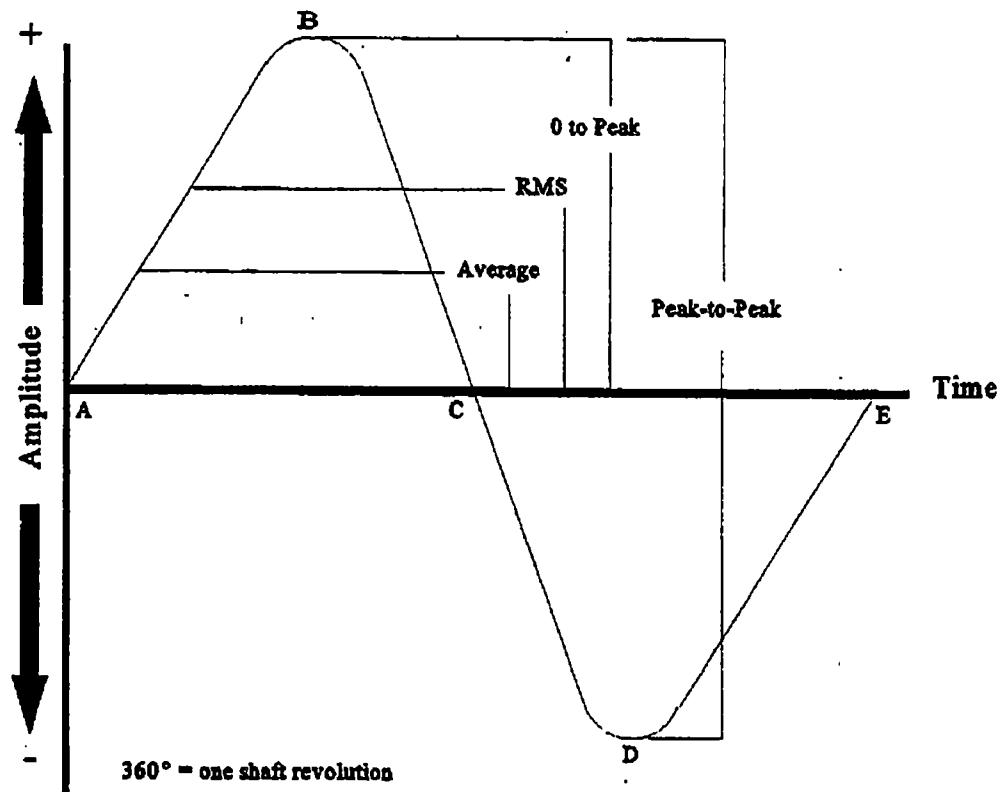


Figure 3: Amplitude Descriptors Commonly Used In Vibration Analysis¹⁶

$$E_{rms} = \sqrt{\frac{1}{T} \int_0^T [E(t)]^2 dt} \quad (2)$$

Vibration information is particularly useful in applications involving rotating equipment because typical problems experienced in such components such as imbalance and misalignment produce distinct vibration signal characteristics⁴¹. For example, the most common vibration characteristic is a dominant frequency corresponding to the turning speed of the machine. The amplitude of this frequency is directly proportional to the degree of rotor balance. Vibration data collected from rotating equipment will contain a complex waveform consisting of many such characteristic frequencies. Table 1 contains a description of the most common causes of vibration in rotating machinery⁵².

The complexity of vibration signals collected from rotating equipment is such that it is impossible to distinguish individual frequencies by viewing only the temporal response of the system. To facilitate this, the vibration data is transformed from the time domain to the frequency domain using the Fourier Transform, which is given in Equation 3⁴⁴:

$$E(f) = \int_0^T E(t) e^{-j2\pi ft} dt \quad (3)$$

The effect of this transformation is a better view of periodic events in a time series.

Table 1: Common Sources of Vibration In Rotating Equipment⁵²

Cause	Amplitude	Frequency	Comments
Imbalance	Directly proportional to the degree of imbalance. Largest in the radial direction.	Typically 1X turning speed, although a significant peak at 2X turning speed may also be present	
Misalignment	Large in both the radial and axial directions. The magnitude of the axial reading is typically 50% or more of the magnitude of the radial reading.	1X and 2X peaks typically dominate, although there is no definite rule. Misalignment is known to manifest at up to 10X turning speed.	Best identified by large axial vibrations
Mechanical Looseness	Manifests in much the same manner as misalignment	1X, 2X, 3X, and higher multiples of turning speed are common.	
Antifriction Bearing Defects	Unsteady	Typically manifest at high frequency ranges (>10X)	Best identified by presence of significant peaks in high frequency ranges.
Gear Defects	Small	Very high frequencies, calculated by multiplying the number of gear teeth by turning speed.	
Drive Belt Defects	Erratic or pulsing	Occur at multiples of belt turning speed	May result in high amplitudes in direction parallel to belt tension.
Electrical Defects	Disappears when electrical power is turned off	Occur at multiples of the input frequency	

5.2 Results of Component Selection Process

Components were selected based on the recommendations of maintenance supervisors and craft personnel. In the absence of data such as failure history or run times, the experience of these personnel is the most reliable resource available. The components selected satisfy the requirements of simplicity in operation and potential for benefit.

5.2.1 Equipment Selected

All information regarding technical specifications of HFIR equipment was gathered from references 27, 28, 29, 30, 31, 32, 33, 34, 35, and 48.

5.2.1.1 Primary Coolant Pumps-The primary coolant system is designed to transfer heat generated by the reactor to the secondary system, and to maintain primary system pressure in the safe operating range. The system contains approximately 13,800 gallons of demineralized water, with an average flow rate of 16,800 gallons per minute. Normal system pressure is approximately 468 psig, with a water temperature of 120 °F when entering the reactor vessel and 155 °F upon exit. The purpose of the primary coolant pumps is to circulate primary coolant through the primary loop. Three of the four available pumps are in service during normal plant operations, providing approximately 16,800 gpm of flow. The operating pumps draw cooled primary coolant from the primary heat exchangers and discharge to the reactor vessel return header. Table 2 provides technical information regarding the components.

Table 2: Primary Coolant Pump Technical Specifications

Specification	Description
Equipment Id	PU-1A, PU-1B, PU-1C, and PU-1D
Pump Manufacturer	Byron Jackson Pumps
Pump Model	Centrifugal; vertical
Capacity	5000 gpm @ 1800 rpm
Motor Manufacturer	Ideal Electric Corporation
Motor Specifications	600 Hp squirrel cage induction motor
Location	Ground Floor; Rooms 110, 111, 112, and 113

5.2.1.2 Special Building Hot Exhaust Fans - The Special Building Hot Exhaust (SBHE) system is designed to prevent the release of airborne activity from the reactor building. Accidents resulting in a breach to the primary coolant system or a release of fuel from the pool is prevented from resulting in a release of radioactivity by this ventilation system. To accomplish this, the system moves the contaminated air through two branches, each containing a series of filters, and discharges the filtered air to the reactor stack. There are three SBHE fans, designated as SBHE FN-1, FN-2, and FN-3. One fan must be operable and one in standby for safe operation of the reactor. Table 3 provides technical information regarding the components.

5.2.1.3 Pressurizer Pumps -The purpose of the pressurizer pumps is to maintain primary system pressure and provide flow for the primary cleanup system. The pressurizer pumps are also responsible for circulating cooling water through the primary coolant pump bearings during pressurized conditions. One of the two available pressurizer pumps is in service during normal operation, providing approximately 110 gpm of flow. The operating pump takes water from the primary head water tank and discharges it into the reactor vessel inlet header. Table 4 provides technical information regarding the components.

5.2.1.4 Auxiliary Pressurizer Pump-The purpose of the auxiliary pressurizer pump is to maintain primary coolant pump seal water pressure upon a loss of the two available pressurizer pumps. This pump is in the standby mode during normal operation, only entering service when the discharge from the pressurizer pumps falls below 75 gpm. Table 5 provides technical information regarding the components.

Table 3: Special Building Hot Exhaust Fans Technical Specifications

Specification	Description
Equipment Ids	SBHE FN-1, FN-2, FN-3
Fan Manufacturer	Westinghouse Electrical Corporation
Fan Model	8040 ARR 1 SWS1 Airfoil Series 800; Class IV Overhung Rotor
Capacity	28,500 cfm @ 13 in. water static pressure, 1750 rpm, 70°F
Motor	Westinghouse Electric Corporation
Manufacturer	
Motor	SNHE FN-1 and FN-2: 75 Hp squirrel cage induction motor
Specifications	SBHE FN-3: 100Hp squirrel cage induction motor
Belt	SNHE FN-1 and FN-2: 6 groove unbelt SBHE FN-3: 8 groove unbelt
Bearings	Antifriction, pillow block
Location	Fan Facility

Table 4: Pressurizer Pumps Technical Specifications

Specification	Description
Equipment Ids	PU-7A and 7B
Pump Manufacturer	Roto-Jet Pump Corporation
Pump Model	Single-stage centrifugal; overhung; belt-driven
Capacity	137 gpm @ 3200 rpm
Motor Manufacturer	Reliance Electric Corporation
Motor Specifications	125 Hp squirrel cage induction motor
Belt Specifications	5VX-900; 3-groove belts, 2 per pump
Location	First Floor

Table 5: Auxiliary Pressurizer Pump Technical Specifications

Specification	Description
Equipment Id	PU-11
Pump Manufacturer	Sundyne Corporation
Pump Model	Centrifugal; vertical
Capacity	30 gpm @ 3500 rpm
Motor Manufacturer	Reliance Electric Corporation
Motor Specifications	20 Hp squirrel cage induction motor
Location	Ground Floor

5.2.1.5 Primary Cleanup Pumps-The purpose of the primary cleanup system is to filter, demineralize, and remove dissolved gases from the primary coolant. The system also assists in the maintenance of primary coolant water pH by facilitating the addition of nitric acid. The system has a rated capacity of 7000 gallons, with an average flow rate of 110 gpm. The purpose of the primary cleanup pumps is to circulate water through the system during normal operation. One of the two pumps is in service during normal plant operations, providing approximately 115 gpm of flow. The operating pump takes water from the primary deaerator and discharges to the primary head tank. Table 6 provides technical information regarding the components.

5.2.1.6 Secondary Coolant Pumps-The purpose of the secondary coolant system is to transfer heat generated by the operation of the HFIR facility and the Radiological Engineering and Development Center (REDC) to the atmosphere. Normal system flow is approximately 26,000 gpm, with 1800 gpm consisting of flow for REDC purposes. The average coolant temperature at the cooling tower outlet is approximately 85° F. The purpose of the secondary coolant pumps is to circulate water through the secondary coolant system during normal operation. Two of the three available pumps are in service during normal reactor operations, providing approximately 26,000 gpm of flow. The operating pumps take water from the basins connected to the cooling tower flume and discharge to the secondary coolant supply header. Table 7 provides technical information regarding the components.

Table 6: Primary Cleanup Pumps Technical Specifications

Specifications	Description
Equipment Ids	PU-2A and 2B
Pump Manufacturer	Aurora Pump Corporation
Pump Model	Centrifugal, overhung
Capacity	200 gpm @ 3500 rpm
Motor Manufacturer	Westinghouse Electric Corporation
Motor Specifications	30 Hp squirrel cage induction motor
Coupling	Type F Steelflex size 6F, Falk Corporation
Location	Ground Floor, Room 2

Table 7: Secondary Coolant Pumps Technical Specifications

Specification	Description
Equipment Ids	PU-6A, PU-6B, PU-6C
Pump Manufacturer	Byron Jackson Pump Corporation
Pump Model	Centrifugal, vertical
Capacity	13000 gpm @ 1160 rpm
Motor Manufacturer	PU-6A and 6B: US Electric PU-6C: Westinghouse
Motor Specifications	450 Hp squirrel cage induction motor
Location	Pump Basin at base of cooling tower

5.2.1.7 Cooling Tower Fans- The purpose of the cooling tower fans is to circulate the warm air rising inside the cooling tower to the atmosphere. The number of cooling tower fans in operation will depend on the time of year. Table 8 provides technical information regarding the components.

5.2.1.8 Emergency Secondary Coolant Pump-The purpose of the emergency secondary cooling pump is to provide emergency cooling following a reactor scram. The pump may also be used to provide reduced cooling during periods of shutdown. This pump is in the standby mode during normal operation, entering service upon receipt of a reactor scram signal. Table 9 provides technical information regarding the components.

5.2.1.9 Pool Coolant Pumps-The purpose of the pool coolant system is to maintain the temperature and level of the water in the reactor pool. Normal system flow rate is approximately 900 gpm at ambient pressure and 95 degrees F nominal pool coolant temperature. The system provides approximately 0.33 MW of heat removal at full reactor power. The purpose of the pool coolant pumps is to circulate water through the pool coolant system. The pumps also transfer pool coolant to and from underground storage when necessary. One of the two available pumps is in service during normal reactor operation, capable of providing approximately 1000 gpm of flow. In the pool cooling alignment, the pumps take water from the pool surge tank and discharges to the pool filter and pool heat exchangers. In the transfer configuration, the pump takes suction

Table 8: Cooling Tower Fans Technical Specifications

Specification	Description
Equipment Ids	FN-4A1, FN-4A2, FN-4B1, FN-4B2, FN-4C1, FN-4C2, FN-4D1, FN-4D2
Gearbox	Western Gear Speed Reducer
Gearbox Model	FW-60A
Motor Manufacturer	FN-4A1 and 4A2: Lincoln Electric FN-4B1, 4B2, 4C1, 4C2, 4D1, AND 4D2: U.S. Electric
Motor Specifications	2-speed (50/12.5 HP) squirrel cage induction motor
Location	Top of cooling tower

Table 9: Emergency Secondary Coolant Pump Technical Specifications

Specification	Description
Equipment Ids	PU-14
Pump Manufacturer	Byron Jackson Pump Corporation
Pump Model	Centrifugal, vertical
Capacity	6000 gpm @ 1200 rpm
Motor Manufacturer	Westinghouse Electric Corporation
Motor Specifications	2-speed (150/37.5 Hp) squirrel cage induction motor
Location	Pump Basin at base of cooling tower

from the fill and drain header and discharges to the underground storage tanks, or vice versa. Table 10 provides technical information regarding the components.

5.2.1.10 Pool Cleanup Pumps- The purpose of the pool cleanup system is to facilitate the long-term storage of defective fuel elements in the reactor pool by continuously removing impurities from the pool coolant. The normal flow rate through the system is approximately 125 gpm at ambient pressure. The purpose of the pool cleanup pumps is to circulate water through the pool cleanup system. One of the two pumps is in service during normal operation, and is capable of providing 200 gpm of flow. The operating pump moves pool coolant from the pool deaerator through a prefilter, a demineralizer, and an afterfilter, before discharging to the reactor pool. Table 11 provides technical information regarding the components.

5.2.1.11 Hot Off-Gas Fans- The purpose of the Hot Off-Gas system is to collect gaseous waste from equipment and experiments that produce radioactive gases. The system is comprised of two smaller systems, the closed hot off gas system and the open hot off gas system. The closed hot off gas system services connections that may be pressurized, while the open hot off gas system services those that cannot be pressurized. Both systems circulate air through filter banks before discharging to the reactor stack. Table 12 provides technical information regarding the components.

Table 10: Pool Coolant Pumps Technical Specifications

Specification	Designation
Equipment Ids	PU-9A and 9B
Pump Manufacturer	Aurora Pump Corporation
Pump Model	4s X 5, Type O-J
Capacity	1000 gpm @ 3500 rpm
Motor Manufacturer	Westinghouse Electric Corporation
Motor Specifications	75 Hp squirrel cage induction motor
Coupling	Type F Steelflex size 8F, Falk Corporation
Location	Ground Floor

Table 11: Pool Cleanup Pumps Technical Specifications

Specification	Designation
Equipment Ids	PU-7A and 7B
Pump Manufacturer	Aurora Pump Corporation
Pump Model	Centrifugal; overhung
Capacity	200 gpm @ 3500 rpm
Motor Manufacturer	Westinghouse Electric Corporation
Motor Specifications	30 Hp squirrel cage induction motor
Coupling	Type F Steelflex size 6F, Falk Corporation
Location	First Floor

Table 12: Hot Off-Gas Fans Technical Specifications

Specification	Description
Equipment Ids	OHOG FN-3 and FN-4 CHOG FN-5 and FN-6
Fan Manufacturer	Buffalo Forge Company
Fan Model	35-1 Y "CB" Exhauster; ARR-1 Overhung Rotor
Capacity	500 cfm @ 53 in. of water static pressure, 3450 rpm, 70°F
Motor Manufacturer	US Electric Motor Corporation
Motor Specifications	7.5 Hp squirrel cage induction motor
Belt	Single Poly-v belt
Bearings	Antifriction, pillow block
Location	Fan Facility

5.2.1.12 Chilled Water Pumps- The purpose of the chilled water system is to provide chilled water for the various air conditioning units located in the reactor building. The normal flow rate through the system is approximately 833 gpm at ambient pressure. The purpose of the chilled water pumps is to circulate water through the chilled water system. One of the two pumps is in service during normal operation, and is capable of providing 833 gpm of flow. The operating pump moves water through chiller RE-1. Table 13 provides technical information regarding the components.

Table 13: Chilled Water Pumps Technical Specifications

Specification	Description
Equipment Ids	PU-1 and PU-2
Pump Manufacturer	Aurora Pump Corporation
Pump Model	Centrifugal; horizontal
Capacity	833 gpm @ 1750 rpm
Motor Manufacturer	US Electric Motor Corporation
Motor Specifications	25 Hp squirrel cage induction motor
Coupling	Lovejoy Jaw-type
Location	First Floor, H&V Room

5.2.1.13 Demineralizer Pumps- The purpose of the demineralizer water system is to provide reactor grade water for final rinsing of the pool cleanup demineralizer columns after regeneration. The normal flow rate through the system is approximately 100 gpm at ambient pressure. The purpose of the demineralizer pumps is to circulate water through the demineralized water system and to provide makeup water to the primary coolant head tank. One of the two pumps is in service during normal operation, and is capable of providing 100 gpm of flow. Table 14 provides technical information regarding the components.

Table 14: Demineralizer Pumps Technical Specifications

Specification	Description
Equipment Ids	PU-18A and PU-18B
Pump Manufacturer	Aurora Pump Corporation
Pump Model	Centrifugal; horizontal
Capacity	100 gpm @ 3500 rpm
Motor Manufacturer	Westinghouse Electric Corporation
Motor Specifications	5 Hp squirrel cage induction motor
Coupling	Type F Steelflex size 4F, Falk Corporation
Location	First Floor

5.3 Results of Implementation

One of the advantages of this implementation was the availability of tools and equipment. As stated earlier, an extensive array of condition monitoring tools and reliability-centered maintenance software had been purchased as part of either the HFIR RECOM or HFIR RCM program. Unfortunately, the validity of much of the previous setup work was questionable in the minds of HFIR maintenance personnel. Those who arrived after the programs had been terminated had neither an understanding of how the software and equipment had been configured, nor confidence in the accuracy of the technical information used in the process. As a result, the decision was made to completely reconfigure the software used for the HFIR predictive maintenance program.

The first step in this process is the collection and validation of current component operating information. The accuracy of this information is crucial to the success of condition monitoring activities at the HFIR, since all component behavior is evaluated based on the particular design and operating characteristics. In addition to locating and updating equipment technical documents, important information such as the running speed of the components must be collected on all of the equipment identified for monitoring. This information was filed in a central location, thus facilitating expansion and development of more detailed records on component configurations and operating characteristics in the future.

The effective performance of condition monitoring, as well as the successful development of both predictive and reliability-centered maintenance capabilities relies on record keeping. The updating and consolidation of component technical information is

one example of the record keeping enhancements that naturally result from the performance of condition monitoring. Instead of viewing record keeping improvements as a priority during the initial implementation of maintenance improvement, the improvements may be thought of as benefits of utilizing condition monitoring. In the normal course of developing vibration analysis expertise, maintenance personnel will have to utilize historical information. As a result, a qualitative improvement in overall record keeping is facilitated. As the amount of historical information stored increases, maintenance personnel will become more receptive of procedural changes to record keeping practices.

5.3.1 RBMWARE™ Software

All information regarding CSI hardware and software was gathered from the copyrighted material contained in references 9, 10, 11, 12, 13, 14, and 15.

5.3.1.1 Description- RBMware™ is a multi-technology data storage and analysis software package produced by Computational Systems Incorporated (CSI). This software package is an upgrade to the MasterTrend package used by HFIR maintenance personnel under the RECOM program, and as a result, is both familiar to HFIR maintenance personnel and compatible with all of the available hardware. It is noteworthy that the abilities of RBMware™ extend far beyond the scope of this initial implementation. This expansive range of abilities is

especially important at HFIR, since the long-term goals of the program necessitate development and growth.

RBMware™ has three functional categories, including setup and communication, analysis, and documentation and reporting²⁰. The setup and communication functions of the package allow transfer of information between data collection devices and the RBMware™ database. The analysis function of the package provides advanced diagnostic and analysis support modules for several condition monitoring technologies including vibration analysis, motor current analysis, thermography, and tribology. The documentation and reporting function of the package provides a means of recording component history and documenting program activities.

5.3.1.2 Organization- RBMware™ is arranged in the hierarchy shown in Figure 4⁹. Areas comprise the top level in the RBMware™ organizational hierarchy. Each Area contains a collection of components grouped according to the anticipated collection route. The HFIR facility database is divided into the following five Areas:

1. Ground Floor
2. First Floor
3. Primary Coolant Cells
4. Cooling Tower
5. Fan Facility

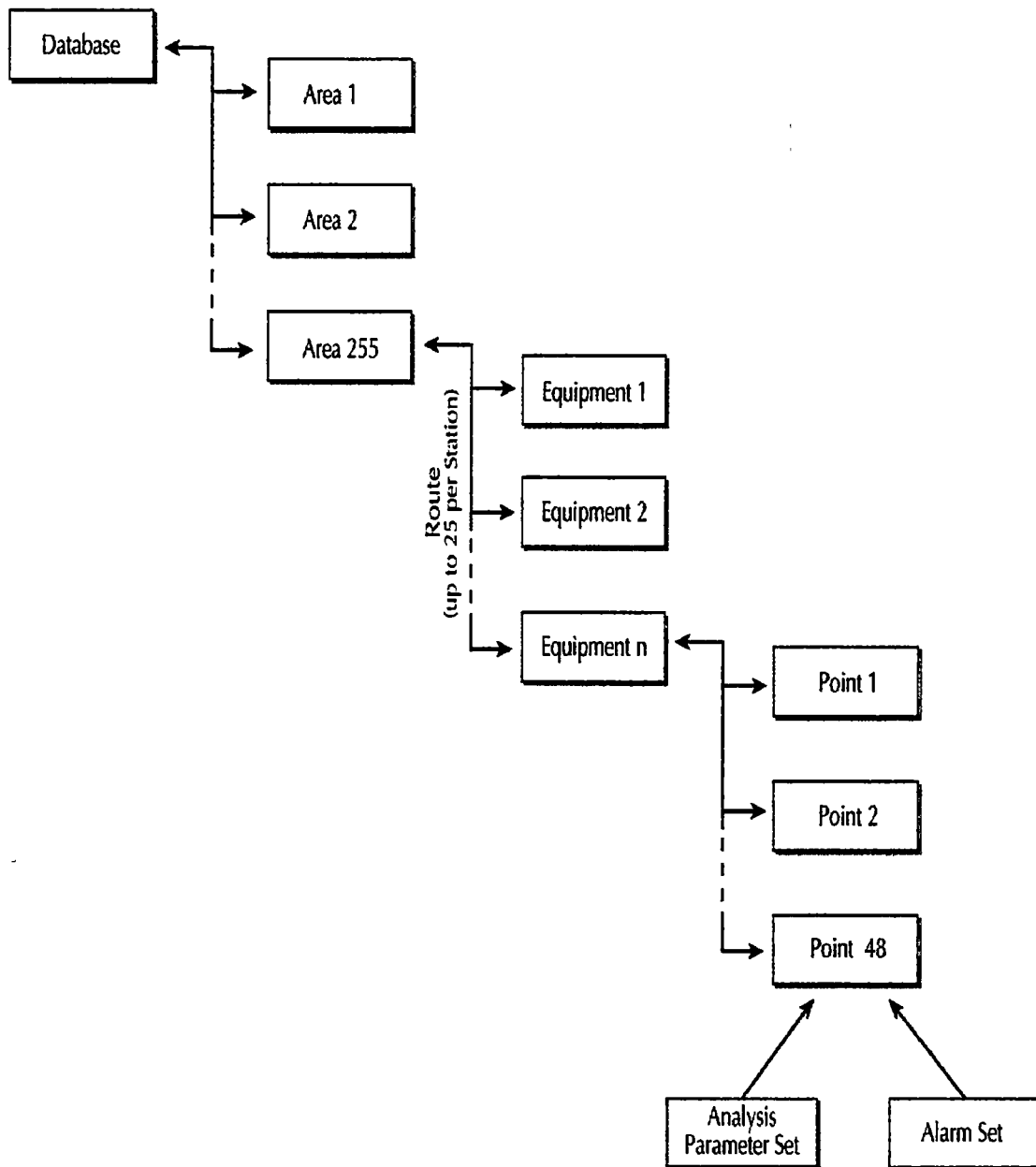


Figure 4: Organizational Hierarchy of RBMware™⁹

The components located in an Area comprise the Equipment category. Table A1 in Appendix A provides a list of the components currently monitored, the monitoring frequency, and classification. Examples of the information necessary to specify a piece of equipment in RBMware™ include horsepower, operating speed, and bearing specifications.

On each piece of equipment a number of strategically placed and uniquely identified Measuring Points were established. There are two radial measurement points per bearing, and one axial measurement point per shaft. Figure 5⁴⁶ shows the typical measuring point orientation and designation employed at HFIR.

Table A2 in Appendix A lists the measurements points from which data is routinely collected. In addition to Areas, Equipment, and Measuring Points, the RBMware™ database also contains analysis parameter sets, alarm limit sets, and fault frequency sets.

Analysis parameter sets identify up to twelve individual frequency bands for each measuring point. Each frequency band corresponds to a vibration parameter indicative of certain conditions. Figure 6 shows a typical analysis parameter set⁹. Table A3 in Appendix A contains a listing of the analysis parameter sets constructed for this initiative.

Alarm limits are predetermined parameter magnitudes that indicate serious degradation in the health of the monitored component. Alarm limit sets contain an alarm limit for the magnitude of the overall signal as well as

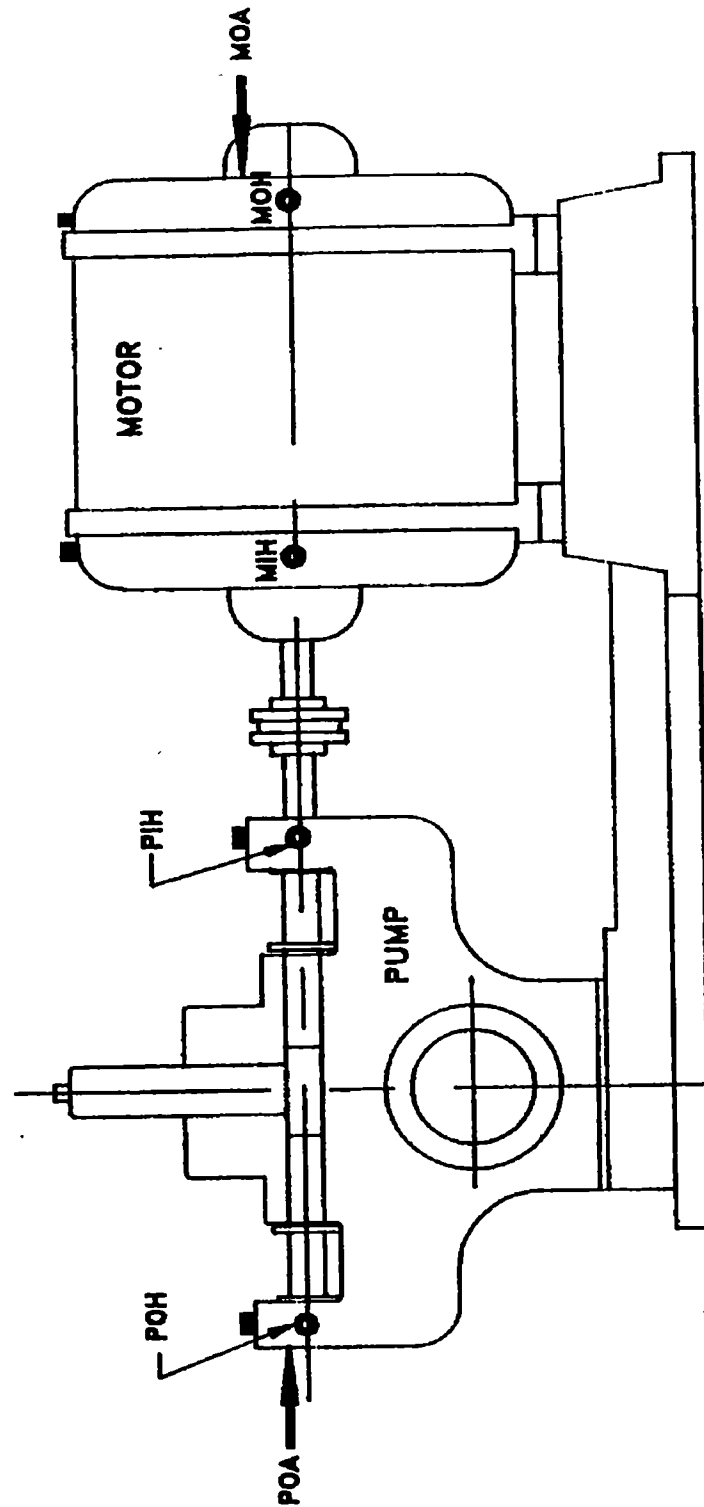


Figure 5: Measuring Point Location and Designation⁴⁶

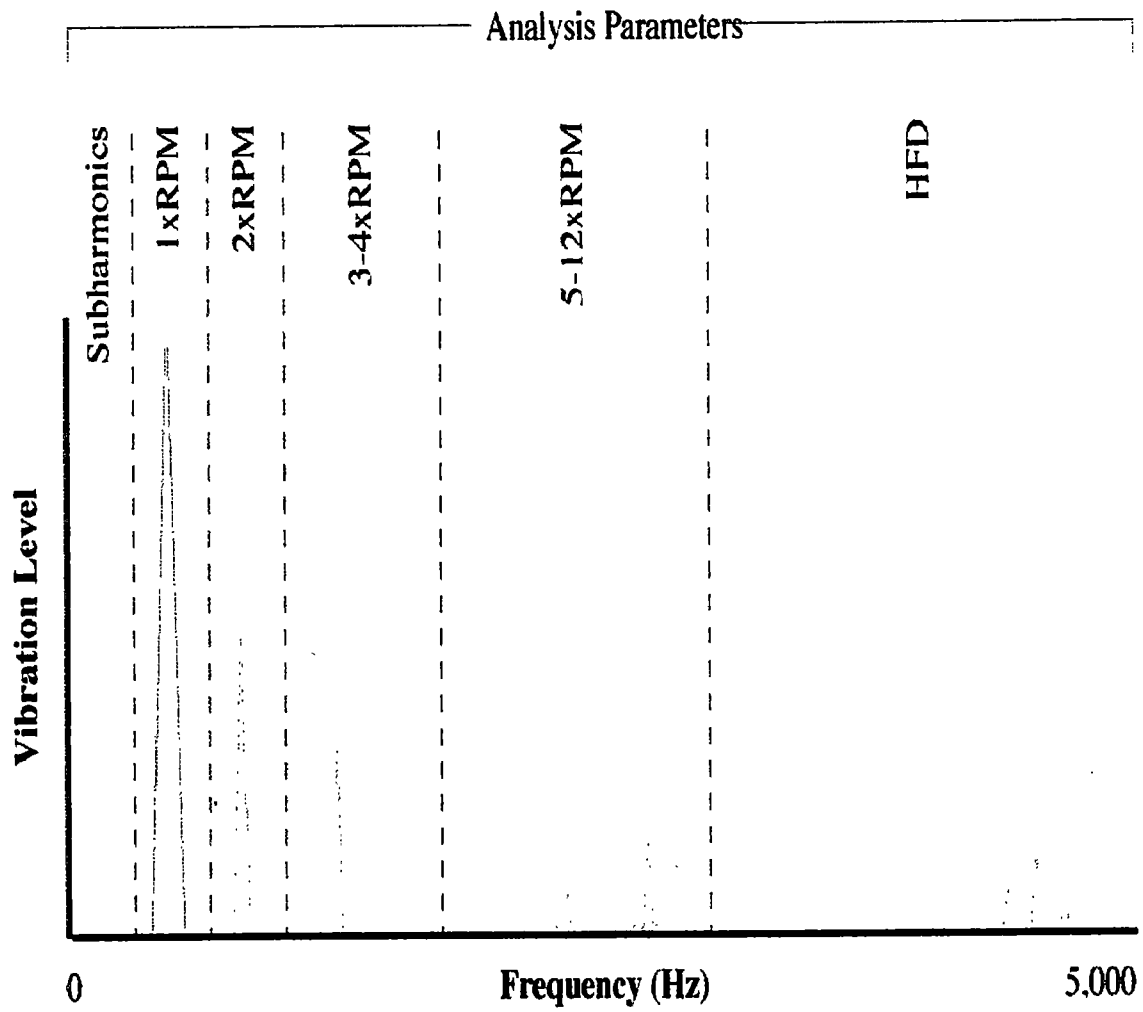


Figure 6: Typical Analysis Parameter Set⁹

individual alarm limits for each analysis parameter. RBMware™ provides four alarm levels⁹:

1. **Fault Level:** This is the most severe alarm level and is indicative of impending component failure. The fault alarm values specified in RBMware™ are based on published standards for applicable Equipment. Figure 7 shows a typical vibration severity index commonly used in industry⁴⁴.
2. **Alert Level:** Though less severe than fault levels, alert levels are indicative of significant component degradation. The alert levels specified by RBMware™ are based on component technical specifications and industry standards.
3. **Weak Side Level:** This alarm is set at a level below the normal operating amplitude of the Equipment. The primary purpose of this alarm is to protect against improper data collection.
4. **Early Warning Alarm:** This is a statistical alarm that is based on the amount of deviation from the normal operating amplitude. There are two methods of calculation, including the Baseline Ratio and the Maximum Deviations. The Baseline Ratio establishes alarm levels based on the percent deviation from the normal value. For example, a Baseline Ratio of 1.3 will trigger an alarm if the magnitude of the collected data is greater than 1.3 times the magnitude of normal data. The Maximum Deviations alarm establishes alarm levels based on the

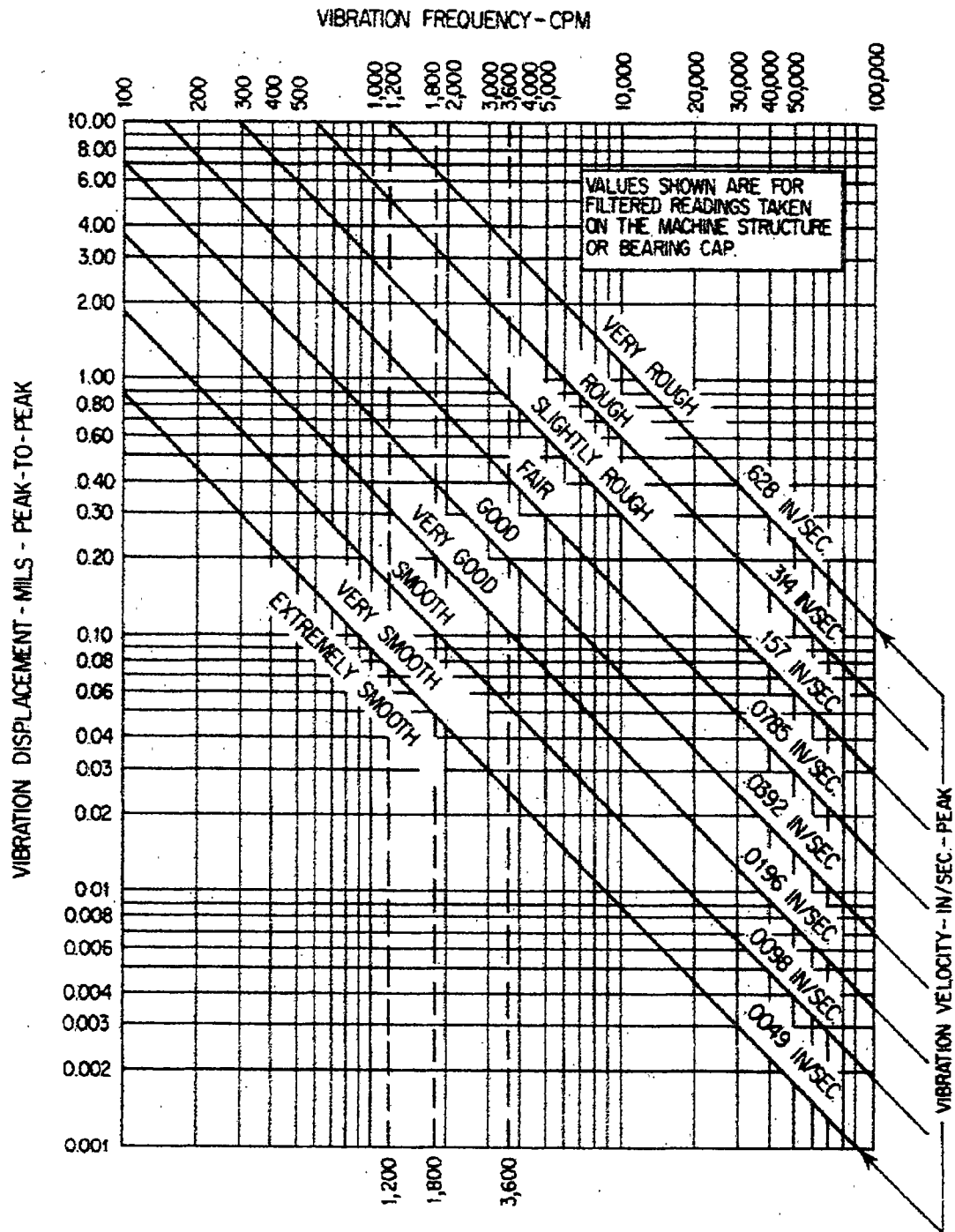


Figure 7: Vibration Severity Index⁴⁴

number of standard deviations from the calculated mean, or average, value.

There are two types of alarms employed in the HFIR Vibration Analysis Program: the dual upper alarm level alarm and the dual upper delta alarm. Figure 8 provides graphical descriptions of these types of alarms, while Table 15 provides a description of the alarm codes used by RBMware™ when generating reports¹⁰.

The “A” alarm code is generated as a result of a trend analysis on the measured parameters, with the goal of early indication of developing faults. The alarm levels generated by RBMware™ are either absolute value or absolute delta alarms. Absolute value alarms rely on the magnitude of a vibration component, while absolute delta alarms rely on the amount of deviation from the normal levels. Normal levels are established by averaging data taken over a period of 12 months. Table A4 in Appendix A contains a listing of the alarm limit sets constructed in support of this project.

Fault Frequencies identify specific frequency ranges whose amplitude patterns may indicate particular component faults. Examples include frequencies associated with unbalance, misalignment, and roller bearing degradation. By evaluating the magnitude of the vibration signal at the frequencies associated with these faults, the analyst can make a determination of the degree of each that a component is experiencing. Fault frequencies are represented as dashed lines on spectral plots and indicate the position of peaks that may be associated with a

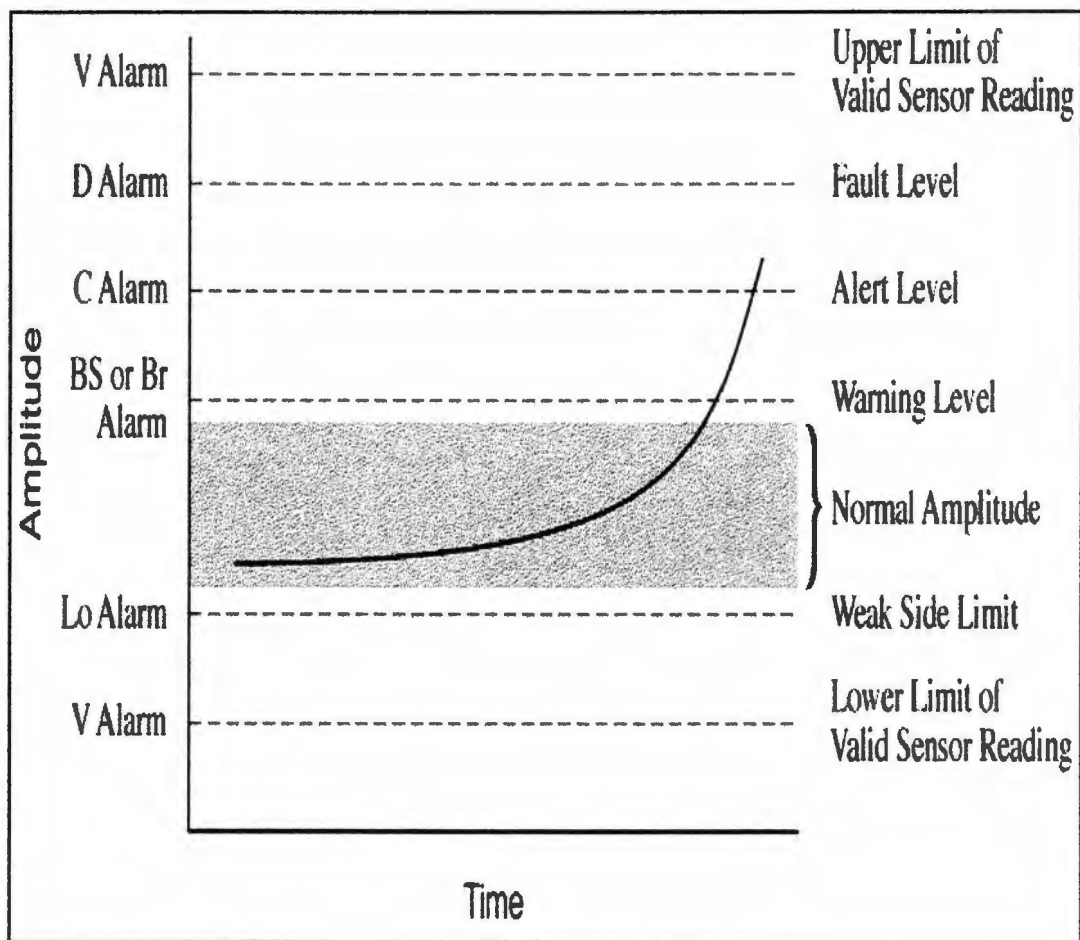


Figure 8: Dual Upper Level and Delta Alarm Description¹⁰

Table 15: Alarm Codes Used By RBMware™ 10

Alarm Code	Alarm Limit
A	The measured parameter is expected to exceed the absolute fault level within three measurement intervals.
Br	An Early Warning Alarm calculated using the Baseline Ratio method.
Bs	An Early Warning Alarm calculated using the Maximum Deviations method.
C	Alert Level Alarm
D	Fault Level Alarm
L	The measured parameter is below the weak side value for a Dual Upper Alarm type.
V	The measured parameter is above the maximum or below the minimum sensor validity alarm.

well-defined fault, as shown in Figure 9¹⁰. In this figure, the large peak is associated with the 2XRPM frequency, which is typically associated with misalignment. The position of the fault frequency lines is calculated by RBMware™ using component technical specifications. The primary function of the fault frequency lines is to provide the analyst with assistance in identifying component faults. Table A5 in Appendix A contains a detailed listing of the fault frequencies currently assigned.

5.3.1.3 Discussion-The discussion of the capabilities of RBMware™ is purposely limited to those relevant to this initiative. RBMware™ is the most comprehensive predictive maintenance software package currently available and many of the capabilities it possesses will be beneficial during later stages of development. The large number of options for data collection and analysis provided by RBMware™ can easily overwhelm the inexperienced analyst. To prevent this, HFIR maintenance personnel must limit their focus to the basic analytical services offered by the package. Although the long-term development of the HFIR maintenance organization is inextricably linked to the effective use of this software, the short-term development of expertise and experience requires a focus on very specific general principles. CSI training on both RBMware™ and the data collection tools is required to implement this program.

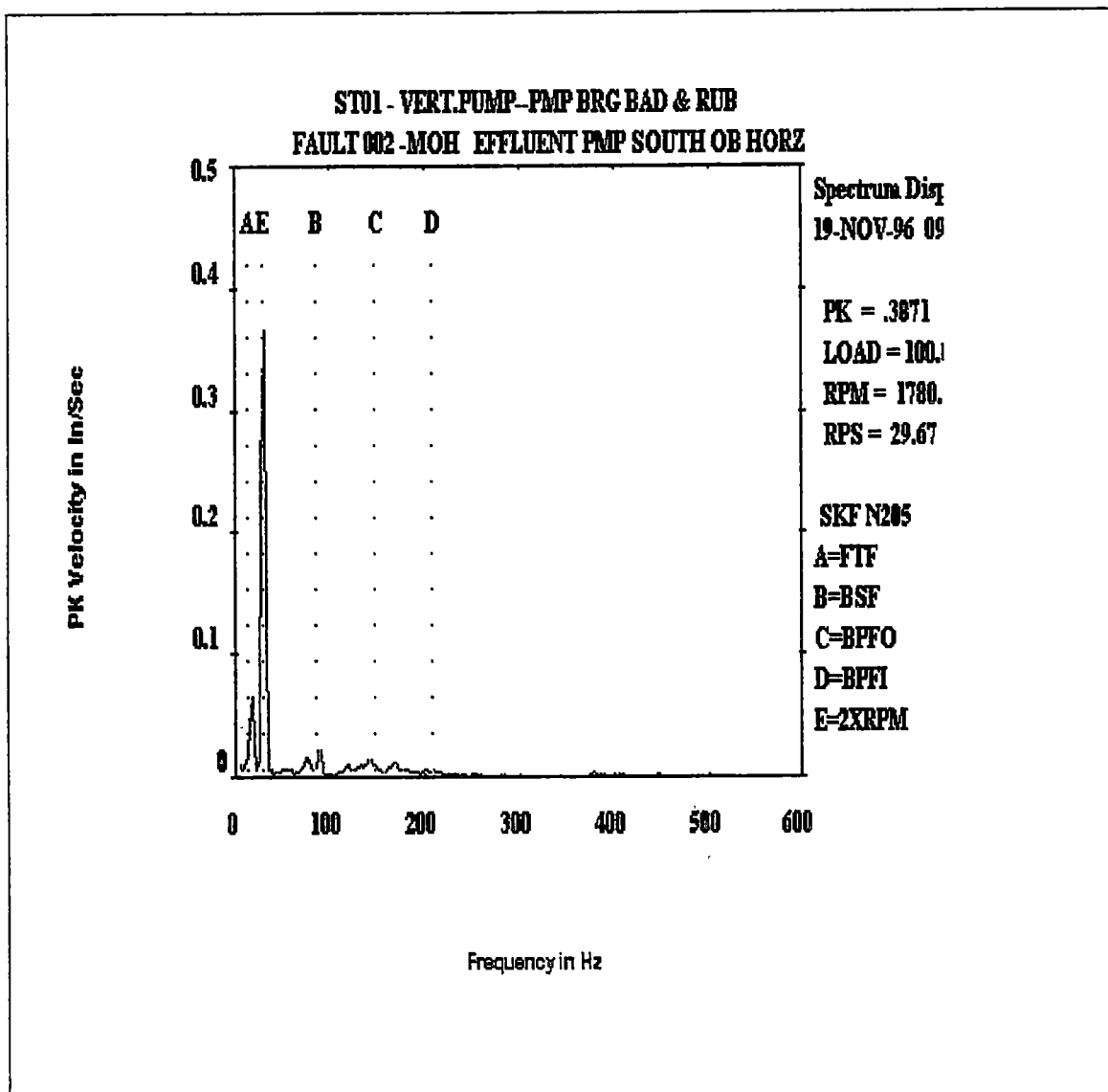


Figure 9: Typical Fault Frequency Set¹⁰

5.3.2 Monitoring Hardware

The hardware used in this initiative was selected from the equipment already purchased under the HFIR RECOM program. The hardware consisted of transducers and mounts, and a data collection device.

A transducer is a device that converts the vibration signal of a machine into an electrical signal. CSI Model 320 quick thread accelerometers were selected by HFIR RECOM personnel and were recycled for this initiative. This device required the setting of stud accelerometers at all Measurement Points, but provides excellent frequency response up to 16,000 Hz.

The data collector, a CSI Model 2120 Data Analyzer, was also recycled from the HFIR RECOM program. This device allows the analyst to collect real-time time and frequency domain signatures, as well as a means of transferring the collected data to storage in the RBMware™ database. All of the HFIR maintenance personnel involved in this initiative are familiar with the device, and many have received CSI training courses on its proper use and maintenance.

5.3.3 Data Collection Strategy

Vibration data are collected on a monthly basis from all the components. The data collection frequency is continuously evaluated as the program develops, since the occurrence of significant component degradation or failure between monitoring cycles may necessitate increased monitoring frequency. To facilitate

regularity in data collection, redundant equipment is rotated in service during each outage. In the past, components were left in service until a problem arose, at which time the standby component was placed into service. The standby component was then designated as the primary component until failure, at which time the original component, after being repaired, was returned to service. In addition to balancing runtime, switching components during each refueling outage provides a rough indicator of run time and a means of documenting component failures. Information such as this is necessary for the development of a comprehensive predictive maintenance program, and provides the foundation for the eventual development of reliability-centered maintenance practices at HFIR.

5.3.4 Analysis Strategy

Just as maintenance as a whole must be tailored to a specific situation, so must the analysis technique. Both HFIR maintenance management and maintenance personnel must understand that the determination of the best strategy for the HFIR will be an ongoing process. This necessitates a continuous process of monitoring and evaluating performance that is will require adjustments to current record keeping and work allocation practices.

As stated before, the alarm levels generated by RBMware™ are based on industry standards and component technical information. While these levels are a good place to begin, they are meant to serve only as guidelines. HFIR maintenance personnel must establish what constitutes degradation or an

impending fault based on experience with their equipment. For example, consider the use of fault frequencies. Characteristics of a vibration signal may be used to characterize underlying behavior, but unless there is some connection between the magnitude of the vibration signal associated with a certain fault frequency and the actual severity of the problem, the analyst can provide no useful information. The only way to establish this connection is through experience, which is facilitated by detailed record keeping. HFIR maintenance personnel have begun collecting and analyzing data, and at the same time are beginning to record observations such as the amount of run time between bearing replacements. Once sufficient data have been collected, including both vibration and component history data, all of the elements needed to make the connection are available.

There will be a period during which the HFIR maintenance organization continues to employ the same breakdown maintenance practices as in the past, while collecting vibration data. Collecting vibration data from failing components both before and after repair will assist HFIR maintenance personnel in several ways. First, collection of vibration data from components known to be approaching failure provides insight into the relationship between the magnitude of the vibration signal and the severity of the problem. Secondly, collection of data from components recently repaired will assist in determining what "normal" vibration levels are in properly functioning components.

The logical place to start building expertise is with components showing the highest levels of vibration. One of the foundational principles of vibration analysis is that the magnitude of vibration levels produced by a component is

indicative of its operating condition. At this stage of development, the numerical values of the signals are somewhat ambiguous in regards to the severity they represent, so the analyst must rely on the relative magnitudes. In other words, the components with the highest vibration levels can be assumed to be in the worst operating condition.

Once the "noisiest" components have been identified, attention should turn to scrutiny of the signals. The previous vibration analysis training received by HFIR maintenance personnel has provided a basic level of understanding and, more importantly, a belief in the merits of the technique. The simplicity of the components and techniques used in this initial implementation allows maintenance personnel to apply basic strategies learned in training. The analysts should collect data from the noisiest components, analyze it, and make observations regarding their conclusions. At this time, no one is going to plan maintenance on recommendations regarding potential degradation of a component, so this diagnosis is made entirely for learning purposes. As time passes, it is reasonable to assume that the noisiest components will eventually experience trouble, at which time the validity of diagnoses may be evaluated.

5.3.4.1 Description-One of the most useful documents produced by RBMware™ is the Measurement Exception Analysis Report. This report provides a detailed listing of all Measurement Points that are either in alarm, or rapidly approaching alarm levels. Figure 10 shows a portion of a typical Measurement Exception Analysis Report.

Measurement Exception Analysis Report

Database: HFIR Facility.rbm
Area: First Floor
Report Date: Aug-20-99 09:51

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM
Chilled Water Pump PU-1		(Aug-16-99)			
PU-1	-	(RPM = 1800.)	(LOAD = 100.0)		
	MOV --- 25-75xTS	.157 In/Sec	.100 .150	D	0
	PIV --- 30-70xTS	.264 G-s	.200 .350	C	???
	PIH --- 30-70xTS	.227 G-s	.200 .350	C	???
	POV --- 30-70xTS	.297 G-s	.200 .350	C	???
	POA --- 30-70xTS	.305 G-s	.200 .350	C	???
Chilled Water Pump PU-2		(Jul-15-99)			
PU-2	-	(RPM = 1800.)	(LOAD = 100.0)		
	MOV --- 1xTS	.024 In/Sec	.350 .400	A	1
	MIV --- 1xTS	.033 In/Sec	.350 .400	A	1
	MIH --- 1xTS	.042 In/Sec	.350 .400	A	1
	PIV --- 1xTS	.035 In/Sec	.250 .350	A	1
	PIV --- 30-70xTS	.166 G-s	.070 .350	Br	43
	PIH --- 30-70xTS	.081 G-s	.070 .350	Br	126
	POV --- 1xTS	.0024 In/Sec	.250 .350	A	2
	POV --- 30-70xTS	.207 G-s	.200 .350	C	27
Demin. Water Pump PU-18A		(Jul-12-99)			
PU-18A	-	(RPM = 3490.)	(LOAD = 100.0)		
	MOV --- 1xTS	.012 In/Sec	.350 .400	A	1
	MOH --- 1xTS	.0065 In/Sec	.350 .400	A	1
	MOH --- 2xTS	.070 In/Sec	.060 .300	Br	111
	MOA --- 1xTS	.011 In/Sec	.350 .400	A	1
	MIV --- 1xTS	.018 In/Sec	.350 .400	A	1
	MIH --- 2xTS	.072 In/Sec	.060 .300	Br	107
	PIV --- 1xTS	.010 In/Sec	.250 .350	A	1
	PIV --- 30-70xTS	1.234 G-s	.200 .350	D	0
	PIH --- 1xTS	.0071 In/Sec	.250 .350	A	1
	PIH --- 25-70xTS	.041 In/Sec	.040 .200	Br	165
	PIH --- 30-70xTS	1.234 G-s	.200 .350	D	0
	POV --- 1xTS	.0054 In/Sec	.250 .350	A	3
	POV --- 30-70xTS	.805 G-s	.200 .350	D	0
	POH --- 1xTS	.0062 In/Sec	.250 .350	A	5
	POH --- 25-70xTS	.049 In/Sec	.040 .200	Br	121
	POH --- 30-70xTS	1.281 G-s	.200 .350	D	0
Jul-15-99	POA --- 30-70xTS	.0014 G-s	.200 .350	A	29

Exceptional Point Total: 24
Exceptional Equipment Total: 3

Clarification Of Vibration Units:
G-s RMS
In/Sec PK

Figure 10: Measurement Exception Analysis Report

The Measurement Exception Analysis Report provides the value of the alarming parameters and a prediction of the number of days until the next alarm level is reached. This prediction is made using linear extrapolation, assuming that at least three data points are available. If the projected number of days until alarm is greater than 300, or if the magnitudes are decreasing in magnitude, the Days Until Alarm column contains “???”.

Once the components with the most significant vibration signals have been identified using the Measurement Exception Analysis Report, the analyst will utilize one of the many the data display options provided by RBMware™. Since most personnel at this time are still in the formative stages of developing expertise in vibration analysis, it is essential that the analysis is conducted with development in mind. For this reason, maintenance personnel should first examine the vibration signatures of the measuring points identified in the Measurement Exception Analysis Report. Both time and frequency domain data should be inspected for obvious signs of component degradation.

The equipment monitored at this time was selected for the simplicity of its operation and the relative ease with which its typical faults could be identified. For this reason, the analyst will rely heavily on frequency domain analysis and fault frequencies in particular. Once HFIR maintenance personnel designated as analysts have mastered the use of these simple techniques for identification of the simplest component problems, they will have a strong foundation for learning more complicated analysis techniques. It is assumed that HFIR maintenance

management will facilitate this process by instituting a policy of continuous training and retraining of analysts.

Another particularly useful tool is the Fault Frequency Report²⁰. This document provides a list of the magnitudes of all fault frequencies assigned to a given measurement point, and identifies the frequencies that have significant magnitude in relationship to the appropriate alarm limit. Figure 11 shows an example of a Fault Frequency Report. This report serves to reinforce the connection between frequency signature and component condition.

The process of developing analytical expertise will likely emphasize to HFIR maintenance personnel the importance of precision alignment and balancing. By viewing the magnitude of the frequencies associated with these conditions and the effect on bearing life, HFIR maintenance personnel will begin to see the merit in increasing the precision of alignment and balancing activities. The fact that much of the maintenance history recited by maintenance personnel focuses on bearing replacement indicates that a great number of the components are operating with too high a degree of imbalance and/or misalignment. These are the major problems that arise in rotating components, and should be addressed from the beginning.

5.3.5 Case Studies Demonstrating the Analysis Strategy

Figure 12 shows the Aug. 20, 1999 Measurement Exception Analysis Report. This report identifies the equipment that are potentially the most useful

IDENTIFICATION OF FAULT FREQUENCY PEAKS						

Equipment:	(FF2) Chilled Water Pump PU-1					
Meas. Point:	PU-1 -PIH --> Pump Inboard Horizontal					
Date/Time:	Aug-16-99 13:23:52 RPM= 1763. Units=In/Sec PK					
-- Component --	1st Frq	2nd Frq	Total			
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present		
-----	-----	-----	-----	-----		
Unbalance	1.00	.000	.0150	1		
Misalignment	1.00	.000	.0183	1	2	3
Looseness	1.00	.000	.0183	1	2	3
Vane Pass	5.00	.000	.0026	3		
>MRC 5207M						
BSF	2.28	.000	.0029	4		
BPFO	4.90	.000	.0035	4		
BPFI	7.10	.000	.0033	1		
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
-----	-----	-----	-----	-----	-----	
1	29.40	.0150	1.00	Unbalance		
				Misalignment		
2	58.77	.0075	2.00	Misalignment		
				Looseness		
3	88.22	.0072	3.00	Misalignment		
				Looseness		
4	119.83	.0136	4.08			
5	146.02	.0035	4.97			
6	154.66	.0029	5.26			
7	208.16	.0033	7.08	BPFI	<MRC 5207M	>
8	239.88	.0136	8.16			
9	268.75	.0029	9.15	BSF	<MRC 5207M	>
10	295.34	.0032	10.05			
11	326.44	.0026	11.11			
12	442.12	.0026	15.05	Vane Pass		
13	445.51	.0027	15.16			
14	488.95	.0027	16.64			
15	501.56	.0033	17.07			
16	545.68	.0029	18.57			
17	560.75	.0038	19.08			
18	564.08	.0037	19.20			
19	574.28	.0035	19.54	BPFO	<MRC 5207M	>
20	582.81	.0030	19.83			
21	595.55	.0033	20.27			
22	608.31	.0029	20.70			
23	657.52	.0028	22.38			
24	1764.76	.0034	60.06			

Figure 11: Fault Frequency Report

Measurement Exception Analysis Report

Database: HFIR Facility.rbm
Area: Cooling Tower
Report Date: Aug-20-99 09:41

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM

Sec. Coolant Pump PU-6C		(Aug-17-99)			
PU-6C	-	(RPM = 1188.)	(LOAD = 100.0)		
	MUY --- 3-8xTS	.136 In/Sec	.071 .250	Br	110
	MUX --- 3-8xTS	.117 In/Sec	.068 .250	Br	154
Cooling Tower Fan 4A-2H		(Jul-27-99)			
4A-2	-	(RPM = 1800.)	(LOAD = 100.0)		
	MOV --- SUBHARMONICS	.070 In/Sec	.100 .200	A	1
Cooling Tower Fan 4C-1H		(Aug-16-99)			
4C-1	-	(RPM = 1800.)	(LOAD = 100.0)		
	MOH --- ROTOR BAR PASS	.157 In/Sec	.080 .400	Br	89
	MOH STATOR SLOT	.157 In/Sec	.080 .400	Br	106
	MOA --- 25-75xTS	.042 In/Sec	.031 .150	Br	229
	MIV --- 25-75xTS	.070 In/Sec	.036 .150	Br	81
	MIH --- 25-75xTS	.068 In/Sec	.045 .150	Br	116
	MIH ROTOR BAR PASS	.148 In/Sec	.080 .400	Br	86
	MIH STATOR SLOT	.148 In/Sec	.142 .400	Br	159
Cooling Tower Fan 4D-1H		(Aug-16-99)			
4D-1	-	(RPM = 1800.)	(LOAD = 100.0)		
	MOH --- ROTOR BAR PASS	.273 In/Sec	.250 .400	C	15
	MOH STATOR SLOT	.273 In/Sec	.250 .400	C	16
	MOA --- ROTOR BAR PASS	.148 In/Sec	.080 .400	Br	79
	MOA STATOR SLOT	.148 In/Sec	.080 .400	Br	81
	MIV --- 25-75xTS	.046 In/Sec	.041 .150	Br	246
	MIV ROTOR BAR PASS	.152 In/Sec	.080 .400	Br	89
	MIV STATOR SLOT	.152 In/Sec	.084 .400	Br	122
	MIH --- ROTOR BAR PASS	.247 In/Sec	.080 .400	Br	26
	MIH STATOR SLOT	.247 In/Sec	.080 .400	Br	27
Cooling Tower Fan 4D-2H		(Aug-16-99)			
4D-2	-	(RPM = 1800.)	(LOAD = 100.0)		
	MIH --- SUBHARMONICS	.111 In/Sec	.100 .200	C	???
Cooling Tower Fan 4A-1L		(Aug-16-99)			
Fan 4A-1	-	(RPM = 900.)	(LOAD = 100.0)		
	MOH --- 2xTS	.108 In/Sec	.060 .300	Br	127
	MOA --- 2xTS	.087 In/Sec	.067 .300	Br	244
	MIH --- 2xTS	.108 In/Sec	.060 .300	Br	126

Exceptional Point Total:		23			
Exceptional Equipment Total:		7			

Clarification Of Vibration Units:
In/Sec PK

Figure 12: Aug. 20, 1999 Measurement Exception Analysis Report

Measurement Exception Analysis Report

Database: HFIR Facility.rbm
Area: Fan Facility
Report Date: Aug-20-99 09:46

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM
CHOG Fan FN-3		(Aug-13-99)			
FN-3	-	(RPM = 3571.) (LOAD = 100.0)			
	MOH --- 2xTS	.213 In/Sec	.060 .300	Br	26
	MOH --- 2xLINE FREQ	.200 In/Sec	.080 .400	Br	80
	MIH --- 2xTS	.207 In/Sec	.060 .300	Br	27
	MIH --- 2xLINE FREQ	.202 In/Sec	.080 .400	Br	79
		(RPM = 3443.)			
	FIV --- 1K-20KHZ	.422 G-s	.400 2.000	Br	293
	FOH --- 1K-20KHZ	.459 G-s	.400 2.000	Br	???
CHOG Fan FN-4		(Aug-13-99)			
FN-4	-	(RPM = 3443.) (LOAD = 100.0)			
	FIV --- 1K-20KHZ	1.305 G-s	1.000 2.000	C	69
	FIH --- 1K-20KHZ	1.516 G-s	1.000 2.000	C	38
	FIA --- 1K-20KHZ	.482 G-s	.400 2.000	Br	207
	FOV --- 1K-20KHZ	.969 G-s	.400 2.000	Br	26
	FOH --- 1K-20KHZ	.996 G-s	.400 2.000	Br	20
OHOG Fan FN-5		(Aug-13-99)			
FN-5	-	(RPM = 3580.) (LOAD = 100.0)			
	MOH --- 2xTS	.109 In/Sec	.060 .300	Br	141
	MOH --- 2xLINE FREQ	.104 In/Sec	.080 .400	Br	248
	MIH --- 2xTS	.108 In/Sec	.060 .300	Br	142
	MIH --- 2xLINE FREQ	.104 In/Sec	.080 .400	Br	253
		(RPM = 3452.)			
	FIV --- 1K-20KHZ	3.719 G-s	1.000 2.000	D	0
	FIH --- 1K-20KHZ	5.031 G-s	1.000 2.000	D	0
	FIA --- 1K-20KHZ	.645 G-s	.400 2.000	Br	215
	FOV --- SUBHARMONICS	.0027 In/Sec	.100 .200	A	1
	FOV --- 1K-20KHZ	.762 G-s	.400 2.000	Br	132
	FOH --- 1K-20KHZ	1.031 G-s	1.000 2.000	C	85
	FOA --- 1K-20KHZ	.500 G-s	.400 2.000	Br	???
SBHE Fan FN-2		(Aug-09-99)			
SBHE FN-2	-	(RPM = 1785.) (LOAD = 100.0)			
	MOV --- SUBHARMONICS	.0060 In/Sec	.100 .200	A	5
	MOV --- 1xTS	.034 In/Sec	.350 .400	A	1
	MOH --- SUBHARMONICS	.0038 In/Sec	.100 .200	A	7
	MOH --- 1xTS	.014 In/Sec	.350 .400	A	5
	MOH --- 2xTS	.064 In/Sec	.060 .300	Br	???
	MOA --- 1xTS	.0078 In/Sec	.350 .400	A	3
	MIV --- SUBHARMONICS	.0082 In/Sec	.100 .200	A	1
	MIV --- 1xTS	.050 In/Sec	.350 .400	A	5
	MIH --- SUBHARMONICS	.0077 In/Sec	.100 .200	A	1
	MIH --- 1xTS	.031 In/Sec	.350 .400	A	2
		(RPM = 1675.)			
	FIV --- SUBHARMONICS	.0018 In/Sec	.100 .200	A	3
	FIV --- 1xTS	.042 In/Sec	.250 .350	A	7
	FIV --- 30-70xTS	.110 G-s	.080 .400	Br	246
	FIH --- 1xTS	.033 In/Sec	.250 .350	A	4
	FIH --- 30-70xTS	.093 G-s	.080 .400	Br	???

Figure 12 (continued)

FIA --- 1xTS	.028 In/Sec	.250	.350	A	3
FIA 30-70xTS	.081 G-s	.080	.400	Br	???
FOV --- 1xTS	.030 In/Sec	.250	.350	A	3
FOH --- 1xTS	.042 In/Sec	.250	.350	A	2
FOA --- 1xTS	.020 In/Sec	.250	.350	A	7
FOA 3-8xTS	.055 In/Sec	.050	.250	Br	???

SBHE Fan FN-3	(Aug-13-99)				
SBHE FN-3 -	(RPM = 1788.)	(LOAD = 100.0)			
MOH --- 3-8xTS	.228 In/Sec	.200	.250	C	9
MOA --- 25-75xTS	.035 In/Sec	.030	.150	Br	50
MIV --- 3-8xTS	.099 In/Sec	.200	.250	A	89
	(RPM = 1753.)				
FOA --- 3-8xTS	.081 In/Sec	.200	.250	A	65

Exceptional Point Total: 37
Exceptional Equipment Total: 6

Clarification Of Vibration Units:

G-s RMS
In/Sec PK

Measurement Exception Analysis Report

Database: HFIR Facility.rbm
Area: Ground Floor
Report Date: Aug-20-99 09:48

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM
Primary Cleanup Pump PU-2B (Aug-09-99)					
PU-2B -		(RPM = 3510.)	(LOAD = 100.0)		
PIV --- 25-70xTS	.117 In/Sec	.100	.200	C	???
PIV 30-70xTS	2.172 G-s	.200	.350	D	0
PIH --- 25-70xTS	.151 In/Sec	.100	.200	C	???
PIH 30-70xTS	2.406 G-s	.200	.350	D	0
POV --- 25-70xTS	.115 In/Sec	.100	.200	C	???
POV 30-70xTS	2.188 G-s	.200	.350	D	0
POH --- 30-70xTS	2.266 G-s	.200	.350	D	0
POA --- 30-70xTS	1.609 G-s	.200	.350	D	0
Pressurizer Pump PU-4A (Aug-02-99)					
PU-4A -		(RPM = 3021.)	(LOAD = 100.0)		
PIV --- 30-70xTS	.210 G-s	.200	.350	C	28
PIH --- 30-70xTS	.227 G-s	.200	.350	C	22
PIA --- 30-70xTS	.200 G-s	.200	.350	C	30
POV --- 30-70xTS	.307 G-s	.200	.350	C	6
POH --- 30-70xTS	.328 G-s	.200	.350	C	3
Pressurizer Pump PU-4B (Aug-16-99)					
PU-4B -		(RPM = 3021.)	(LOAD = 100.0)		
PIV --- 30-70xTS	.231 G-s	.200	.350	C	45
PIH --- 30-70xTS	.233 G-s	.200	.350	C	27
PIA --- 30-70xTS	.346 G-s	.200	.350	C	???
POV --- 30-70xTS	.328 G-s	.200	.350	C	???
POH --- 30-70xTS	.314 G-s	.200	.350	C	???

Figure 12 (continued)

Pool Cleanup Pump PU-7A		(Aug-16-99)				
PU-7A	-	(RPM = 3510.)	(LOAD = 100.0)			
PIV ---	30-70xTS	.980 G-s	.200 .350	D	0	
PIH ---	30-70xTS	.906 G-s	.200 .350	D	0	
POV ---	30-70xTS	.773 G-s	.200 .350	D	0	
POH ---	30-70xTS	.594 G-s	.200 .350	D	0	
Pool Coolant Pump PU-9A		(Aug-16-99)				
PU-9A	-	(RPM = 3555.)	(LOAD = 100.0)			
MOV ---	SUBHARMONICS	.0077 In/Sec	.100 .200	A	6	
MOV	1xTS	.054 In/Sec	.350 .400	A	6	
MOH ---	SUBHARMONICS	.0065 In/Sec	.100 .200	A	10	
MOH	1xTS	.049 In/Sec	.350 .400	A	11	
MOH	2xTS	.111 In/Sec	.060 .300	Br	196	
MOH	2xLINE FREQ	.106 In/Sec	.080 .400	Br	???	
MOA ---	SUBHARMONICS	.0059 In/Sec	.100 .200	A	11	
MOA	1xTS	.039 In/Sec	.350 .400	A	4	
MIV ---	1xTS	.031 In/Sec	.350 .400	A	8	
MIV	2xTS	.064 In/Sec	.060 .300	Br	???	
MIH ---	1xTS	.021 In/Sec	.350 .400	A	12	
MIH	2xTS	.103 In/Sec	.060 .300	Br	230	
MIH	2xLINE FREQ	.098 In/Sec	.080 .400	Br	???	
PIV ---	SUBHARMONICS	.0071 In/Sec	.100 .200	A	7	
PIV	1xTS	.033 In/Sec	.250 .350	A	4	
PIV	2xTS	.065 In/Sec	.060 .300	Br	???	
PIV	30-70xTS	1.578 G-s	.200 .350	D	0	
PIH ---	SUBHARMONICS	.014 In/Sec	.100 .200	A	21	
PIH	1xTS	.056 In/Sec	.250 .350	A	13	
PIH	2xTS	.156 In/Sec	.060 .300	Br	112	
PIH	30-70xTS	1.008 G-s	.200 .350	D	0	
POV ---	SUBHARMONICS	.0075 In/Sec	.100 .200	A	18	
POV	1xTS	.036 In/Sec	.250 .350	A	16	
POV	2xTS	.074 In/Sec	.060 .300	Br	???	
POV	30-70xTS	1.938 G-s	.200 .350	D	0	
POH ---	SUBHARMONICS	.0091 In/Sec	.100 .200	A	9	
POH	1xTS	.046 In/Sec	.250 .350	A	1	
POH	2xTS	.138 In/Sec	.060 .300	Br	127	
POH	30-70xTS	1.586 G-s	.200 .350	D	0	
POA ---	SUBHARMONICS	.0083 In/Sec	.100 .200	A	22	
POA	1xTS	.055 In/Sec	.250 .350	A	8	
POA	2xTS	.084 In/Sec	.060 .300	Br	298	
POA	30-70xTS	2.172 G-s	.200 .350	D	0	
Pool Coolant Pump PU-9B		(Jul-15-99)				
PU-9B	-	(RPM = 3555.)	(LOAD = 100.0)			
MOV ---	2xTS	.066 In/Sec	.060 .300	Br	240	
MOH ---	2xTS	.085 In/Sec	.060 .300	Br	162	
MOH	2xLINE FREQ	.081 In/Sec	.080 .400	Br	293	
MIH ---	2xTS	.067 In/Sec	.060 .300	Br	240	
PIV ---	30-70xTS	.762 G-s	.200 .350	D	0	
PIH ---	2xTS	.105 In/Sec	.060 .300	Br	130	
PIH	30-70xTS	.996 G-s	.200 .350	D	0	
POV ---	25-70xTS	.064 In/Sec	.049 .200	Br	214	
POV	30-70xTS	2.516 G-s	.200 .350	D	0	
POH ---	2xTS	.109 In/Sec	.060 .300	Br	118	
POH	3-8xTS	.072 In/Sec	.060 .300	Br	282	
POH	30-70xTS	.969 G-s	.200 .350	D	0	
POA ---	9-25xTS	.053 In/Sec	.050 .250	Br	???	
POA	30-70xTS	1.656 G-s	.200 .350	D	0	

Figure 12 (continued)

Exceptional Point Total: 42
Exceptional Equipment Total: 7

Clarification Of Vibration Units:

G-s RMS
In/Sec PK

Measurement Exception Analysis Report

Database: HFIR Facility.rbm
Area: First Floor
Report Date: Aug-20-99 09:51

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM
Chilled Water Pump PU-1 (Aug-16-99)					
PU-1	-	(RPM = 1800.) (LOAD = 100.0)			
MOV ---	25-75xTS	.157 In/Sec	.100 .150	D	0
PIV ---	30-70xTS	.264 G-s	.200 .350	C	???
PIH ---	30-70xTS	.227 G-s	.200 .350	C	???
POV ---	30-70xTS	.297 G-s	.200 .350	C	???
POA ---	30-70xTS	.305 G-s	.200 .350	C	???
Chilled Water Pump PU-2 (Jul-15-99)					
PU-2	-	(RPM = 1800.) (LOAD = 100.0)			
MOV ---	1xTS	.024 In/Sec	.350 .400	A	1
MOH ---	1xTS	.011 In/Sec	.350 .400	A	2
MIV ---	SUBHARMONICS	.0011 In/Sec	.100 .200	A	2
MIV	1xTS	.033 In/Sec	.350 .400	A	1
MIH ---	1xTS	.042 In/Sec	.350 .400	A	1
PIV ---	SUBHARMONICS	.0059 In/Sec	.100 .200	A	9
PIV	1xTS	.035 In/Sec	.250 .350	A	1
PIV	30-70xTS	.166 G-s	.070 .350	Br	43
PIH ---	30-70xTS	.081 G-s	.070 .350	Br	126
POV ---	SUBHARMONICS	.0015 In/Sec	.100 .200	A	2
POV	1xTS	.0024 In/Sec	.250 .350	A	2
POV	30-70xTS	.207 G-s	.200 .350	C	27
POH ---	SUBHARMONICS	.0018 In/Sec	.100 .200	A	1
POH	1xTS	.0016 In/Sec	.250 .350	A	2
POH	30-70xTS	.099 G-s	.070 .350	Br	98
POA ---	SUBHARMONICS	.0024 In/Sec	.100 .200	A	2
POA	30-70xTS	.320 G-s	.200 .350	C	7
Demin. Water Pump PU-18A (Jul-12-99)					
PU-18A	-	(RPM = 3490.) (LOAD = 100.0)			
MOV ---	SUBHARMONICS	.0075 In/Sec	.100 .200	A	2
MOV	1xTS	.012 In/Sec	.350 .400	A	1
MOH ---	SUBHARMONICS	.0029 In/Sec	.100 .200	A	2
MOH	1xTS	.0065 In/Sec	.350 .400	A	1
MOH	2xTS	.070 In/Sec	.060 .300	Br	111
MOA ---	SUBHARMONICS	.0038 In/Sec	.100 .200	A	1
MOA	1xTS	.011 In/Sec	.350 .400	A	1
MIV ---	SUBHARMONICS	.0067 In/Sec	.100 .200	A	2
MIV	1xTS	.018 In/Sec	.350 .400	A	1
MIH ---	SUBHARMONICS	.0047 In/Sec	.100 .200	A	3
MIH	1xTS	.014 In/Sec	.350 .400	A	2
MIH	2xTS	.072 In/Sec	.060 .300	Br	107
PIV ---	1xTS	.010 In/Sec	.250 .350	A	1

Figure 12 (continued)

	PIV	30-70xTS	1.234 G-s	.200	.350	D	0
	PIH ---	SUBHARMONICS	.0028 In/Sec	.100	.200	A	2
	PIH	1xTS	.0071 In/Sec	.250	.350	A	1
	PIH	25-70xTS	.041 In/Sec	.040	.200	Br	165
	PIH	30-70xTS	1.234 G-s	.200	.350	D	0
	POV ---	SUBHARMONICS	.0065 In/Sec	.100	.200	A	7
	POV	1xTS	.0054 In/Sec	.250	.350	A	3
	POV	30-70xTS	.805 G-s	.200	.350	D	0
	POH ---	SUBHARMONICS	.0038 In/Sec	.100	.200	A	5
	POH	1xTS	.0062 In/Sec	.250	.350	A	5
	POH	25-70xTS	.049 In/Sec	.040	.200	Br	121
	POH	30-70xTS	1.281 G-s	.200	.350	D	0
Jul-15-99	POA ---	30-70xTS	.0014 G-s	.200	.350	A	29
Exceptional Point Total:			24				
Exceptional Equipment Total:			3				
Clarification Of Vibration Units:							
		G-s	RMS				
		In/Sec	PK				
Measurement Exception Analysis Report							

Database: HFIR Facility.rbm							
Area: Primary Coolant Pumps							
Report Date: Aug-20-99 09:52							
	MEASUREMENT	ANALYSIS	PARAMETER	ALARM/FAULT	ALARM	DAYS TO	
	POINT	PARAMETER	VALUE	LEVELS	CODE	ALARM	
	-----	-----	-----	-----	-----	-----	
Primary Coolant Pump PU-1F			(Aug-01-99)				
PU-1F -			(RPM = 3600.)	(LOAD = 100.0)			
	MUA ---	1xTS	.010 In/Sec	.0026	6.000	Br	???
	MLX ---	1xTS	.0023 In/Sec	.0021	6.000	Bs	???
Primary Coolant Pump PU-1G			(Aug-01-99)				
PU-1G -			(RPM = 3600.)	(LOAD = 100.0)			
	MUY ---	1xTS	.0040 In/Sec	.0029	6.000	Bs	???
	MUX ---	1xTS	.0026 In/Sec	.0021	6.000	Bs	???
	MUA ---	1xTS	.0069 In/Sec	.0039	6.000	Br	???
Primary Coolant Pump PU-1H			(Aug-01-99)				
PU-1H -			(RPM = 3600.)	(LOAD = 100.0)			
	MUY ---	1xTS	.0026 In/Sec	.0020	6.000	Bs	???
	MUX ---	1xTS	.0027 In/Sec	.0020	6.000	Bs	???
	MUA ---	1xTS	.0016 In/Sec	.0013	6.000	Bs	???
	MLY ---	1xTS	.0017 In/Sec	.0013	6.000	Bs	???
Exceptional Point Total:			9				
Exceptional Equipment Total:			3				
Clarification Of Vibration Units:							
		G-s	RMS				
		In/Sec	PK				

Figure 12 (continued)

learning cases at this time, and should serve to maintain the focus of HFIR maintenance personnel on equipment in potentially poor condition. An initial survey of the results indicates that misalignment, imbalance, looseness, and resulting bearing degradation are present. The following analyses serve to illuminate the method that HFIR personnel will use to establish the connection between the vibration levels and equipment condition.

5.3.5.1 Analysis of Chilled Water Pump PU-1- The first step in the analysis is the evaluation of the information presented on the Measurement Exception Analysis Report. All of the alarms are for high frequency analysis parameters, which is indicative of antifriction bearing failure. The report also indicates that the outboard bearing on the motor is near failure. This information alone is useful to the maintenance organization, as it allows the procurement of a replacement to begin immediately. Further analysis focuses not only on evaluating the severity of the problem, but also identification of possible causes for premature bearing failure.

The next step in the analysis is to begin a visual inspection of the signals associated with the alarming Measurement Points listed in the Measurement Exception Analysis Report. Figure 13 displays the time and frequency domain information recorded from the MOV Measurement Point.

The frequency domain plot is exceptional in the dominance of high frequency peaks. While the severity associated with absolute magnitudes is still indeterminate, the relative magnitude of the high frequency peaks in regards to

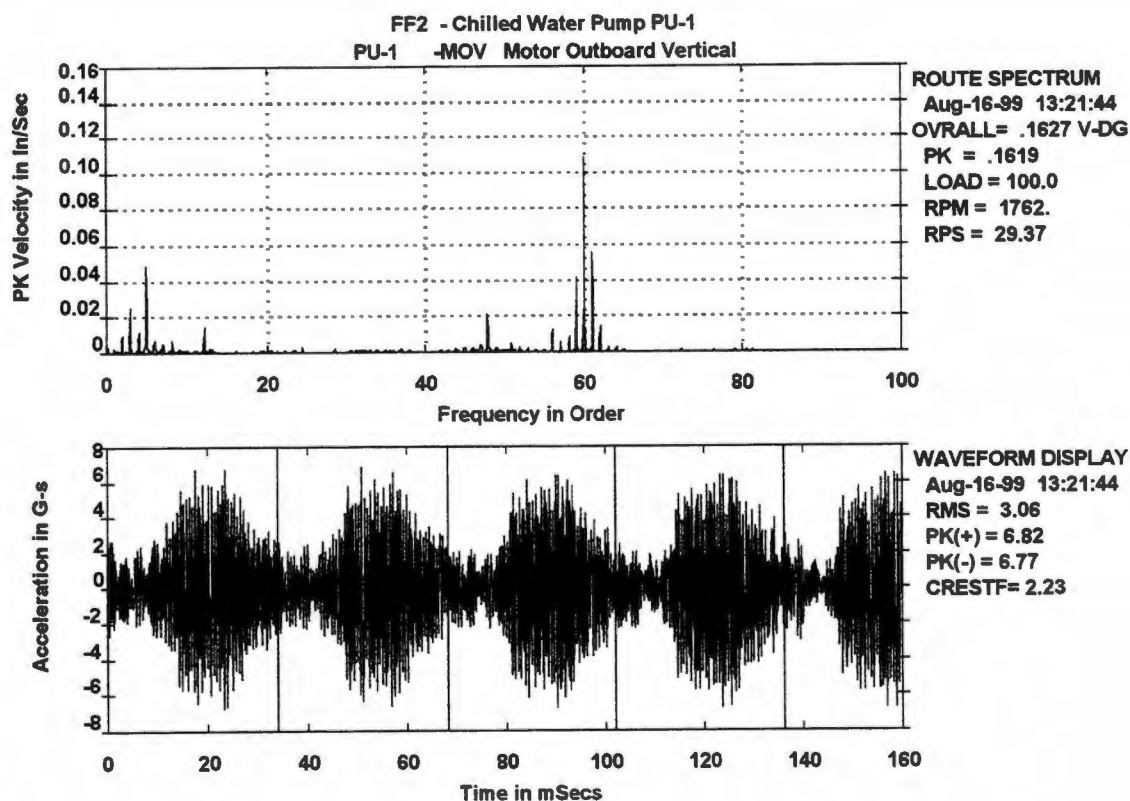


Figure 13: Vibration Data Collected from the MOV measuring Point of PU-1

the magnitude of peaks at lower multiples of running speed is unambiguous in its identification of impending antifriction bearing failure. This is reinforced by reference to the time domain plot, which shows signs of significant impacting. The difference between the maximum positive peak and the maximum negative peak, known as the G-swing, is approximately 13 G's. The industry standard is that G-swings greater than 2 G's are indicative of fault conditions, thus confirming the diagnosis made from the frequency domain plot⁴².

The time domain plot is also an excellent example of what is known as bearing ringdown. In this process, a significant spike of energy is seen when the bearing defect impacts. The vibrations produced by this impact "ringdown" until the next defect impact. The next step in the analysis process is to generate a Fault Frequency Report for this Measuring Point, shown in Figure 13.

This report indicates that there are significant peaks associated with lower multiples of running speed. This is indicative of either misalignment or looseness, as is indicated in Figure 14. The dominant harmonic is at 5X turning speed, which corresponds to the vane pass fault frequency. The presence of many large harmonics is not typical of impeller trouble, but the dominance of this harmonic raises the possibility. The fault frequency report also confirms the presence of significant energy in the high frequency range, again indicative of impending bearing failure.

Figure 15 displays the time and frequency data collected from the MOH Measuring Point of PU-1. The frequency domain plot shows significant energy in the high frequency range, as well as in low frequency harmonics. The relative

IDENTIFICATION OF FAULT FREQUENCY PEAKS						

Equipment:	(FF2) Chilled Water Pump PU-1					
Meas. Point:	PU-1	-MOV	-->	Motor Outboard Vertical		
Date/Time:	Aug-16-99	13:21:44	RPM=	1762.	Units=In/Sec	PK
-- Component --	1st Frq	2nd Frq	Total			
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family	Members	Present
-----	-----	-----	-----	-----	-----	-----
Unbalance	1.00	.000	.0034	1		
Misalignment	1.00	.000	.0301	1	2 3	
Looseness	1.00	.000	.0587	1	2 3 5 6	
Vane Pass	5.00	.000	.0498	1		
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
-----	-----	-----	-----	-----	-----	
1	29.34	.0034	1.00	Unbalance		
2	58.77	.0110	2.00	Misalignment		
3	88.11	.0278	3.00	Misalignment		
4	119.89	.0126	4.08	Looseness		
5	146.80	.0498	5.00	Misalignment		
6	176.17	.0075	6.00	Looseness		
7	208.11	.0062	7.09	Vane Pass		
8	239.93	.0083	8.17	Looseness		
9	359.89	.0157	12.25			
10	719.79	.0035	24.51			
11	1375.51	.0045	46.84			
12	1382.49	.0048	47.07			
13	1404.80	.0224	47.83			
14	1492.93	.0052	50.83			
15	1524.76	.0035	51.92			
16	1644.75	.0136	56.00			
17	1676.49	.0064	57.09			
18	1705.98	.0087	58.09			
19	1735.33	.0472	59.09			
20	1764.71	.1229	60.09			
21	1794.08	.0576	61.09			
22	1823.44	.0147	62.09			
23	1852.78	.0033	63.09			
24	1884.68	.0033	64.17			

Figure 14: Fault Frequency Report for MOV Measuring Point on PU-1

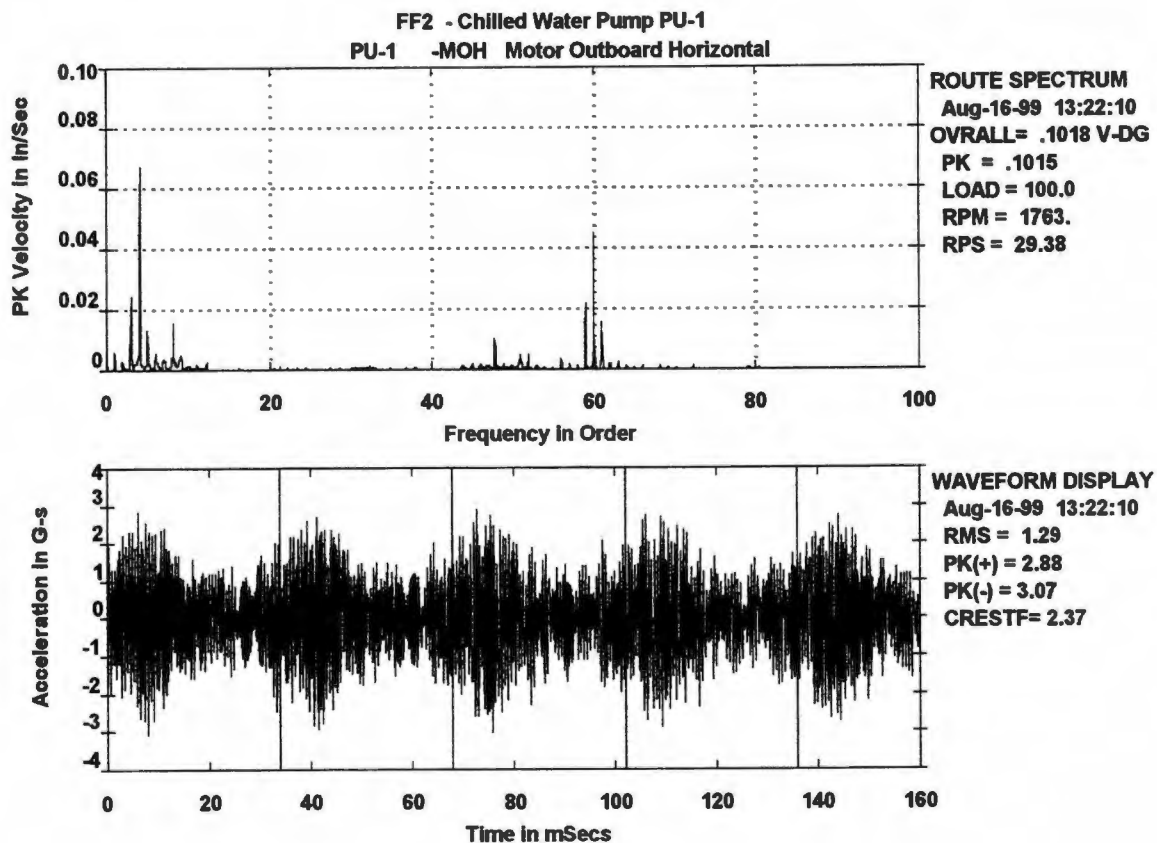


Figure 15: Data Collected from MOH Measuring Point on PU-1

magnitude of the high frequency peaks has decreased, while the overall magnitude of the low frequency peaks has risen slightly. There is also a significant reduction in the magnitude of the G-swing, which is still approximately 6 G's. Although the magnitude has lessened, the time domain plot once again provides an excellent example of bearing ringdown pattern. Figure 16 shows the Fault Frequency Report for the MOH point.

The Fault Frequency Report produces approximately the same results as for the MOV point, with the notable exception of the dominant harmonic. In this case, the dominant frequency was not 5X but 4X turning speed. This does not rule out the possibility of impeller problems, but it certainly reinforces the diagnosis of misalignment or looseness. Figure 17 displays the time and frequency data collected from the PIV Measuring Point of PU-1.

The magnitude of the entire frequency plot is significantly less than that of the MO points, and the raised floor of the plot at high frequencies is typical of degrading bearings. This is also seen in the G-swing of the time domain display, approximately 2 G's at this point. The time domain plot is also significantly different in appearance. The pattern still displays signs of impacting and ringdown, but it is much more random. Figure 18 shows the Fault Frequency Report for this Measuring Point.

The dominant frequency is once again at vane pass frequency, or 5X turning speed. In this case, there are no significant harmonics other than 5X, once again raising the possibility of impeller problems. The dominance of this harmonic does not reflect on the possibility of a misalignment or looseness

IDENTIFICATION OF FAULT FREQUENCY PEAKS									

Equipment:	(FF2) Chilled Water Pump PU-1								
Meas. Point:	PU-1 -MOH --> Motor Outboard Horizontal								
Date/Time:	Aug-16-99 13:22:10 RPM= 1763. Units=In/Sec PK								
-- Component --	1st Frq	2nd Frq	Total						
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present					
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Unbalance	1.00	.000	.0066	1					
Misalignment	1.00	.000	.0277	1	2	3			
Looseness	1.00	.000	.0321	1	2	3	5	6	7
Vane Pass	5.00	.000	.0139	1					
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY < COMPONENT DESC >					
-----	-----	-----	-----	-----					
1	29.37	.0066	1.00	Unbalance					
2	58.76	.0035	2.00	Misalignment					
3	88.12	.0266	3.00	Misalignment					
4	109.74	.0037	3.74	Looseness					
5	119.97	.0694	4.08	Misalignment					
6	146.77	.0139	5.00	Looseness					
7	176.12	.0055	6.00	Vane Pass					
8	205.72	.0045	7.00	Looseness					
9	210.25	.0034	7.16	Looseness					
10	235.03	.0050	8.00	Looseness					
11	239.97	.0185	8.17						
12	246.24	.0035	8.38						
13	260.19	.0040	8.86						
14	266.53	.0060	9.07						
15	1405.00	.0113	47.83						
16	1493.13	.0037	50.83						
17	1497.94	.0056	50.99						
18	1524.97	.0057	51.91						
19	1644.96	.0044	56.00						
20	1735.56	.0229	59.08						
21	1764.94	.0513	60.08						
22	1794.30	.0175	61.08						
23	1823.72	.0027	62.08						
24	1853.04	.0030	63.08						

Figure 16: Fault Frequency Report for MOH Measuring Point on PU-1

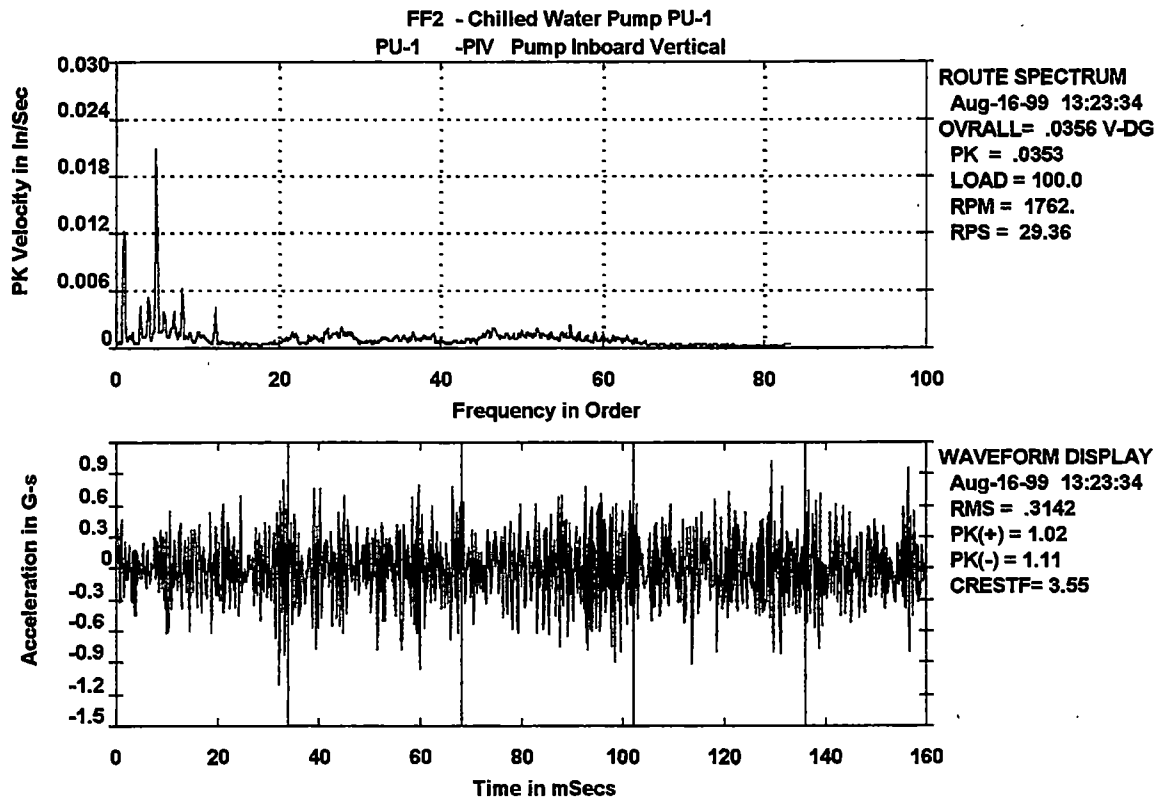


Figure 17: Data Collected from PIV Measuring Point on PU-1

IDENTIFICATION OF FAULT FREQUENCY PEAKS						

Equipment:	(FF2) Chilled Water Pump PU-1					
Meas. Point:	PU-1 -PIV --> Pump Inboard Vertical					
Date/Time:	Aug-16-99 13:23:34 RPM= 1762. Units=In/Sec PK					
-- Component --	1st Frq	2nd Frq	Total			
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present		
-----	-----	-----	-----	-----		
Unbalance	1.00	.000	.0137	1		
Misalignment	1.00	.000	.0144	1	3	
Looseness	1.00	.000	.0259	1	3	5 6
Vane Pass	5.00	.000	.0211	1		
>MRC 5207M						
BSF	2.28	.000	.0020	4		
BPFI	7.10	.000	.0040	1		
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
----	-----	-----	-----	-----	-----	
1	29.41	.0137	1.00	Unbalance		
2	88.13	.0045	3.00	Misalignment		
3	119.70	.0058	4.08	Misalignment		
4	146.72	.0211	5.00	Looseness		
5	164.33	.0021	5.60	Looseness		
6	176.02	.0042	6.00	Looseness		
7	208.53	.0040	7.10	BPFI	<MRC 5207M	>
8	217.72	.0019	7.42			
9	239.88	.0067	8.17			
10	267.11	.0020	9.10	BSF	<MRC 5207M	>
11	298.19	.0020	10.16			
12	359.94	.0042	12.26			
13	766.69	.0021	26.11			
14	798.70	.0019	27.20			
15	817.35	.0026	27.84			
16	829.86	.0020	28.27			
17	841.94	.0021	28.68			
18	854.33	.0020	29.10			
19	1345.41	.0021	45.83			
20	1366.98	.0024	46.56			
21	1492.71	.0019	50.84			
22	1526.03	.0022	51.98			
23	1614.35	.0021	54.99			
24	1645.20	.0029	56.04			

Figure 18: Fault Frequency Report for PIV Measuring Point on PU-1

problem. Both of these faults manifest at harmonics; the particular harmonic depends on the specific component and operating environment. The report is also conspicuous for the absence of significant high frequency peaks. Figure 19 displays the time and frequency data collected from the PIH Measuring Point of PU-1.

The raised floor at high frequencies is once again present, providing indication of bearing degradation. The 5X harmonic does not dominate the spectrum, as there are several large harmonics. The G-swing of the time domain plot is approximately the same as for the PIV point, and shows indication of impacting and ringdown. Figure 20 shows the Fault Frequency Report for this Measuring Point.

Once again, different harmonics dominate the spectrum. The report also identifies particular antifriction bearing fault frequencies, but at very low magnitudes. Figure 21 displays the time and frequency data collected from the POV Measuring Point of PU-1.

The time and frequency domain plots are virtually indistinguishable from the pump inboard points, with the exception of a slight increase in overall magnitude. The impacting in the time domain plot is slightly larger, as is the magnitude of the dominant low frequency harmonics. Figure 22 shows the fault frequency report for this Measuring Point.

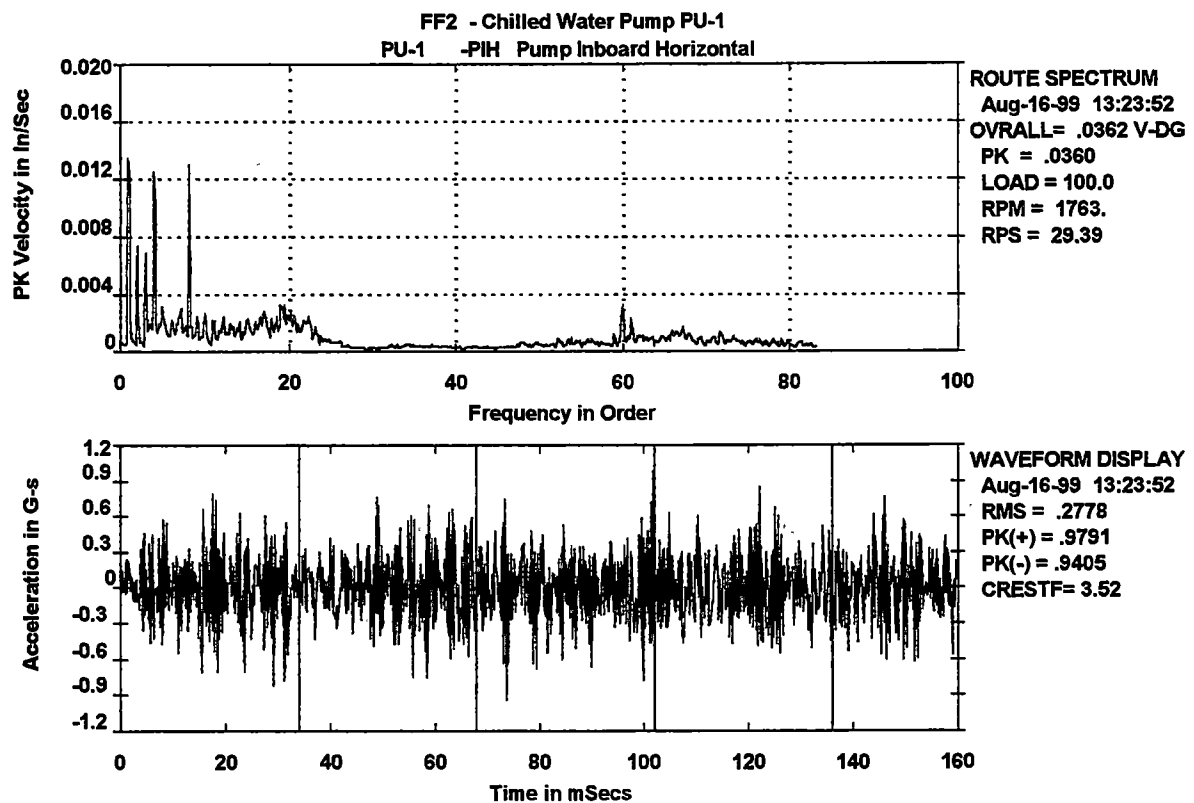


Figure 19: Data Collected from PIH Measuring Point on PU-1

IDENTIFICATION OF FAULT FREQUENCY PEAKS						

Equipment:	(FF2) Chilled Water Pump PU-1					
Meas. Point:	PU-1 -PIH --> Pump Inboard Horizontal					
Date/Time:	Aug-16-99 13:23:52 RPM= 1763. Units=In/Sec PK					
-- Component --	1st Frq	2nd Frq	Total			
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present		
-----	-----	-----	-----	-----		
Unbalance	1.00	.000	.0150	1		
Misalignment	1.00	.000	.0183	1	2	3
Looseness	1.00	.000	.0183	1	2	3
Vane Pass	5.00	.000	.0026	3		
>MRC 5207M						
BSF	2.28	.000	.0029	4		
BPFO	4.90	.000	.0035	4		
BPFI	7.10	.000	.0033	1		
PEAK	FREQUENCY	PEAK	ORDER			
NO.	(Hz)	VALUE	VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
----	-----	-----	-----	-----	-----	
1	29.40	.0150	1.00	Unbalance		
2	58.77	.0075	2.00	Misalignment		
3	88.22	.0072	3.00	Misalignment		
				Looseness		
4	119.83	.0136	4.08	Misalignment		
5	146.02	.0035	4.97	Looseness		
6	154.66	.0029	5.26			
7	208.16	.0033	7.08	BPFI	<MRC 5207M	>
8	239.88	.0136	8.16			
9	268.75	.0029	9.15	BSF	<MRC 5207M	>
10	295.34	.0032	10.05			
11	326.44	.0026	11.11			
12	442.12	.0026	15.05	Vane Pass		
13	445.51	.0027	15.16			
14	488.95	.0027	16.64			
15	501.56	.0033	17.07			
16	545.68	.0029	18.57			
17	560.75	.0038	19.08			
18	564.08	.0037	19.20			
19	574.28	.0035	19.54	BPFO	<MRC 5207M	>
20	582.81	.0030	19.83			
21	595.55	.0033	20.27			
22	608.31	.0029	20.70			
23	657.52	.0028	22.38			
24	1764.76	.0034	60.06			

Figure 20: Fault Frequency Report for PIH Measuring Point on PU-1

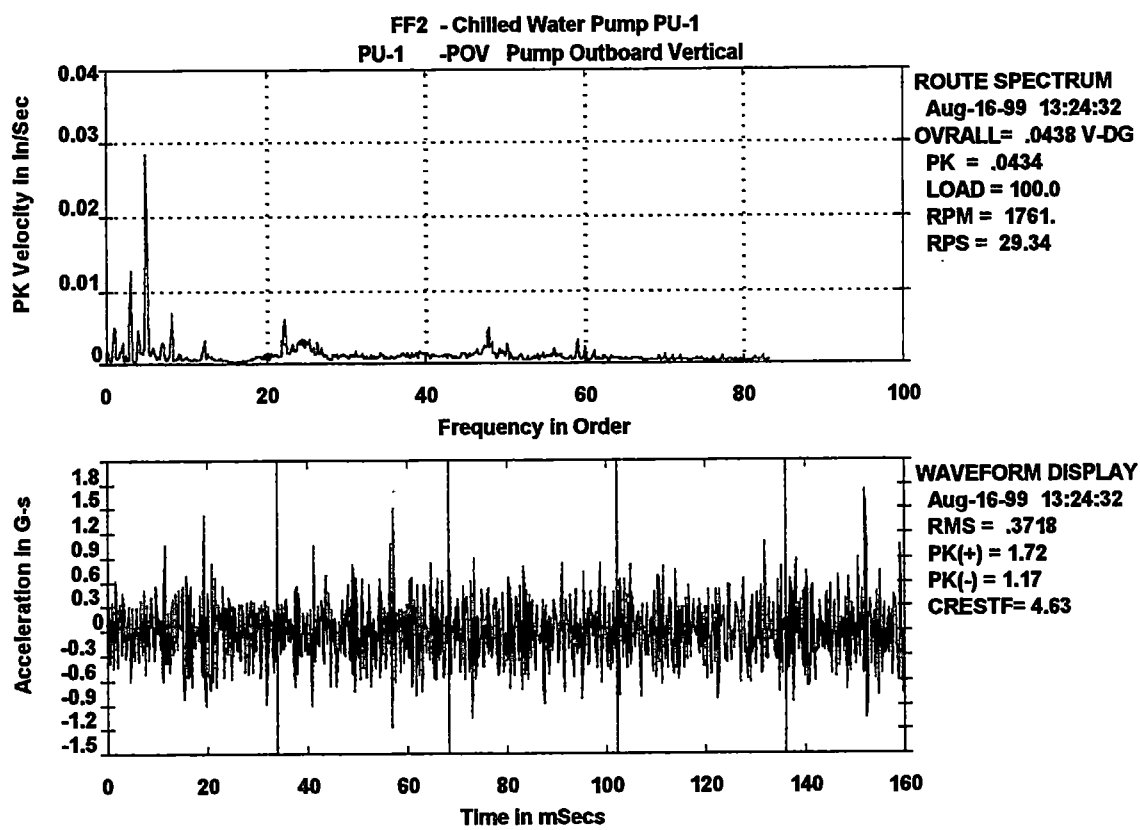


Figure 21: Data Collected from POV Measuring Point on PU-1

IDENTIFICATION OF FAULT FREQUENCY PEAKS

Equipment: (FF2) Chilled Water Pump PU-1

Meas. Point: PU-1 -POV --> Pump Outboard Vertical

Date/Time: Aug-16-99 13:24:32 RPM= 1761. Units=In/Sec PK

-- Component --	1st Frq	2nd Frq	Total							
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present						
Unbalance	1.00	.000	.0057	1						
Misalignment	1.00	.000	.0148	1	2	3				
Looseness	1.00	.000	.0331	1	2	3	4	5	7	
Vane Pass	5.00	.000	.0290	1						

PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >
1	29.42	.0057	1.00	Unbalance	
2	58.68	.0030	2.00	Misalignment	
3	88.16	.0133	3.00	Misalignment	
4	117.65	.0052	4.01	Looseness	
5	146.58	.0290	5.00	Looseness	
6	170.65	.0025	5.82	Vane Pass	
7	204.72	.0035	6.98	Looseness	
8	239.76	.0076	8.17		
9	359.94	.0031	12.27		
10	647.97	.0036	22.08		
11	655.08	.0068	22.32		
12	685.50	.0028	23.36		
13	704.62	.0031	24.01		
14	708.22	.0034	24.13		
15	720.08	.0041	24.54		
16	732.77	.0038	24.97		
17	744.91	.0037	25.38		
18	775.85	.0034	26.44		
19	1392.08	.0027	47.44		
20	1404.74	.0056	47.87		
21	1414.47	.0033	48.20		
22	1474.23	.0031	50.24		
23	1735.53	.0036	59.14		
24	1764.57	.0027	60.13		

Figure 22: Fault Frequency Report for POV Measuring Point on PU-1

The dominant 5X turning speed harmonic is once again evident. While the magnitude of the high frequency is small, it is somewhat larger than that of the PI points. Figure 23 displays the time and frequency data collected from the POA Measuring Point of PU-1.

The magnitude of both the dominant low frequency harmonics in the frequency spectrum and the G-swing of the time domain plot are significantly larger than those associated with the inboard Measuring Points. A large magnitude in the axial direction is typically indicative of misalignment. Figure 24 shows the Fault Frequency Report for this Measuring Point.

The dominant 5X turning speed peak has returned, accompanied by several significant peaks at lower harmonics. The magnitude of the dominant peak is greater than the corresponding magnitude in the radial direction, confirming that misalignment is the dominant source of vibration. There is also evidence of a significantly larger peak in the high frequency range.

The immediate diagnosis is that the outboard bearing on the motor is approaching failure. Both the inboard and outboard bearings on the pump also show signs of degradation, although much less severe than that of the motor outboard bearing. The recommended course of action at this time is to increase the vibration monitoring frequency to weekly, with the addition of temperature monitoring of the bearings. The decision to replace the motor outboard bearing should be made in the same manner as previous replacements, typically using a combination of the temperature and sound emitted by the bearing. This

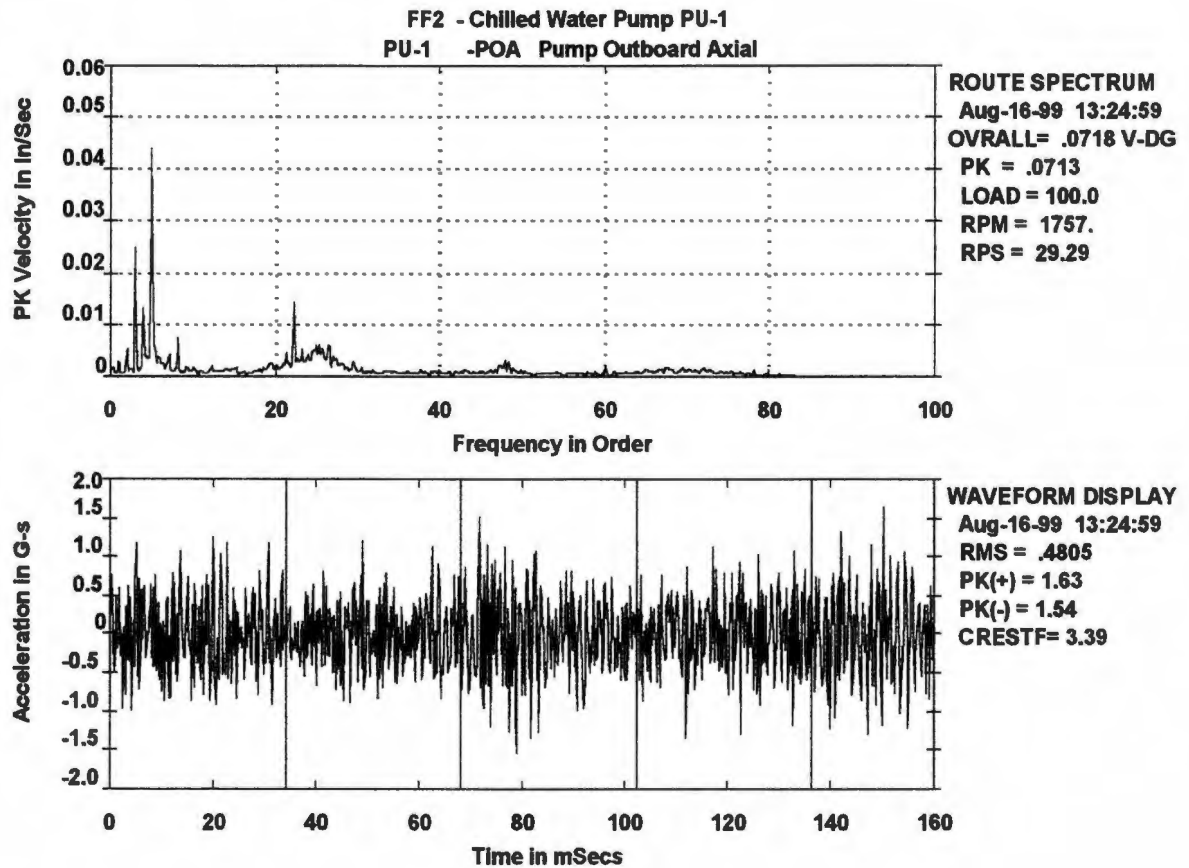


Figure 23: Data Collected from POA Measuring Point on PU-1

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IDENTIFICATION OF FAULT FREQUENCY PEAKS
*****
Equipment:      (FF2 ) Chilled Water Pump PU-1
Meas. Point:    PU-1      -POA -->  Pump Outboard Axial
Date/Time:      Aug-16-99  13:24:59      RPM= 1757.  Units=In/Sec  PK

-- Component --      1st Frq      2nd Frq      Total
Fault Frequency      ( xRPM)      ( xRPM)      Amplitude      Family Members Present
-----
Misalignment          1.00          .000          .0265          2      3
>MRC 5207M
BPFI                  7.10          .000          .0049          1

PEAK      FREQUENCY      PEAK      ORDER
NO.        (Hz)        VALUE      VALUE      FAULT FREQUENCY      < COMPONENT DESC >
-----
1          58.58          .0055      2.00      Misalignment
2          88.13          .0259      3.01      Misalignment
3          117.32         .0160      4.01
4          126.80         .0050      4.33
5          135.55         .0049      4.63
6          146.20         .0459      4.99
7          170.28         .0048      5.81
8          208.02         .0049      7.10      BPFI          <MRC 5207M      >
9          239.86         .0082      8.19
10         626.33         .0053      21.39
11         654.76         .0171      22.36
12         666.80         .0040      22.77
13         683.44         .0062      23.34
14         701.44         .0044      23.95
15         707.82         .0051      24.17
16         723.42         .0062      24.70
17         733.30         .0071      25.04
18         744.52         .0064      25.42
19         751.45         .0057      25.66
20         757.77         .0064      25.88
21         764.15         .0047      26.09
22         776.59         .0072      26.52
23         795.02         .0043      27.15
24         804.52         .0043      27.47

```

Figure 24: Fault Frequency Report for POA Measuring Point on PU-1

will assist maintenance personnel in translating current techniques for assessing the condition of components into the magnitude and shape of vibration signatures. By trending the degradation of these bearings, the maintenance organization can gain an understanding of how the bearings degrade. At this time it is not known how soon the bearings will fail, so this is an excellent learning opportunity.

The dominant source of vibration appears to be misalignment. The effect of this degree of misalignment must be evaluated by careful attention to the life of bearings. While it is clear that PU-1 is exhibiting signs of misalignment, it must be emphasized that this is to be expected. All components are misaligned to some extent; the relevant question is the impact of this degree of misalignment on the continued operation of PU-1.

5.3.5.2 Analysis of Hot Off Gas Fan FN-5- According to the Measurement Exception Analysis Report, the fan bearings are near failure. FN-5 is also alarming in the 2X turning speed analysis parameter. Although this is indicative of an electrical problem such as a broken rotor bar, the small size of the motor and its maintenance history makes the possibility slight. A visual inspection of the signals associated with the alarming Measurement Points listed in the Measurement Exception Analysis Report is once again performed. Figure 25 displays the time and frequency domain information recorded from the MOH Measurement Point of FN-5.

The frequency domain plot of FN-5 is entirely dominated by low frequency harmonics. This dominance is visible in the time domain plot by the

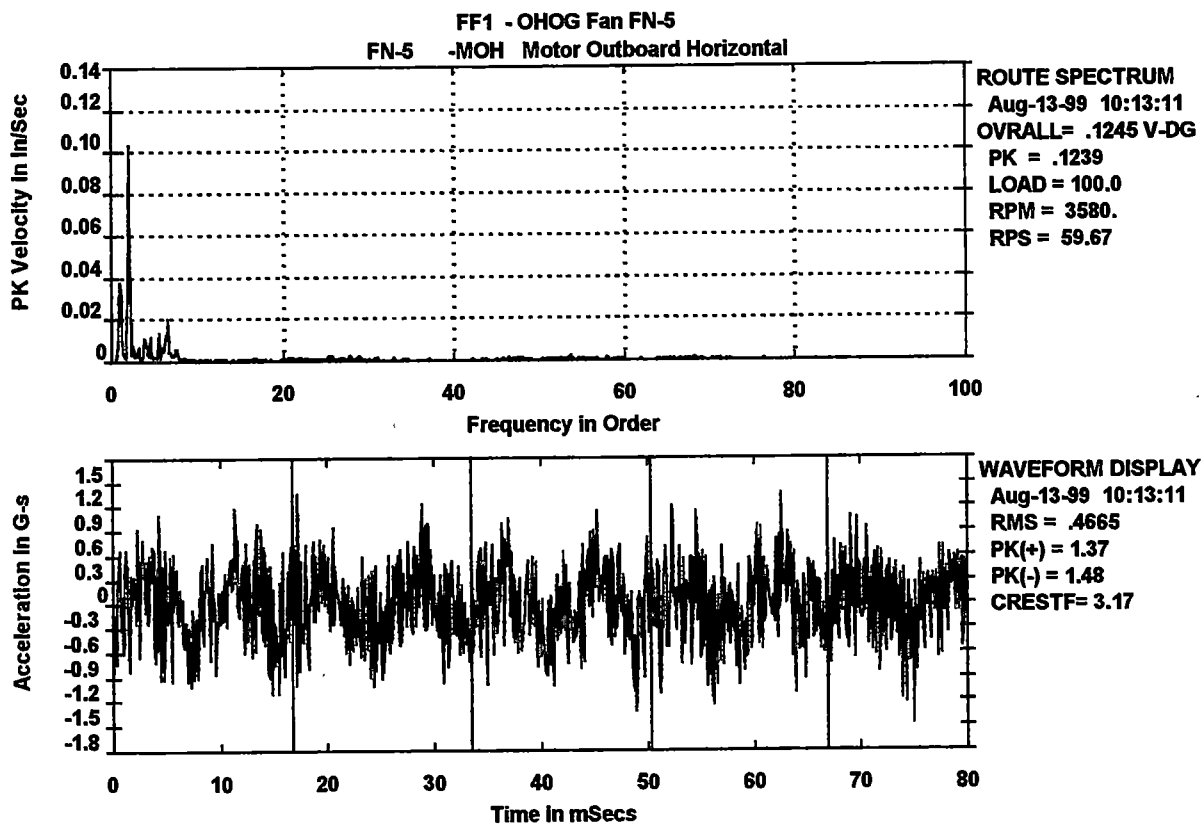


Figure 25: Data Collected from MOH Measuring Point on FN-5

clear sinusoidal tendency of the waveform. The vertical lines on the time waveform plot correspond to one revolution. With this information, it is clear that the sinusoidal tendency of the waveform is two cycles per revolution. This is indicative of misalignment. The frequency domain plot also shows hints of bearing degradation, although the magnitude of the high frequency peaks is relatively small. Figure 26 shows the fault frequency report for this Measuring Point.

The fault frequency associated with the 1X turning speed analysis parameter provides indication of an eccentric sheave. This amounts to a sheave that is not perfectly round, resulting in a 1X turning speed impact every time the “hump” in the pulley comes around. However, the dominance of the 2X and 3X turning speed harmonics reinforces the diagnosis of misalignment. In particular, the two cycles per revolution frequency of the time waveform is evident by the dominance of the 2X turning speed harmonic. The presence of ball spin fault frequency and the ball pass inner race fault frequencies is typical of the early stages of bearing degradation⁴³. Figure 27 displays the time and frequency data collected from the MIH Measuring Point of FN-5.

Both the frequency and time domain plots are very similar to those associated with the MOH point. Early signs of bearing degradation are again apparent in the peakedness of the spectrum at frequencies above 20X turning speed. There is a slight increase in the G-swing of the time domain plot, but the waveform retains its frequency of two cycles per revolution. Figure 28 shows the Fault Frequency Report for this Measuring Point.

IDENTIFICATION OF FAULT FREQUENCY PEAKS					

Equipment:	(FF1) OHOG Fan FN-5				
Meas. Point:	FN-5	-MOH -->	Motor Outboard Horizontal		
Date/Time:	Aug-13-99	10:13:11	RPM=	3580.	Units=In/Sec PK
-- Component --	1st Frq	2nd Frq	Total		
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present	
-----	-----	-----	-----	-----	
Looseness	1.00	.000	.0026	5	
>SNR 6309EE					
BSF	1.96	.000	.0069	3	
BPFI	4.96	.000	.0026	1	
>GOO 560L					
Sped2 Out	.96	.000	.0410	1	
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >
-----	-----	-----	-----	-----	-----
1	32.74	.0028	.55		
2	58.27	.0410	.98	Sped2 Out	<GOO 560L >
3	120.31	.1078	2.02		
4	148.94	.0090	2.50		
5	185.73	.0068	3.11		
6	228.28	.0132	3.83		
7	266.80	.0123	4.47		
8	297.21	.0026	4.98	Looseness	
				BPFI	<SNR 6309EE >
9	326.36	.0136	5.47		
10	352.05	.0069	5.90	BSF	<SNR 6309EE >
11	370.34	.0134	6.21		
12	386.26	.0220	6.47		
13	446.22	.0080	7.48		
14	1002.09	.0026	16.79		
15	1257.90	.0030	21.08		
16	1313.50	.0030	22.01		
17	1365.49	.0018	22.89		
18	1514.53	.0027	25.38		
19	1538.60	.0024	25.79		
20	1663.74	.0022	27.88		
21	1729.30	.0036	28.98		
22	1969.86	.0021	33.01		
23	3204.00	.0023	53.70		
24	3459.85	.0025	57.99		

Figure 26: Fault Frequency Report for MOH Measuring Point on FN-5

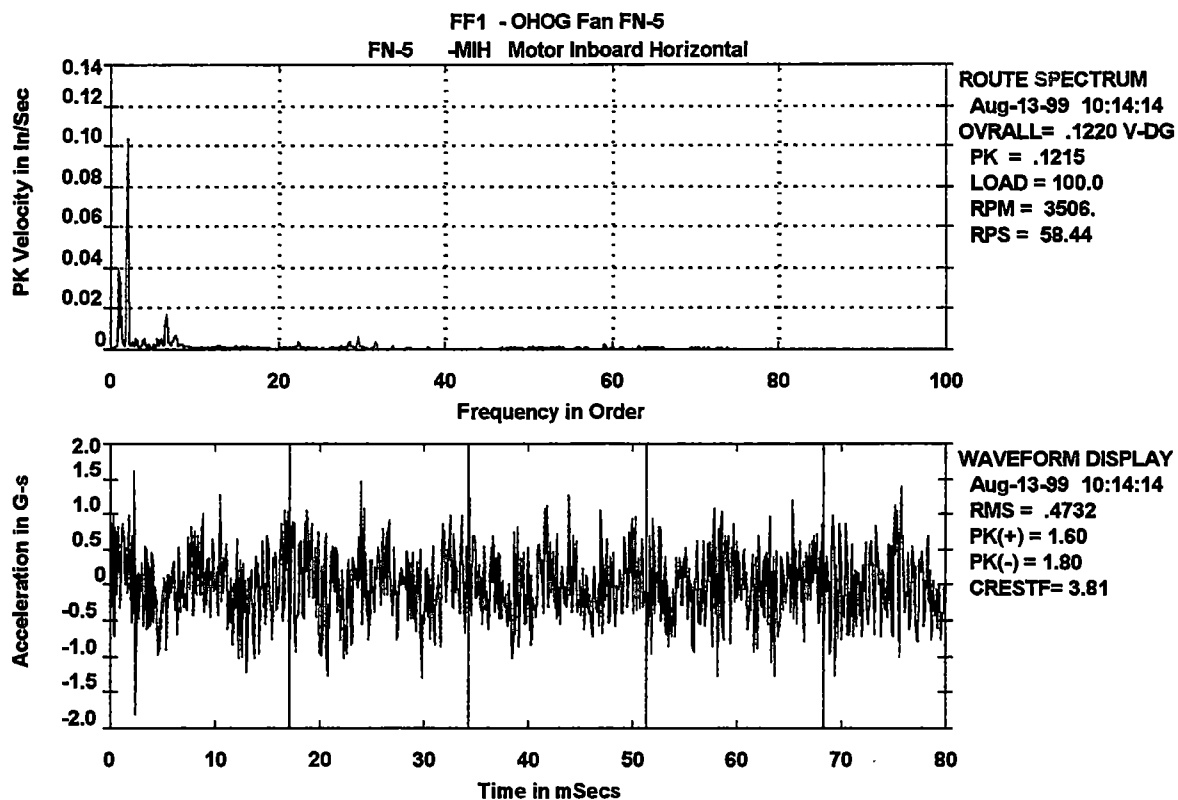


Figure 27: Data Collected from MIH Measuring Point on FN-5

```

IDENTIFICATION OF FAULT FREQUENCY PEAKS
*****
Equipment:      (FF1 ) OHOG Fan FN-5
Meas. Point:    FN-5      -MIH -->  Motor Inboard Horizontal
Date/Time:      Aug-13-99  10:14:14    RPM=  3506.    Units=In/Sec  PK

-- Component --      1st Frq      2nd Frq      Total
Fault Frequency      ( xRPM)      ( xRPM)      Amplitude      Family Members Present
-----
Unbalance              1.00          .000          .0424           1
Misalignment           1.00          .000          .0424           1
Looseness              1.00          .000          .0430           1   4   7

PEAK      FREQUENCY      PEAK      ORDER
NO.        (Hz)        VALUE      VALUE      FAULT FREQUENCY  < COMPONENT DESC >
-----
  1         38.11        .0030         .65
  2         58.31        .0424         1.00      Unbalance
                                     Misalignment
  3         73.89        .0167         1.26
  4        120.24        .1075         2.06
  5        152.27        .0034         2.61
  6        183.45        .0060         3.14
  7        233.83        .0057         4.00      Looseness
  8        266.07        .0028         4.55
  9        297.52        .0030         5.09
 10        326.34        .0062         5.58
 11        352.35        .0057         6.03
 12        369.68        .0046         6.33
 13        386.04        .0174         6.61
 14        410.03        .0046         7.02      Looseness
 15        427.97        .0045         7.32
 16        447.31        .0076         7.65
 17        485.42        .0032         8.31
 18        746.62        .0021        12.78
 19       1313.26        .0039        22.47
 20       1663.93        .0048        28.47
 21       1681.25        .0023        28.77
 22       1729.75        .0071        29.60
 23       1849.95        .0037        31.66
 24       3459.87        .0028        59.20

```

Figure 28: Fault Frequency Report for MIH Measuring Point on FN-5

Once again, the dominant 2X turning speed harmonic is present, reinforcing the diagnosis of misalignment as the dominant source of vibration. Figure 29 displays the time and frequency data collected from the FIV Measuring Point of FN-5.

Both the time and frequency domain plots provide indication of significant bearing degradation. The degradation is evident in the peakedness of the vibration spectrum at high frequencies. The most dramatic evidence is evident in the time domain plot. The previously discussed bearing ringdown pattern is evident, as well as a G-swing of 15 G's. Clearly, the fan inboard bearing is approaching failure. Figure 30 shows the Fault Frequency Report for this Measuring Point.

The 2X turning speed harmonic is still the largest, but is accompanied by several other large harmonics. The magnitude of the high frequency peaks relative to the magnitude of the low frequency peaks is large enough to conclude that significant degradation of the fan inboard bearing has occurred. Figure 31 displays the time and frequency data collected from the FIH Measuring Point of FN-5.

The frequency domain plot shows a significant increase in the magnitude of the low frequency harmonics. The familiar impacting and ringdown pattern is present in the time domain waveform, although the G-swing has decreased by approximately 5 G's. Figure 32 shows the Fault Frequency Report for this Measuring Point.

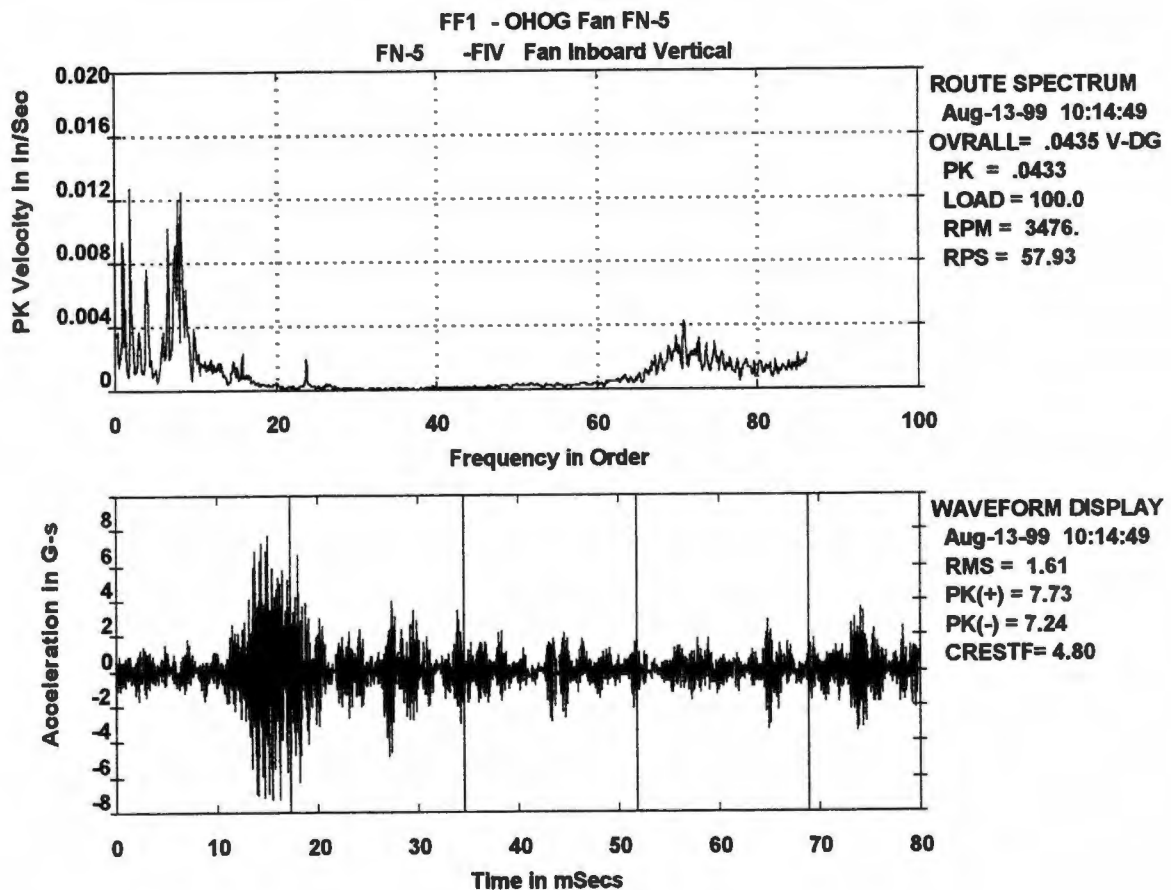


Figure 29: Data Collected from FIV Measuring Point on FN-5

IDENTIFICATION OF FAULT FREQUENCY PEAKS

Equipment: (FF1) OHOG Fan FN-5
 Meas. Point: FN-5 -FIV --> Fan Inboard Vertical
 Date/Time: Aug-13-99 10:14:49 RPM= 3476. Units=In/Sec PK

-- Component --	1st Frq	2nd Frq	Total	Family Members Present		
Fault Frequency	(xRPM)	(xRPM)	Amplitude			
Unbalance	1.00	.000	.0100	1		
Misalignment	1.00	.000	.0181	1	2	
Looseness	1.00	.000	.0197	1	2	4
>FAF GN115KLLB						
BSF	1.98	.000	.0207	1	4	
BPFO	3.05	.000	.0069	1	2	3
BSF	1.98	.000	.0207	1	4	
BPFO	3.05	.000	.0069	1	2	3

PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
-----	-----	-----	-----	-----	-----	
1	15.88	.0042	.27			
2	58.22	.0100	1.00	Unbalance		
				Misalignment		
3	76.39	.0053	1.32			
4	115.63	.0150	2.00	Misalignment		
				Looseness		
5	176.22	.0037	3.04	BPFO	<FAF GN115KLLB	>
				BPFO	<FAF GN115KLLB	>
6	232.50	.0078	4.01	Looseness		
7	352.11	.0039	6.08	BPFO	<FAF GN115KLLB	>
				BPFO	<FAF GN115KLLB	>
8	386.18	.0106	6.67			
9	414.34	.0036	7.15			
10	435.28	.0098	7.51			
11	459.41	.0142	7.93	BSF	<FAF GN115KLLB	>
				BSF	<FAF GN115KLLB	>
12	483.28	.0134	8.34			
13	515.05	.0071	8.89			
14	528.60	.0043	9.12	BPFO	<FAF GN115KLLB	>
				BPFO	<FAF GN115KLLB	>
15	576.45	.0041	9.95			
16	3997.10	.0032	69.00			
17	4053.60	.0038	69.97			
18	4072.44	.0032	70.30			
19	4108.79	.0047	70.93			
20	4184.52	.0029	72.23			
21	4202.53	.0032	72.54			
22	4222.00	.0037	72.88			
23	4267.07	.0030	73.66			
24	4328.86	.0033	74.73			

Figure 30: Fault Frequency Report for FIV Measuring Point on FN-5

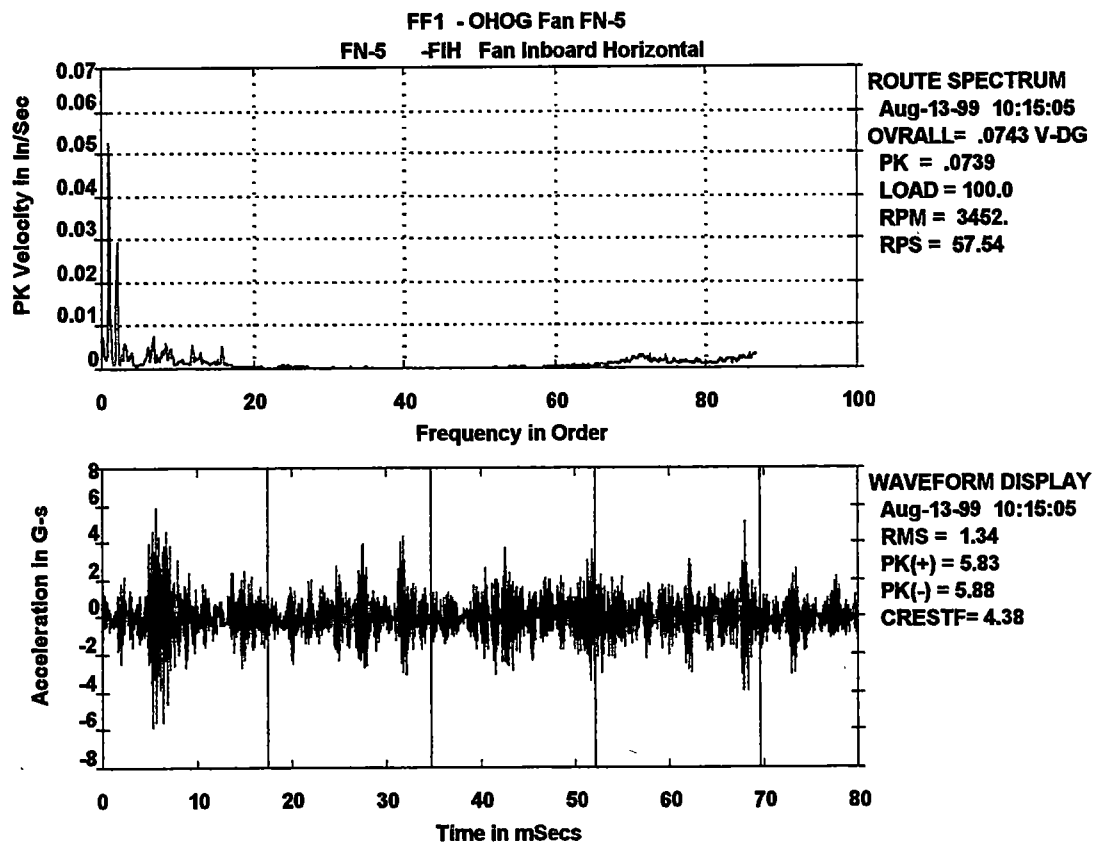


Figure 31: Data Collected from FIH Measuring Point on FN-5

IDENTIFICATION OF FAULT FREQUENCY PEAKS					

Equipment:	(FF1) OHOG Fan FN-5				
Meas. Point:	FN-5	-FIH -->	Fan Inboard Horizontal		
Date/Time:	Aug-13-99	10:15:05	RPM=	3452.	Units=In/Sec PK
-- Component --	1st Frq	2nd Frq	Total		
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present	

Looseness	1.00	.000	.0075	8	9
Blade Pass	8.00	.000	.0053	1	
>FAF GN115KLLB					
BSF	1.98	.000	.0046	2	
BSF	1.98	.000	.0046	2	
>GOO 560L					
Sped1 In	1.04	.000	.0297	2	
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >

1	58.27	.0569	1.01		
2	119.81	.0297	2.08	Sped1 In	<GOO 560L >
3	148.29	.0036	2.58		
4	177.44	.0064	3.08		
5	185.03	.0064	3.22		
6	204.26	.0033	3.55		
7	228.20	.0046	3.97	BSF	<FAF GN115KLLB >
				BSF	<FAF GN115KLLB >
8	347.17	.0061	6.03		
9	386.34	.0079	6.71		
10	410.98	.0036	7.14		
11	459.53	.0053	7.99	Looseness	
				Blade Pass	
12	483.21	.0069	8.40		
13	516.09	.0054	8.97	Looseness	
14	535.80	.0035	9.31		
15	688.08	.0055	11.96		
16	747.65	.0043	12.99		
17	917.28	.0058	15.94		
18	4052.26	.0032	70.43		
19	4102.74	.0034	71.31		
20	4115.17	.0036	71.52		
21	4154.58	.0032	72.21		
22	4934.88	.0038	85.77		
23	4971.72	.0038	86.41		
24	4978.31	.0038	86.53		

Figure 32: Fault Frequency Report for FIH Measuring Point on FN-5

The 1X turning speed harmonic is the largest, which is typical of imbalance or misalignment. Figure 33 displays the time and frequency data collected from the FIA Measuring Point of FN-5.

The ringdown pattern in the time series confirms the diagnosis of impending bearing failure, as does the peakedness of the frequency spectrum at high frequencies. Figure 34 shows the Fault Frequency Report for this Measuring Point.

The report indicates that no fault frequencies were found, which is understandable upon reference to the Measurement Exception Analysis Report. The FIA Measuring Point was alarming in the high frequency analysis parameter, which does not have a particular fault frequency assigned. The magnitude of the dominant low frequency peak is significant enough to indicate the presence of misalignment. Figure 35 displays the time and frequency data collected from the FOV Measuring Point of FN-5.

The outboard bearing of FN-5 also appears to have significantly degraded, as evidenced by the peaks at high frequencies in the frequency spectrum and the ringdown pattern in the time domain plot. Figure 36 shows the Fault Frequency Report for this Measuring Point. The 1X turning speed harmonic dominates the spectrum, once again indicating misalignment and imbalance. The magnitude of the peaks associated with bearing defects is approximately the same as for the FIV Measuring Point, again providing an excellent opportunity to witness the

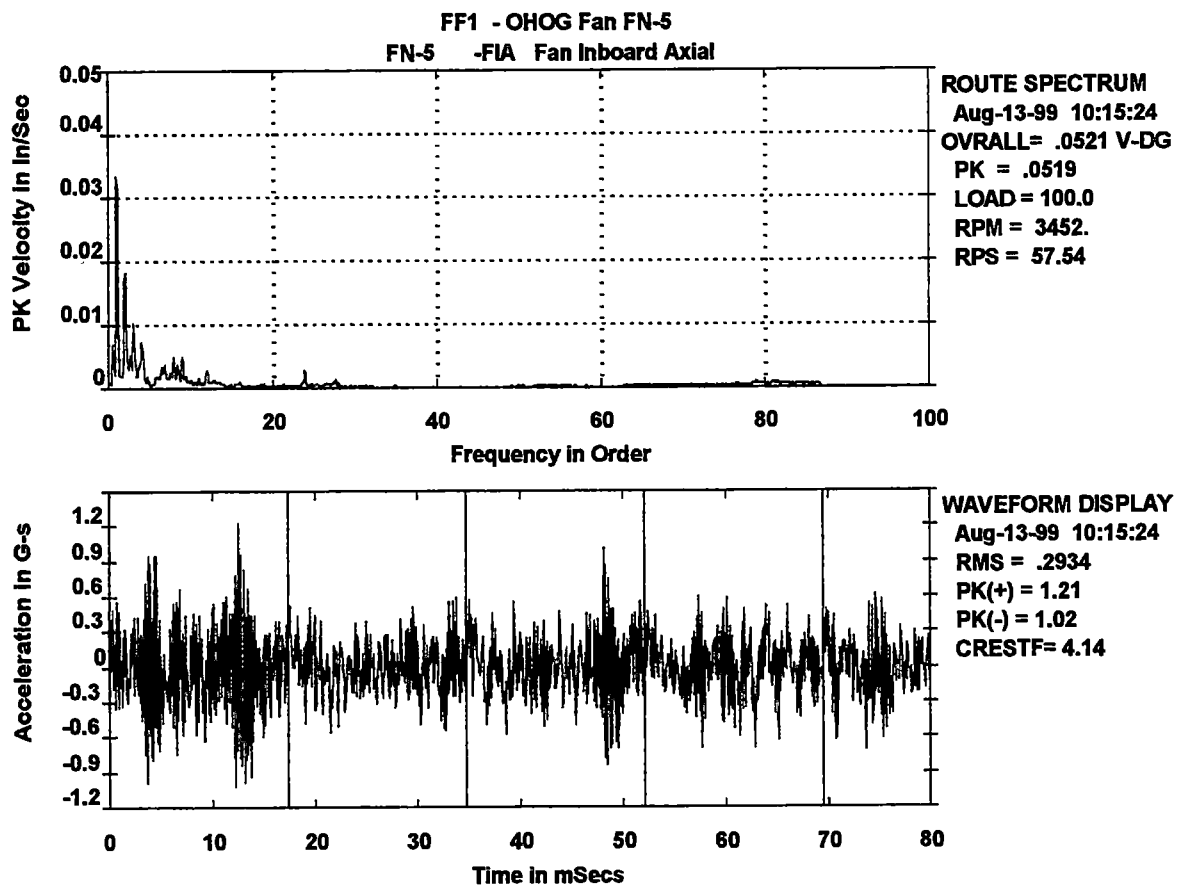


Figure 33: Data Collected from FIA Measuring Point on FN-5

```

                                IDENTIFICATION OF FAULT FREQUENCY PEAKS
                                *****
Equipment:      (FF1 ) OHOG Fan FN-5
Meas. Point:    FN-5      -FIA -->  Fan Inboard Axial
Date/Time:      Aug-13-99  10:15:24   RPM=  3452.   Units=In/Sec  PK

-- Component --   1st Frq  2nd Frq   Total
Fault Frequency   ( xRPM)  ( xRPM)  Amplitude  Family Members Present
-----

```

No PEAKS in this spectrum MATCHED any Fault Frequencies!

Figure 34: Fault Frequency Report for FIA Measuring Point on FN-5

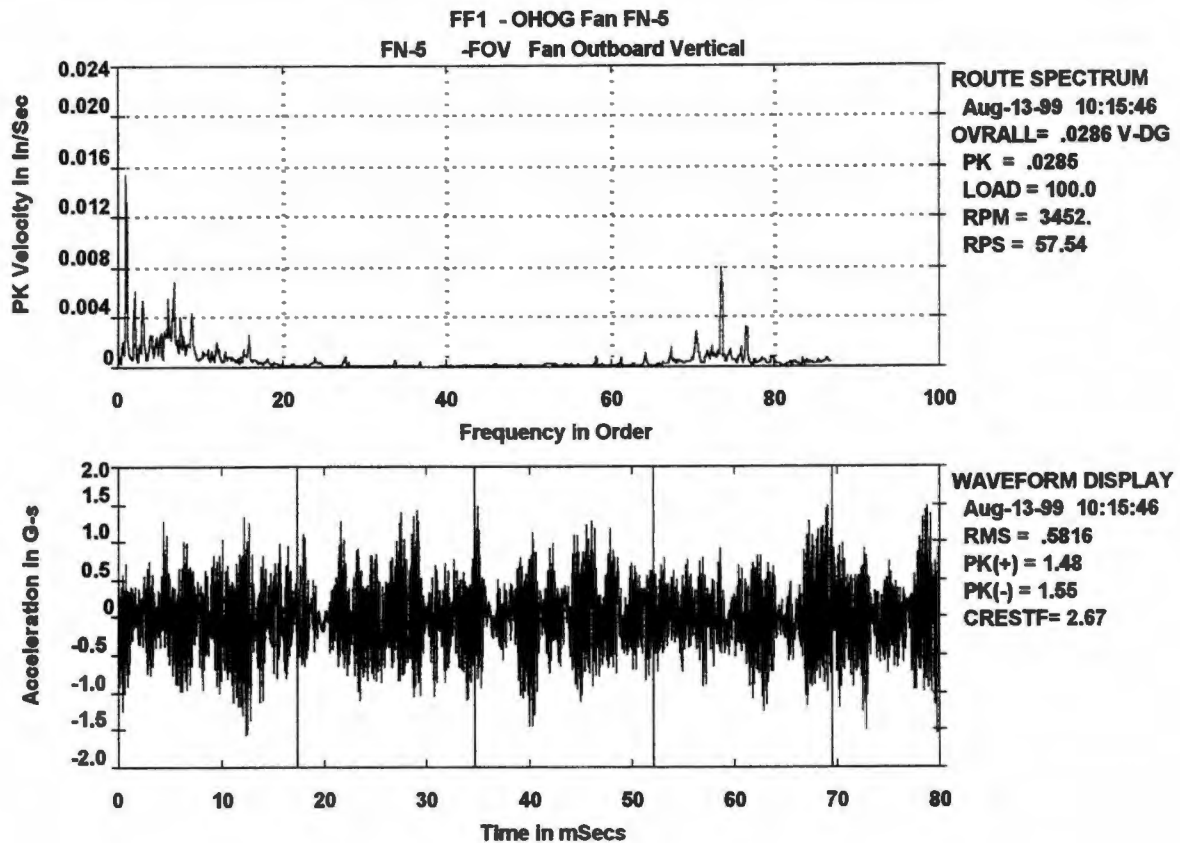


Figure 35: Data Collected from FOV Measuring Point on FN-5

IDENTIFICATION OF FAULT FREQUENCY PEAKS					

Equipment:	(FF1) OHOG Fan FN-5				
Meas. Point:	FN-5	-FOV -->	Fan Outboard Vertical		
Date/Time:	Aug-13-99	10:15:46	RPM=	3452.	Units=In/Sec PK
-- Component --	1st Frq	2nd Frq	Total		
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present	
-----	-----	-----	-----	-----	
Unbalance	1.00	.000	.0162	1	
Misalignment	1.00	.000	.0162	1	
Looseness	1.00	.000	.0165	1	8
Blade Pass	8.00	.000	.0028	1	
>FAF GN115KLLB					
BSF	1.98	.000	.0030	2	
BSF	1.98	.000	.0030	2	
>GOO 560L					
Sped1 In	1.04	.000	.0061	2	
PEAK	FREQUENCY	PEAK	ORDER		
NO.	(Hz)	VALUE	VALUE	FAULT FREQUENCY	< COMPONENT DESC >
----	-----	-----	-----	-----	-----
1	34.40	.0023	.60		
2	57.77	.0162	1.00	Unbalance	
				Misalignment	
3	119.64	.0061	2.08	Sped1 In	<GOO 560L >
4	153.04	.0022	2.66		
5	173.91	.0055	3.02		
6	227.46	.0030	3.95	BSF	<FAF GN115KLLB >
				BSF	<FAF GN115KLLB >
7	234.92	.0029	4.08		
8	266.79	.0027	4.64		
9	297.18	.0031	5.17		
10	327.06	.0032	5.68		
11	353.09	.0065	6.14		
12	366.03	.0029	6.36		
13	388.74	.0069	6.76		
14	409.54	.0025	7.12		
15	435.91	.0044	7.58		
16	459.16	.0028	7.98	Looseness	
				Blade Pass	
17	484.25	.0023	8.42		
18	514.31	.0045	8.94		
19	528.53	.0019	9.19		
20	688.65	.0022	11.97		
21	917.19	.0029	15.94		
22	4055.61	.0029	70.49		
23	4232.63	.0083	73.57		
24	4409.18	.0036	76.63		

Figure 36: Fault Frequency Report for FOV Measuring Point on FN-5

gradual degradation of a roller bearing. Figure 37 displays the time and frequency data collected from the FOH Measuring Point of FN-5.

Both the time and frequency domain plots are approximately identical to those of the FOV Measuring Point, leading to the same observations. Figure 38 shows the Fault Frequency Report for this Measuring Point.

The report once again provides indications of either misalignment or imbalance. Figure 39 displays the time and frequency data collected from the FOA Measuring Point.

It is rare for imbalance to manifest in the axial direction, implying that the 1X peak is attributable more to misalignment. Figure 40 shows the Fault Frequency Report for this Measuring Point.

The presence of several significant low frequency harmonics reinforces the diagnosis of misalignment. The immediate diagnosis is that the inboard and outboard bearing on the fan are approaching failure. The inboard bearing on the motor also shows signs of degradation, although much less severe than that of the fan bearings. The recommended course of action at this time is to increase the vibration monitoring frequency to weekly, with the addition of temperature monitoring of the bearings. The decision to replace the bearing should be made in the same manner as previous replacements, typically using a combination of the temperature and sound emitted by the bearing. Again, the objective of using this approach is to assist maintenance personnel in translating current techniques for assessing the condition of components into the magnitude and shape of vibration signatures.

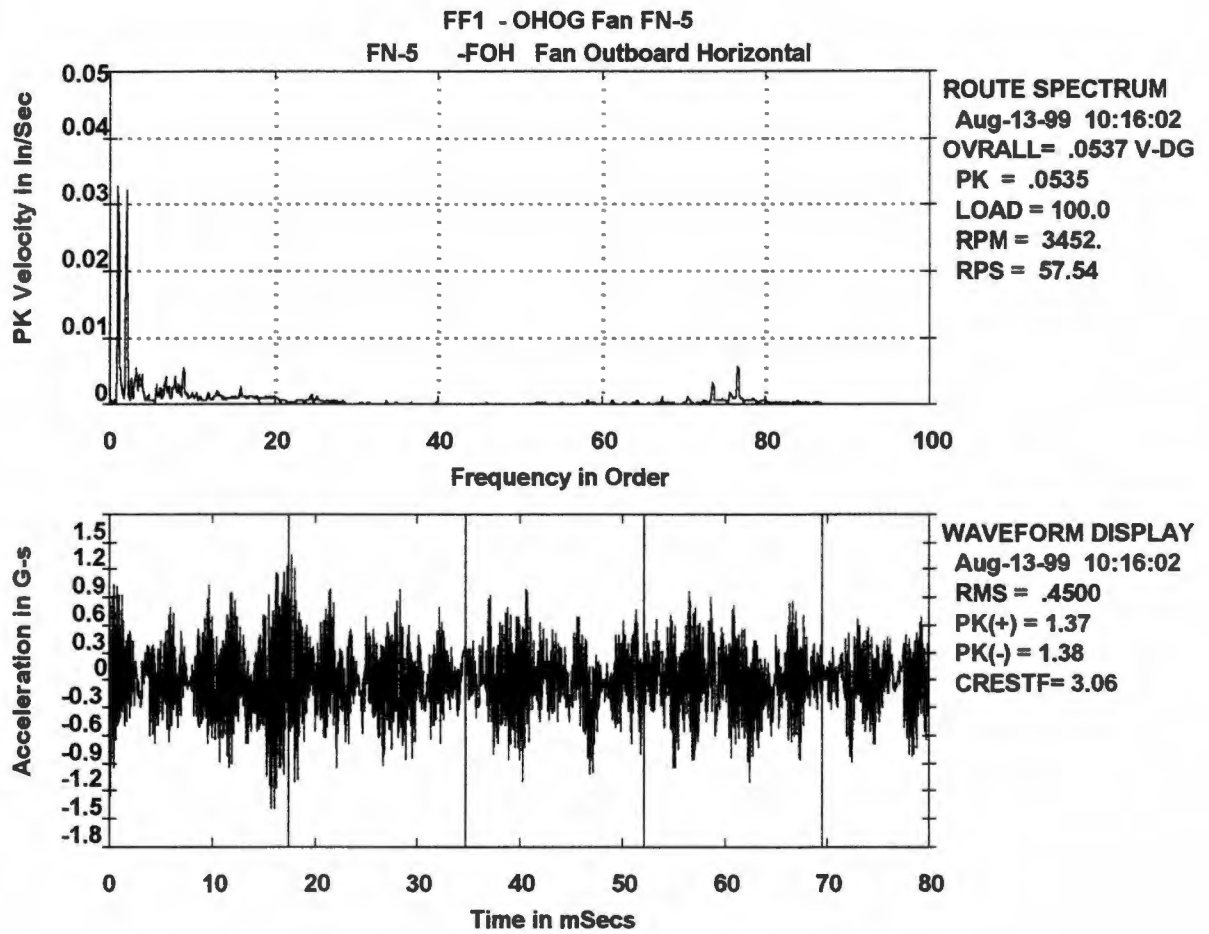


Figure 37: Data Collected from FOH Measuring Point on FN-5

IDENTIFICATION OF FAULT FREQUENCY PEAKS					

Equipment:	(FF1) OHOG Fan FN-5				
Meas. Point:	FN-5	-FOH -->	Fan Outboard Horizontal		
Date/Time:	Aug-13-99	10:16:02	RPM=	3452.	Units=In/Sec PK
-- Component --	1st Frq	2nd Frq	Total		
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members	Present
-----	-----	-----	-----	-----	-----
Unbalance	1.00	.000	.0348	1	
Misalignment	1.00	.000	.0348	1	
Looseness	1.00	.000	.0348	1	
>GOO 560L					
Spd1 In	1.04	.000	.0329	2	
PEAK	FREQUENCY	PEAK	ORDER	FAULT FREQUENCY	< COMPONENT DESC >
NO.	(Hz)	VALUE	VALUE	-----	-----
-----	-----	-----	-----	-----	-----
1	58.03	.0348	1.01	Unbalance	
2	120.00	.0329	2.09	Misalignment	
3	148.65	.0040	2.58	Spd1 In	<GOO 560L >
4	185.56	.0061	3.23		
5	203.98	.0049	3.55		
6	223.27	.0047	3.88		
7	325.70	.0031	5.66		
8	352.52	.0031	6.13		
9	388.52	.0042	6.75		
10	410.21	.0029	7.13		
11	440.27	.0030	7.65		
12	458.32	.0045	7.97		
13	483.06	.0034	8.40		
14	515.04	.0060	8.95		
15	538.96	.0022	9.37		
16	572.28	.0020	9.95		
17	607.64	.0017	10.56		
18	689.18	.0020	11.98		
19	753.31	.0025	13.09		
20	916.74	.0031	15.93		
21	977.47	.0017	16.99		
22	4232.87	.0034	73.57		
23	4352.26	.0019	75.64		
24	4408.88	.0065	76.63		

Figure 38: Fault Frequency Report for FOH Measuring Point on FN-5

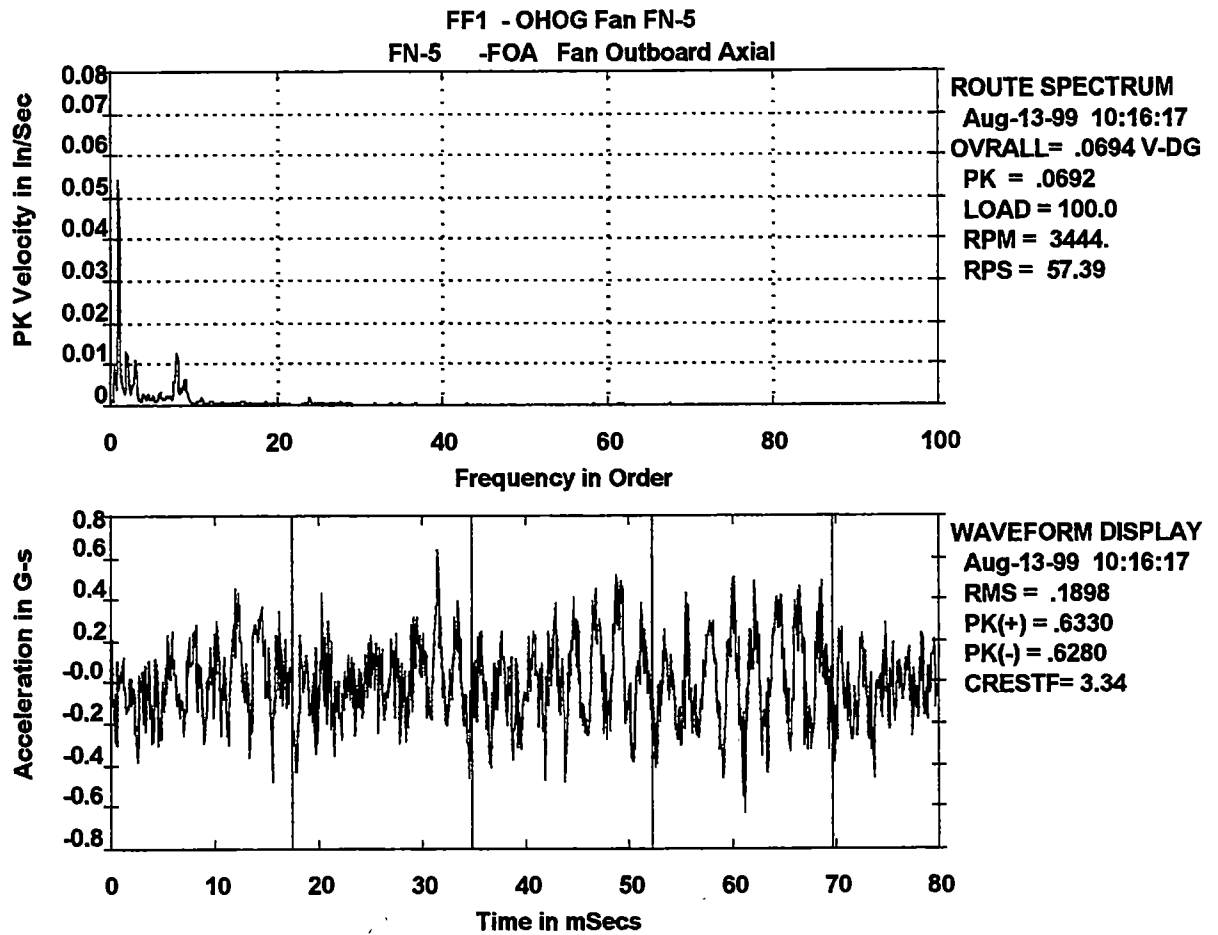


Figure 39: Data Collected from FOA Measuring Point on FN-5

IDENTIFICATION OF FAULT FREQUENCY PEAKS *****						
Equipment: (FF1) OHOG Fan FN-5						
Meas. Point: FN-5 -FOA --> Fan Outboard Axial						
Date/Time: Aug-13-99 10:16:17 RPM= 3444. Units=In/Sec PK						
-- Component --	1st Frq	2nd Frq	Total			
Fault Frequency	(xRPM)	(xRPM)	Amplitude	Family Members Present		
Unbalance	1.00	.000	.0577	1		
Misalignment	1.00	.000	.0611	1	2	3
PEAK NO.	FREQUENCY (Hz)	PEAK VALUE	ORDER VALUE	FAULT FREQUENCY	< COMPONENT DESC >	
1	32.78	.0099	.57			
2	57.99	.0577	1.01	Unbalance		
3	115.09	.0151	2.01	Misalignment		
4	147.16	.0054	2.56	Misalignment		
5	172.37	.0131	3.00	Misalignment		
6	208.99	.0015	3.64			
7	228.57	.0035	3.98			
8	259.94	.0036	4.53			
9	296.53	.0029	5.17			
10	326.49	.0013	5.69			
11	341.33	.0036	5.95			
12	359.57	.0024	6.27			
13	390.77	.0028	6.81			
14	409.58	.0025	7.14			
15	440.52	.0068	7.68			
16	458.66	.0138	7.99			
17	484.61	.0051	8.44			
18	502.00	.0051	8.75			
19	515.57	.0077	8.98			
20	528.52	.0036	9.21			
21	630.26	.0020	10.98			
22	689.92	.0013	12.02			
23	918.30	.0015	16.00			
24	1377.59	.0023	24.00			

Figure 40: Fault Frequency Report for FOA Measuring Point on FN-5

5.3.5.3 Discussion- These analyses serve as a useful example of the potential benefits of condition monitoring. Although it is clear that several bearing are significantly degraded in each component, breakdown maintenance policy directs that the bearings be replaced only upon failure. With experience, HFIR maintenance personnel will be able to assess the severity of the degradation in all of a component's bearings. This information will assist in determining if all bearings should be replaced when the component is removed from service, or only the worst. In this manner, the number of times that a component is removed from service for maintenance can be reduced.

It is important that vibration data be taken immediately following repair of the component. The actual connection between vibration magnitude and severity will be made based on this baseline data and the life of the newly installed bearing. Early failure of the bearing is typically indicative of imbalance, misalignment, or looseness. Once such an early failure has occurred, HFIR maintenance personnel can then assess the severity associated with magnitude of the vibration data. It is this process of continuous comparison and assessment that will be required to establish the proper alarm levels for all monitored components. The most valuable asset possessed by HFIR maintenance management is the experience of their personnel. Adherence to this analysis strategy during this initial stage of development will facilitate the transfer of much of this expertise into the predictive maintenance program via alarm levels and monitoring.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.0 Introduction

The objective of this effort was to establish a condition monitoring program at the HFIR that possessed the elements necessary for developing into a comprehensive predictive maintenance program. This was accomplished by performing the following tasks:

1. A thorough review and discussion of relevant issues regarding maintenance, maintenance management, and maintenance improvement strategies such as predictive maintenance.
2. A review of the problems encountered during previous maintenance improvement attempts at HFIR and recommendations for strategies to prevent them from reoccurring.
3. The development of technical expertise through proper selection of monitoring techniques and tools, components to be monitored, and monitoring and analysis strategies.
4. Set up and configuration of associated hardware and software.
5. The introduction of enhancements to record keeping such as updated component technical specification records, a means to quantify component run-time and failures, and the practice of recording observations associated with vibration data.

6. The communication of the need for a program of training and retraining to HFIR maintenance management.
7. The communication of the need to establish progressive performance metrics to HFIR maintenance management.
8. The communication of the need for a means to justify the expense associated with predictive activities to HFIR maintenance management.

The primary concern regarding the long-term success of the program is the appropriateness of maintenance improvement strategies designed for commercial facilities when applied to a government facility. Much of the rationale behind both predictive and reliability-centered maintenance strategies is predicated on the notion of identifying and attacking maintenance management deficiencies. All of these deficiencies are quantified in terms of their impact on the overall profitability of a facility. A similar performance metric should be identified at HFIR to facilitate justification of predictive maintenance activities.

6.1 Recommendations for Future Work

The recommendations for future work are organized in a manner that will assist HFIR maintenance management in understanding the proper sequence of programmatic development. This discussion is made in the context of the current organization and the expected impact of this program.

6.1.1 Initial Implementation (Phase 1)

The HFIR maintenance organization should allow at least one year of consistent data collection before making an attempt to expand the program. During this time, HFIR maintenance personnel should be trained on RBMware™, vibration analysis, and the concepts of condition monitoring and predictive maintenance. Both lower-level maintenance personnel and maintenance management should be involved in periodic reviews of the perceived benefits and problems associated with the introduction of new maintenance practices. This will facilitate the establishment of performance criteria that both parties feel are appropriate.

6.1.2 Establish Comprehensive Condition Monitoring Program (Phase 2)

At this point in time, the initial implementation can be expanded to include more equipment and technologies. The natural progression is to increase the number of rotating components monitored with vibration analysis, while encouraging the use of thermography by maintenance supervisors in charge of electrical equipment. Maintenance personnel should continue to focus on expanding their technical expertise and repertoire of techniques while collecting data for at least another year. This will be the only action required if the decision has been made to restrict the focus of the program to condition monitoring and forgo a comprehensive predictive maintenance program. Otherwise, attention

must turn to the development of a predictive maintenance strategy designed to incorporate overall organizational objectives into maintenance management decisions.

The HFIR maintenance organization must carefully evaluate potential strategies appropriate to a facility concerned primarily with safety and regulatory compliance. The benefits associated with a condition monitoring program may be more consistent with the goals of the facility than those associated with predictive maintenance. However, the only way to know is to establish metrics, identify deficiencies, and plot a course of action. Introduction of a productivity-based predictive maintenance strategy will require an organizational commitment to monitoring of investment and return on investment.

6.1.3 Establish a Comprehensive PdM Program (Phase 3)

Once the decision has been made to implement a predictive maintenance program, the HFIR maintenance organization has made a commitment to a continuous process of evaluation and improvement. With the introduction of quantifiable performance metrics, maintenance management will be able to identify the most effective monitoring strategies and techniques. This allows maintenance management to assume responsibility for the direction of condition monitoring activities.

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APPENDICES

APPENDIX A

Contents-Appendix A

A1.	List of Equipment, Monitoring Frequency, and Classification.....	154
A2.	List of Measuring Points.....	156
A3.	List of Analysis Parameter Sets.....	175
A4.	List of Alarm Limit Sets.....	178
A5.	List of Fault Frequency Sets.....	180

Table A1- Equipment, Monitoring Frequency, and Classification

Component	Designation	Monitoring Frequency	Classification
Primary Coolant Pumps (High Speed)	PU-1A	Monthly	Safety-Related
	PU-1B	Monthly	Safety-Related
	PU-1C	Monthly	Safety-Related
	PU-1D	Monthly	Safety-Related
Primary Coolant Pumps (Low Speed)	PU-1E	Monthly	Safety-Related
	PU-1F	Monthly	Safety-Related
	PU-1G	Monthly	Safety-Related
	PU-1H	Monthly	Safety-Related
Air Compressors	C-1A	Monthly	Non-Safety
	C-1B	Monthly	Non-Safety
	C-1C	Monthly	Non-Safety
	Plant Air	Monthly	Non-Safety
Secondary Coolant Pumps	PU-6A	Monthly	Non-Safety
	PU-6B	Monthly	Non-Safety
	PU-6C	Monthly	Non-Safety
Emergency Secondary Coolant Pump	PU-14	Monthly	Non-Safety
Cooling Tower Fans (High Speed)	FN-4A1H	Monthly	Non-Safety
	FN-4A2H	Monthly	Non-Safety
	FN-4B1H	Monthly	Non-Safety
	FN-4B2H	Monthly	Non-Safety
	FN-4C1H	Monthly	Non-Safety
	FN-4C2H	Monthly	Non-Safety
	FN-4D1H	Monthly	Non-Safety
	FN-4D2H	Monthly	Non-Safety
Cooling Tower Fans (Low Speed)	FN-4A1L	Monthly	Non-Safety
	FN-4A2L	Monthly	Non-Safety
	FN-4B1L	Monthly	Non-Safety
	FN-4B2L	Monthly	Non-Safety
	FN-4C1L	Monthly	Non-Safety
	FN-4C2L	Monthly	Non-Safety
	FN-4D1L	Monthly	Non-Safety
	FN-4D2L	Monthly	Non-Safety
Pool Coolant Pump	PU-9A	Monthly	Non-Safety
	PU-9B	Monthly	Non-Safety

Table A1- Equipment, Monitoring Frequency, and Classification (continued)

Component	Designation	Monitoring Frequency	Classification
Pool Cleanup Pumps	PU-7A	Monthly	Non-Safety
	PU-7B	Monthly	Non-Safety
Primary Cleanup Pumps	PU-2A	Monthly	Non-Safety
	PU-2B	Monthly	Non-Safety
Pressurizer Pumps	PU-4A	Monthly	Non-Safety
	PU-4B	Monthly	Non-Safety
Aux. Pressurizer Pump	PU-11	Monthly	Non-Safety
Chilled Water Pumps	PU-1	Monthly	Non-Safety
	PU-2	Monthly	Non-Safety
Demineralized Water Pumps	PU-18A	Monthly	Non-Safety
	PU-18B	Monthly	Non-Safety
Special Building Hot Exhaust Fans	FN-1*	Monthly	Safety-Related
	FN-2*	Monthly	Safety-Related
Hot Off Gas Fans	FN-3	Monthly	Non-Safety
	FN-4	Monthly	Non-Safety
	FN-5	Monthly	Non-Safety
	FN-6	Monthly	Non-Safety

Table A2- Measuring Points

Component	Component ID	Measuring Point	Point ID
Primary Coolant Pumps	PU-1A	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
	PU-1B	Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
	PU-1C	Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
	PU-1D	Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
		Motor Lower X	MLY

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Primary Coolant Pumps (cont.)	PU-1E	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
	PU-1F	Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
	PU-1G	Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
	PU-1H	Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
		Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Primary Coolant Pumps (cont.)		Motor Lower X (E/W)	MLY
Chilled Water Pumps	PU-1	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
	PU-2	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Chilled Water Pumps (cont.)		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
Demineralizer Pumps	PU-18A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
	PU-18B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Demineralizer Pumps (cont.)		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
Primary Cleanup Pump	PU-2A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
	PU-2B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Primary Cleanup Pumps (continued)		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
Pressurizer Pumps	PU-4A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Inboard Axial	PIA
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
	PU-4B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Pressurizer Pumps (cont.)		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Inboard Axial	PIA
		Pump Outboard Vertical	POV
	PU-4B	Pump Outboard Horizontal	POH
Auxiliary Pressurizer Pump	PU-11	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Upper Axial	MUA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
Pool Cleanup Pumps	PU-7A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Pool Cleanup Pumps (cont.)		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
	PU-7B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
Pool Coolant Pumps	PU-9A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Pool Coolant Pumps (continued)		Pump Outboard Vertical	POV
		Pump Outboard Horiz.	POH
	PU-9A	Pump Outboard Axial	POA
	PU-9B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Pump Inboard Vertical	PIV
		Pump Inboard Horizontal	PIH
		Pump Outboard Vertical	POV
		Pump Outboard Horizontal	POH
		Pump Outboard Axial	POA
Air Compressor	C-1B	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
Plant Air Compressor	Plant Air	Motor Outboard Vertical	MOV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Plant Air Compressor (cont.)		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
Secondary Coolant Pumps	PU-6A	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Lower Axial	MLA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
	PU-6B	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Lower Axial	MLA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY
	PU-6C	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Lower Axial	MLA
		Motor Lower Y (N/S)	MLY
		Motor Lower X (E/W)	MLY

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Emergency Secondary Coolant Pump	PU-14	Motor Upper Y (N/S)	MUY
		Motor Upper X (E/W)	MUX
		Motor Lower Axial	MLA
		Motor Lower Y (N/S)	MLY
Cooling Tower Fans (High Speed)	4A-1	Motor Lower X (E/W)	MLY
		Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
	4A-2	Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
	4B-1	Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Cooling Tower Fans (High Speed); (cont.)		Motor Inboard Horizontal	MIH
	4B-2	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4C-1	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4C-2	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
	4C-2	Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4D-1	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Cooling Tower Fans (High Speed); (cont.)		Motor Inboard Horizontal	MIH
	4D-2	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
Cooling Tower Fans (Low Speed)	4A-1L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4A-2L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4B-1L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Cooling Tower Fans (Low Speed); (cont.)		Motor Inboard Horizontal	MIH
	4B-2L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4C-1L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
	4C-1L	Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4C-2L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	4D-1L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Cooling Tower Fans (Low Speed); (cont.)		Motor Inboard Horizontal	MIH
	4D-2L	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
HOG Fans	FN-3	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
	FN-4	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
HOG Fans (continued)		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
	FN-5	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
	FN-6	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
HOG Fans (continued)		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
Special Building Hot Exhaust Fans (SBHE)	FN-1	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Special Building Hot Exhaust Fans (SBHE); (continued)	FN-2	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV
		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
	FN-3	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
		Fan Inboard Vertical	FIV
		Fan Inboard Horizontal	FIH
		Fan Inboard Axial	FIA
		Fan Outboard Vertical	FOV

Table A2- Measuring Points (continued)

Component	Component ID	Measuring Point	Point ID
Special Building Hot Exhaust Fans (SBHE); (continued)		Fan Outboard Horizontal	FOH
		Fan Outboard Axial	FOA
Air Compressors	C-1A	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH
	C-1C	Motor Outboard Vertical	MOV
		Motor Outboard Horizontal	MOH
		Motor Outboard Axial	MOA
		Motor Inboard Vertical	MIV
		Motor Inboard Horizontal	MIH

Table A3-Analysis Parameter Sets

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#1-AC Motor (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
#2-AC Motor (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
#3-AC Motor (3200 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
#4-Fan (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Blade Pass	In/Sec	7.40-8.40*RPM

Table A3-Analysis Parameter Sets (continued)

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#5-Fan (800 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Blade Pass	In/Sec	7.40-8.40*RPM
#7-Pump	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	4.40-5.40*RPM
	Vane Pass 2	In/Sec	0.00-0.40*RPM
	30-70xTS	G's	30.40-70.50*RPM
#8-Pump	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	2.40-3.40*RPM
	Vane Pass 2	In/Sec	6000-12000 Hz
#12-Pump	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	30-70xTS	G's	30.40-70.50*RPM

Table A3-Analysis Parameter Sets (continued)

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#12 Pump (cont.)	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	5.40-6.40*RPM
	Vane Pass 2	In/Sec	0.00-0.40*RPM
	30-70xTS	G's	30.40-70.50*RPM
#14-Secondary Pump	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Rotor Bar Pass	In/Sec	53.00-63.00*RPM
	Stator Slot	In/Sec	67.00-77.00*RPM

Table A4-Alarm Limit Sets

Alarm Limit Set	Signal Parameter	Fault Level	Alert Level	Baseline Alert Ratio
#1-AC Motor	0	.354	.283	2.00
	1	.141	.071	2.00
	2	.283	.248	2.00
	3	.212	.177	2.00
	4	.177	.141	2.00
	5	.141	.106	2.00
	6	.106	.071	2.00
	7	.283	.212	2.00
	8	2.00	1.00	2.00
	9	.283	.177	2.00
	10	.283	.177	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00
#2-Secondary Pump Motor	0	.530	.354	2.00
	1	.141	.071	2.00
	2	.283	.248	2.00
	3	.212	.177	2.00
	4	.177	.141	2.00
	5	.141	.106	2.00
	6	.106	.071	2.00
	7	.283	.212	2.00
	8	2.00	1.00	2.00
	9	.283	.177	2.00
	10	.283	.177	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00
#7-Pump	0	.283	.212	2.00
	1	.141	.071	2.00
	2	.248	.177	2.00
	3	.212	.141	2.00
	4	.212	.141	2.00
	5	.177	.106	2.00
	6	.141	.071	2.00
	7	2.00	1.00	2.00
	8	.248	.141	2.00
	9	.248	.141	2.00

Table A4-Alarm Limit Sets (continued)

Alarm Limit Set	Signal Parameter	Fault Level	Alert Level	Baseline Alert Ratio
#7- Pump (cont.)	10	.248	.141	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00

Table A5-Fault Frequency Sets

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
Cooling Tower Fan Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	6.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Gear Mesh	1.00	3.00
HOG FN Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
HOG FN Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00
SBHE FN-1, 2 Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
SBHE FN-1, 2 Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00
SBHE FN-3 Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00

Table A5-Fault Frequency Sets (continued)

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
SBHE FN-3 Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00
Pressurizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
Pressurizer Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
Cleanup Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	3.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Cleanup Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	3.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Pool Coolant Pump Motor	Unbalance	1.00	1.00

Table A5-Fault Frequency Sets (continued)

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Pool Coolant Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Auxiliary Pressurizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Demineralizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Demineralizer Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Primary Coolant Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00

APPENDIX B-HFIR TECHNICAL BASIS DOCUMENT

1.0 PURPOSE

The purpose of this document is to establish a basis for definition of appropriate predictive maintenance (PdM) activities at the High Flux Isotope Reactor (HFIR).

2.0 REFERENCES

1. "RBMware™ Software for Reliability Based Maintenance®"; CSI Reference Manual Rev. 0; (1998)
2. "RBMwizard™ Automated RBMware™ Database Builder"; CSI Reference Manual Rev. 0; (1998)
3. "Vibview® Software for Reliability Based Maintenance"; CSI Reference Manual Rev. 0; (1998)
4. "RBMview™ Integrated Status and Reporting"; CSI Reference Manual Rev. 0; (1998)
5. "AutoStat® Automated Statistical Limits"; CSI Reference Manual Rev. 0; (1998)
6. "Nspectr® Automated Vibration Diagnostics"; CSI Reference Manual Rev. 0; (1998)
7. "Infranalysis® for RBMware™; Infrared Thermography Software"; CSI Reference Manual Rev. 0; (1998)
8. "MotorView® for RBMware™; Induction Motor Analysis Software"; CSI Reference Manual Rev. 0; (1998)
9. "OilView® for RBMware™; In-Shop Oil Analysis"; CSI Reference Manual Rev. 0; (1998)
10. "Model 2120 Machinery Analyzer"; CSI Reference Manual Rev. 6; (1998)
11. Equipment Maintenance Histories
12. "Maintenance Engineering Handbook (Fifth Edition)"; Lindley R. Higgins; McGraw-Hill, Inc. (1995)
13. "The Simplified Handbook of Vibration Analysis (Vols. 1&2)"; Arthur R. Crawford; CSI (1992)
14. "The Handbook of Condition Monitoring (First Edition)"; B.K.N. Rao; Elsevier Science Limited (1996)
15. ORNL/TM-5711/R2; "HFIR Technical Specifications"; (1998)
16. ORNL/RRD/INT-70/R1; "HFIR Safety-Related Systems and Equipment Definition Report and Safety-Related Equipment List"; (1998)
17. "HFIR Systems Training Manual (Weeks 1-6)"

3.0 RESPONSIBILITIES

3.1 Predictive Maintenance Program Manager

The Predictive Maintenance Program Manager is responsible for the following:

1. Selection of appropriate personnel
2. Periodic evaluation of the program

3.2 Mechanical Predictive Maintenance Engineer

The Mechanical Predictive Maintenance Engineer oversees the HFIR Vibration Analysis, Tribology, and Motor Current Signature Analysis programs and is responsible for completion of the following tasks:

1. Selection of components and appropriate monitoring technologies
2. Determination of effective monitoring frequency
3. Data analysis
4. Maintenance and control of PdM equipment
5. Evaluation of new technologies and practices for applicability to HFIR mechanical equipment
6. Determination of appropriate training for personnel involved in the program

3.3 Electrical Predictive Maintenance Engineer

The Electrical Predictive Maintenance Engineer oversees the HFIR Thermography program and is responsible for completion of the following tasks:

1. Selection of components and appropriate monitoring technologies
2. Determination of effective monitoring frequency
1. Data collection and storage
3. Data analysis
4. Maintenance and control of thermography equipment
5. Evaluation of new technologies and practices for applicability to HFIR electrical equipment
6. Determination of appropriate training for personnel involved in the program

3.4 Predictive Maintenance Craft

Predictive Maintenance Craft must have expertise commensurate with their degree of involvement, as determined by the Predictive Maintenance Engineer. In addition, these personnel are responsible for:

2. Data collection and storage
3. Data Analysis

4.0 DISCUSSION

4.1 Background

Condition monitoring is the process of evaluating the mechanical behavior of a component through the use of predictive technologies such as vibration analysis, thermography, tribology, motor current signature analysis, and flux coil signature

analysis. The information provided by condition monitoring may be used by a maintenance organization to perform certification, diagnostic analysis, and predictive maintenance.

Certification, also known as post maintenance testing or PMT, is the use of predictive technologies to provide functional verification of proper component operation. Certification is performed after corrective maintenance or when a new component is placed in service.

Diagnostic analysis is the use of predictive technologies to identify the cause of component faults. Assuming that an appropriate technique is employed, characteristics of the data collected from a failing component will provide indication of the underlying cause of failure. This type of analysis is reactive in nature since it is performed only after a fault has occurred.

Predictive maintenance, also known as potential fault analysis, is the systematic use of the information provided by condition monitoring to enhance the overall effectiveness and efficiency of maintenance activities. To support the implementation of a predictive maintenance strategy, data reflecting the values of key component parameters are collected at established intervals using one or more predictive techniques. Significant deviation in the magnitudes of one or more of the monitored parameters from normal levels is indicative of changing component condition. Once a deviation has been identified, further analysis is performed to determine the underlying cause. Routine performance of this process provides a maintenance organization with the ability to predict which components are most likely to fail and approximately how long these components may remain in service before failure occurs.

Statistical strategies for optimizing the allocation of maintenance resources rely on the consistency and integrity of condition monitoring information. For this reason, the first step in the integration of predictive maintenance activities is the development of a reliable source of information. Subsequent to this development, the maintenance organization will begin to employ techniques for optimizing predictive maintenance activities.

4.2 Component Selection

Components are selected for monitoring based on their importance to plant safety, maintenance history, effect on plant availability, and replacement cost. The selected components are classified as either safety related or non-safety related. Safety related components are required for safe shutdown of the reactor, and are identified in Reference 16. Non-safety related components have no effect on the ability to safely shutdown, but are required for operation of the reactor.

4.3 Predictive Maintenance Technologies

The predictive technologies considered for use at HFIR include vibration analysis, thermography, tribology, and motor current and flux coil signature analyses. Appropriate technologies are identified for each component based on the ability to provide accurate and timely identification of typical problems.

4.3.1 Vibration Analysis

Vibration analysis is the process of collecting and analyzing machinery vibration signatures. The term vibration refers to oscillation about a reference point. Such oscillations result from the dynamic forces generated during the operation of a rotating component. The magnitude of the vibration is dependent on the units used for measurement, typically displacement, velocity, or acceleration.

Vibration signatures collected from rotating components contain the most comprehensive set of information available regarding mechanical condition. The typical problems experienced by rotating equipment, such as imbalance, misalignment, electrical defects, bearing problems, and blade/impeller defects, all manifest in vibration signatures. For this reason, vibration analysis is the single most potentially useful predictive technology considered for applications involving rotating equipment. Attachment 1 contains a description of the HFIR Vibration Analysis Program.

4.3.2 Thermography

Thermography is based on the scientific principle that all bodies possessing a temperature above absolute zero emit energy. In particular, thermography examines the amount of energy emitted at the infrared wavelengths. The intensity of the infrared radiation emitted from an object is directly dependent on the surface temperature of the object. This is accomplished through the use of thermal image processing equipment that provides an image of the infrared energy emitted from a component.

Component faults that affect temperature necessarily affect the amount of infrared energy emitted. The analyst looks for indication of abnormal temperatures, be they higher or lower than the expected value. The location and magnitude of these temperature anomalies are used to locate and diagnose equipment problems.

Thermographic images are useful in detecting rotating equipment problems such as overheated bearings and misaligned couplings, but routine collection and storage of such images is too resource intensive for

widespread application on rotating equipment at the HFIR. Thermography will be used in a limited capacity in such applications, primarily to provide validation of conclusions made with vibration analysis.

Thermography is very useful in applications involving electrical equipment such as power panels or bus ducts. Attachment 2 provides a description of the HFIR Thermography Program.

4.3.3 Tribology

Tribology refers to the activities associated with collection and analysis of data regarding the condition of machine lubricants. The basic functions of lubricants in mechanical equipment are to reduce friction between moving parts, reduce wear, control temperature rise, and minimize corrosion.

Lubricating oil analysis consists of analyzing the physical characteristics and contents of a lubricant sample. All mechanical components are designed to operate with specified lubricant characteristics. Lubricating oil analysis determines the ability of the lubricant to meet its design service, but does not provide insight into the condition of the component from which the sample was drawn. The primary benefit of lubricating oil analysis is the ability to schedule oil changes based on the condition of the lubricant and not a time-based strategy. As a result, it is expected that the frequency of oil changes will diminish.

Wear particle analysis differs from lubricating oil analysis in its ability to provide information about the condition of the component from which the sample was collected. The shape, composition, and quantity of particles entrained in the lubricant sample are analyzed, the result being an understanding of how the component is wearing. The analysis is typically accomplished in two steps. The first step is the trending of the size and quantity of the particulate matter found in oil samples. Changes in the operating characteristics of the component will result in an increase in one or more of the trended quantities, prompting the analyst to initiate the second step in the wear particle analysis process. The next step consists of a more detailed analysis of the composition and shape of the particles. This analysis allows the identification of the source and severity of the wear responsible for the particles.

Significant degradation of rotating equipment at the HFIR will be detected by vibration analysis, eliminating the need for wear particle analysis and limiting the use of lubricating oil analysis to applications where costs associated with oil changes warrant. Attachment 3 provides a description of the HFIR Tribology program.

4.3.4 Motor Current and Flux Coil Signature Analysis

Motor current signature analysis (MCSA) and flux coil signature analysis (FCSA) consist of the collection and analysis of motor electrical signatures. These technologies are useful primarily for the detection of electrical problems in motors. Typical electrical problems experienced by motors are readily visible in vibration signatures, making the widespread use of motor current and flux coil signature analyses on rotating components redundant. MCSA and FCSA will be used in a limited capacity in such applications, primarily to provide validation of conclusions made with vibration analysis.

One application where MCSA will produce benefits is in trending the response of motor operated valves. Attachment 4 provides a description of the HFIR MCSA Program.

4.4 Summary of Predictive Maintenance Activities

Table 1 lists the components routinely monitored, the predictive technology employed, and the current monitoring frequency.

Table 1: Summary of Current Predictive Maintenance Activities

Components	Designation	Vibration Analysis	Thermography	Tribology	MCSA
Primary Coolant Pumps (High Speed)	PU-1A*	Monthly	Diagnostic	Semi-Annually	Diagnostic
	PU-1B*	Monthly	Diagnostic	Semi-Annually	Diagnostic
	PU-1C*	Monthly	Diagnostic	Semi-Annually	Diagnostic
	PU-1D*	Monthly	Diagnostic	Semi-Annually	Diagnostic
Primary Coolant Pumps (Low Speed)	PU-1E*	Monthly	Diagnostic	NA	Diagnostic
	PU-1F*	Monthly	Diagnostic	NA	Diagnostic
	PU-1G*	Monthly	Diagnostic	NA	Diagnostic
	PU-1H*	Monthly	Diagnostic	NA	Diagnostic
Air Compressors	C-1A	Monthly	Diagnostic	Annually	Diagnostic
	C-1B	Monthly	Diagnostic	Annually	Diagnostic
	C-1C	Monthly	Diagnostic	Annually	Diagnostic
	Plant Air	Monthly	Diagnostic	Annually	Diagnostic
Secondary Coolant Pumps	PU-6A	Monthly	Diagnostic	Semi-Annually	Diagnostic

Components	Designation	Vibration Analysis	Thermography	Tribology	MCSA
Secondary Coolant Pumps	PU-6B	Monthly	Diagnostic	Semi-Annually	Diagnostic
	PU-6C	Monthly	Diagnostic	Semi-Annually	Diagnostic
Emergency Secondary Coolant Pump	PU-14	Monthly	Diagnostic	Diagnostic	Diagnostic
Cooling Tower Fans (High Speed)	FN-4A1H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4A2H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4B1H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4B2H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4C1H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4C2H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4D1H	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4D2H	Monthly	Diagnostic	Diagnostic	Diagnostic
Cooling Tower Fans (Low Speed)	FN-4A1L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4A2L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4B1L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4B2L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4C1L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4C2L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4D1L	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4D2L	Monthly	Diagnostic	Diagnostic	Diagnostic
Pool Coolant Pump	PU-9A	Monthly	Diagnostic	Diagnostic	Diagnostic
Pool Coolant Pump	PU-9B	Monthly	Diagnostic	Diagnostic	Diagnostic
Pool Cleanup Pumps	PU-7A	Monthly	Diagnostic	Diagnostic	Diagnostic
	PU-7B	Monthly	Diagnostic	Diagnostic	Diagnostic
Primary Cleanup Pumps	PU-2A	Monthly	Diagnostic	Diagnostic	Diagnostic
	PU-2B	Monthly	Diagnostic	Diagnostic	Diagnostic
Pressurizer Pumps	PU-4A	Monthly	Diagnostic	Semi-Annually	Diagnostic
	PU-4B	Monthly	Diagnostic	Semi-Annually	Diagnostic
Aux. Pressurizer Pump	PU-11	Monthly	Diagnostic	Diagnostic	Diagnostic
Chilled Water Pumps	PU-1	Monthly	Diagnostic	Diagnostic	Diagnostic
	PU-2	Monthly	Diagnostic	Diagnostic	Diagnostic

Components	Designation	Vibration Analysis	Thermography	Tribology	MCSA
Demineralized Water Pumps	PU-18A	Monthly	Diagnostic	Diagnostic	Diagnostic
	PU-18B	Monthly	Diagnostic	Diagnostic	Diagnostic
Special Building Hot Exhaust Fans	FN-1*	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-2*	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-3	Monthly	Diagnostic	Diagnostic	Diagnostic
Hot Off Gas Fans	FN-3	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-4	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-5	Monthly	Diagnostic	Diagnostic	Diagnostic
	FN-6	Monthly	Diagnostic	Diagnostic	Diagnostic
Limiterorque Actuators	FCV-140	NA	Diagnostic	NA	Semi-Annually
	FCV-142	NA	Diagnostic	NA	Semi-Annually
	FCV-144	NA	Diagnostic	NA	Semi-Annually
	FCV-149	NA	Diagnostic	NA	Semi-Annually
	FCV-151	NA	Diagnostic	NA	Semi-Annually
	FCV-153	NA	Diagnostic	NA	Semi-Annually
	FCV-344	NA	Diagnostic	NA	Semi-Annually
	FCV-345	NA	Diagnostic	NA	Semi-Annually
	FCV-346	NA	Diagnostic	NA	Semi-Annually
	FCV-347	NA	Diagnostic	NA	Semi-Annually
	FCV-348	NA	Diagnostic	NA	Semi-Annually
	FCV-349	NA	Diagnostic	NA	Semi-Annually
	FCV-550	NA	Diagnostic	NA	Semi-Annually
	FCV-551	NA	Diagnostic	NA	Semi-Annually
	FCV-552	NA	Diagnostic	NA	Semi-Annually
	FCV-553	NA	Diagnostic	NA	Semi-Annually

Components	Designation	Vibration Analysis	Thermography	Tribology	MCSA
Power Panels	P-31*	NA	Annually	NA	NA
	P-32*	NA	Annually	NA	NA
	P-33*	NA	Annually	NA	NA
	P-22*	NA	Annually	NA	NA
	P-29*	NA	Annually	NA	NA
	P-1A	NA	Biannually	NA	NA
	P-1B	NA	Biannually	NA	NA
	P-2	NA	Biannually	NA	NA
	P-3	NA	Biannually	NA	NA
	P-4	NA	Biannually	NA	NA
	P-5	NA	Biannually	NA	NA
	P-6	NA	Biannually	NA	NA
	P-7	NA	Biannually	NA	NA
	P-10	NA	Biannually	NA	NA
	P-12	NA	Biannually	NA	NA
	P-15	NA	Biannually	NA	NA
	P-16	NA	Biannually	NA	NA
	P-17	NA	Biannually	NA	NA
	P-18	NA	Biannually	NA	NA
	P-20	NA	Biannually	NA	NA
	P-21	NA	Biannually	NA	NA
	P-23	NA	Biannually	NA	NA
	P-24	NA	Biannually	NA	NA
	P-25	NA	Biannually	NA	NA
	P-26	NA	Biannually	NA	NA
	P-27	NA	Biannually	NA	NA
	P-28	NA	Biannually	NA	NA
	P-34	NA	Biannually	NA	NA
	P-35	NA	Biannually	NA	NA
	P-36	NA	Biannually	NA	NA
	P-37	NA	Biannually	NA	NA
	P-39	NA	Biannually	NA	NA
	P-50	NA	Biannually	NA	NA
	P-51	NA	Biannually	NA	NA
	P-52	NA	Biannually	NA	NA
	R	NA	Biannually	NA	NA
	C	NA	Biannually	NA	NA
	EIP	NA	Biannually	NA	NA
	MIF	NA	Biannually	NA	NA
	DPZ	NA	Biannually	NA	NA
	Reg.	NA	Biannually	NA	NA
	Cln.	NA	Biannually	NA	NA

Components	Designation	Vibration Analysis	Thermography	Tribology	MCSA
Power Panels	NP-2	NA	Biannually	NA	NA
	NP-3	NA	Biannually	NA	NA
	NP-4	NA	Biannually	NA	NA
	IP-A	NA	Biannually	NA	NA
	IP-B	NA	Biannually	NA	NA
	IP-C	NA	Biannually	NA	NA
	IP-D	NA	Biannually	NA	NA
	SSP	NA	Biannually	NA	NA
	A	NA	Biannually	NA	NA
	A1	NA	Biannually	NA	NA
	B	NA	Biannually	NA	NA
Lighting Panels	C	NA	Biannually	NA	NA
	D	NA	Biannually	NA	NA
	E	NA	Biannually	NA	NA
	F	NA	Biannually	NA	NA
	G	NA	Biannually	NA	NA
	H	NA	Biannually	NA	NA
	J	NA	Biannually	NA	NA
	K	NA	Biannually	NA	NA
	L	NA	Biannually	NA	NA
	M	NA	Biannually	NA	NA
	N	NA	Biannually	NA	NA
	Q	NA	Biannually	NA	NA
	HOG-1	NA	Biannually	NA	NA
600 amp Experiment Room Bus Duct		NA	Annually	NA	NA
600 amp Beam Room Bus Duct		NA	Annually	NA	NA
225 amp West Experiment Room Bus Duct		NA	Annually	NA	NA
225 amp South Experiment Room Bus Duct		NA	Annually	NA	NA
225 amp Beam Room Bus Duct		NA	Annually	NA	NA
100 amp Experiment Room Bus Duct		NA	Annually	NA	NA

100 amp Beam Room Bus Duct		NA	Annually	NA	NA
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*-Denotes safety related equipment

Attachment 1: Vibration Analysis

SCOPE

The following sections describe the organization and operations of the HFIR Vibration Analysis Program. The HFIR Vibration Analysis Program is inextricably linked to the software platform used to implement and support it. A working knowledge of the software and associated hardware is required for all personnel involved in data collection and analysis.

INSTRUMENTATION AND SOFTWARE

NOTE

This manual is intended to provide an overview of the structure and organization of the HFIR vibration analysis program; specific concerns regarding vibration analysis equipment should be addressed by referring to the applicable user's manual.

SOFTWARE

RBMware™ is a multi-technology data storage and analysis software package produced by Computational Systems Incorporated (CSI). RBMware™ is stored on the hard-drive of a dedicated computer located in the HFIR PdM office and provides the foundation for the vibration analysis program. RBMware™ has three functional categories:

1. **Setup/Communication** –allows transfer of information between data collection devices and the RBMware™ database
2. **Analysis** – provides numerous support modules designed to assist the analyst in evaluating component condition
3. **Documentation and Reporting** –provides a means of recording component history and documenting program activities

Figure 1¹ shows the hierarchical organization of RBMware™:

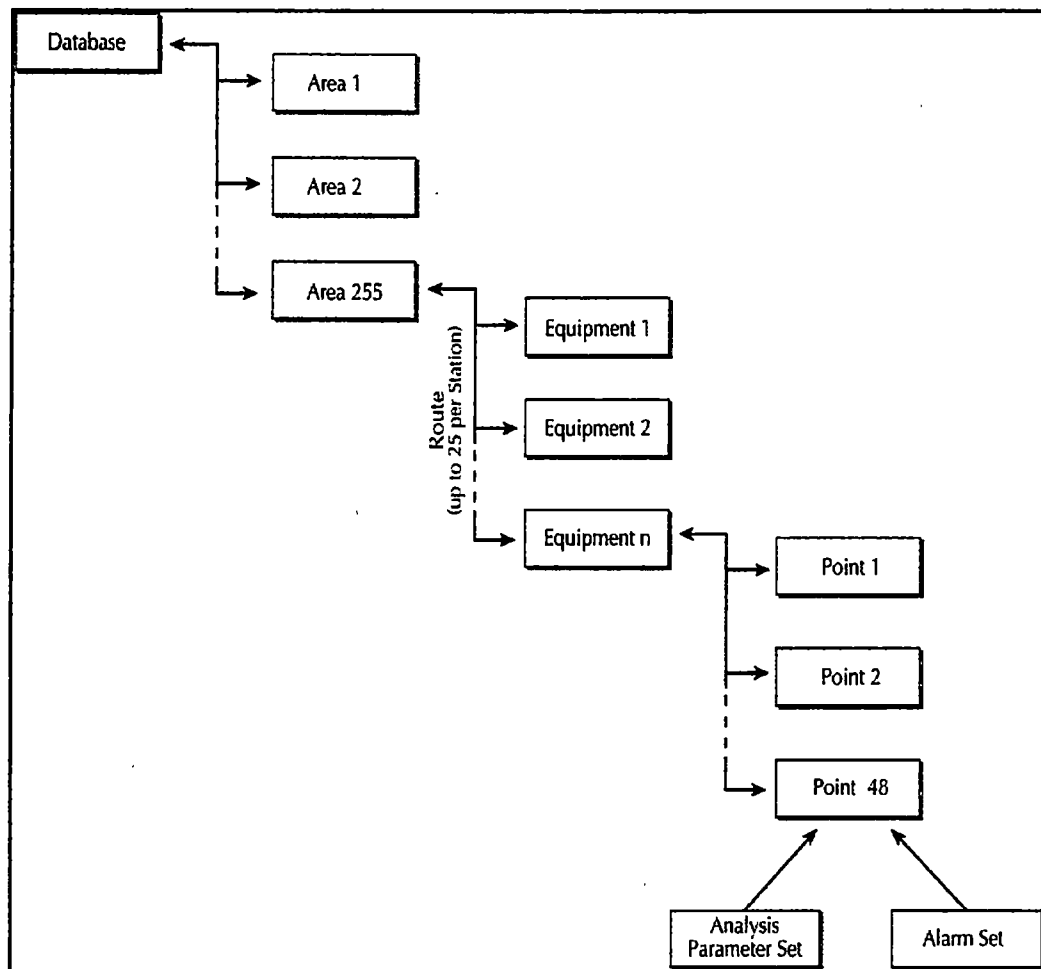


Figure 1¹: Organizational Hierarchy of RBMware™

Three databases were created for the HFIR vibration analysis program:

1. HFIR Facility database- repository for all routinely collected vibration data.
2. HFIR Troubleshooting database- repository for data collected for diagnostic purposes
3. HFIR History database- repository for historical data collected under previous vibration programs

In addition to Areas, Equipment, and Measuring Points, these databases also contain analysis parameter sets, alarm limit sets, and fault frequency sets.

NOTE

Since the HFIR Facility database will be accessed on a routine basis, further discussion is limited to this database alone.

AREAS

Areas are the top levels in the RBMware™ organizational hierarchy. Each Area contains a collection of components grouped according to the anticipated collection route. The HFIR Facility database is divided into five Areas:

1. Ground Floor
2. First Floor
3. Fan Facility
4. Primary Coolant Pumps
5. Cooling Tower

EQUIPMENT

The components located in an Area comprise the Equipment category. Typical information necessary to specify a piece of equipment includes horsepower, operating speed, bearing specifications, etc. Technical information for all monitored components is located in the HFIR PdM office, and is updated as changes warrant.

MEASURING POINTS

On each piece of equipment there are a number of strategically placed and uniquely identified Measuring Points. These Measuring points are typically located in the following scheme:

1. Two radial points per bearing. These points are located approximately 90° apart, almost exclusively in the vertical and horizontal positions. The notable exceptions are the belt-driven over-hung fans located in the fan facility. The radial points are positioned relative to the angle of the belt. The horizontal point is located parallel to this angle, and the vertical point is placed 90° away.
2. One axial point per common shaft. The term common shaft refers to coupled shafts that are vertically and horizontally aligned.

Figures 2,3, and 4 show measuring point orientation and designation for typical equipment arrangements:

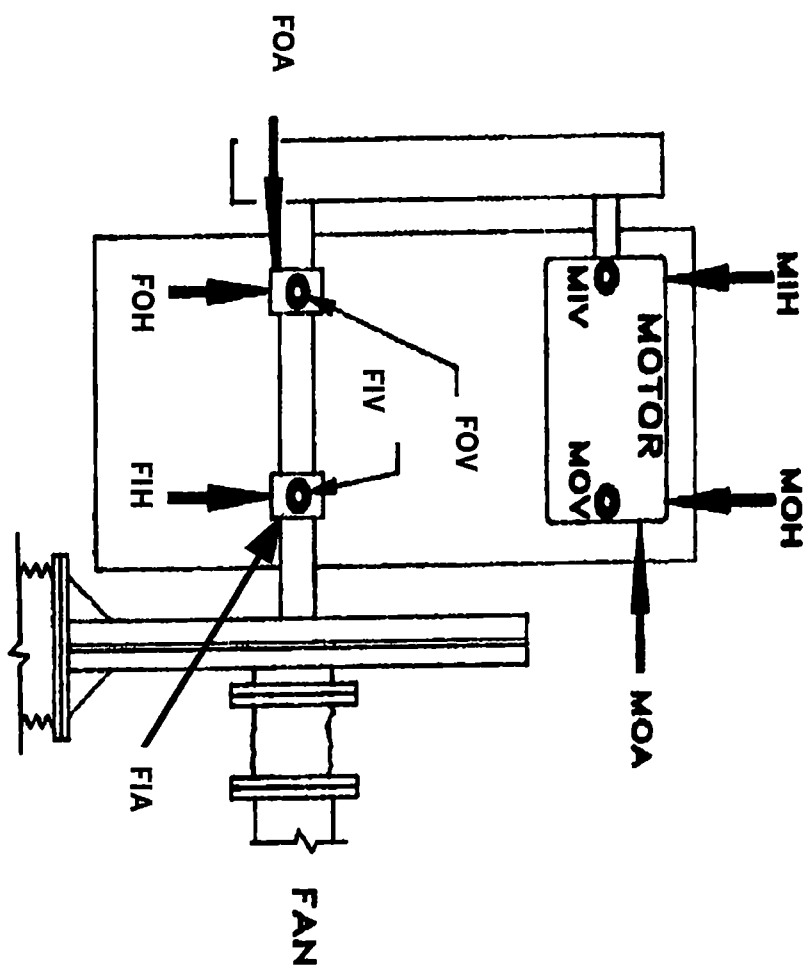


Figure 2: Measurement Point Location and Designation for Typical Belt-Driven Over-hung Fan

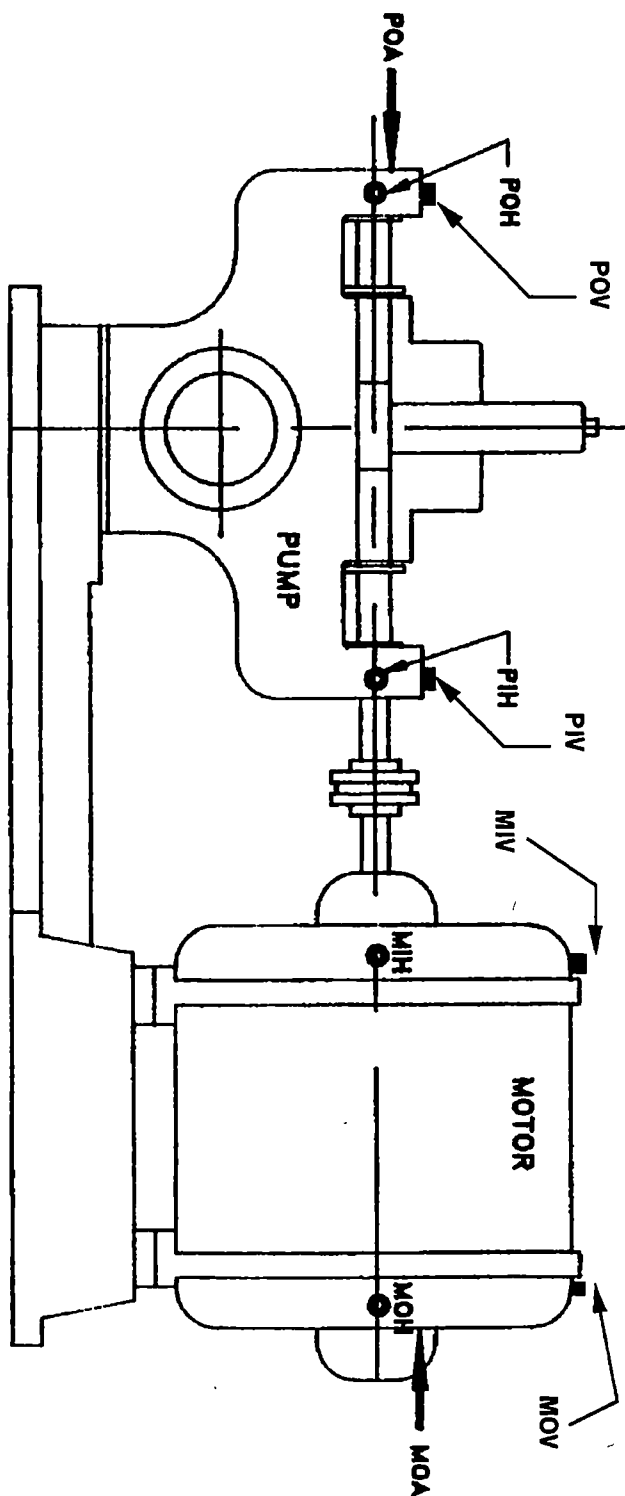


Figure 3: Measurement Point Location and Designation for Typical Horizontal Equipment Arrangement

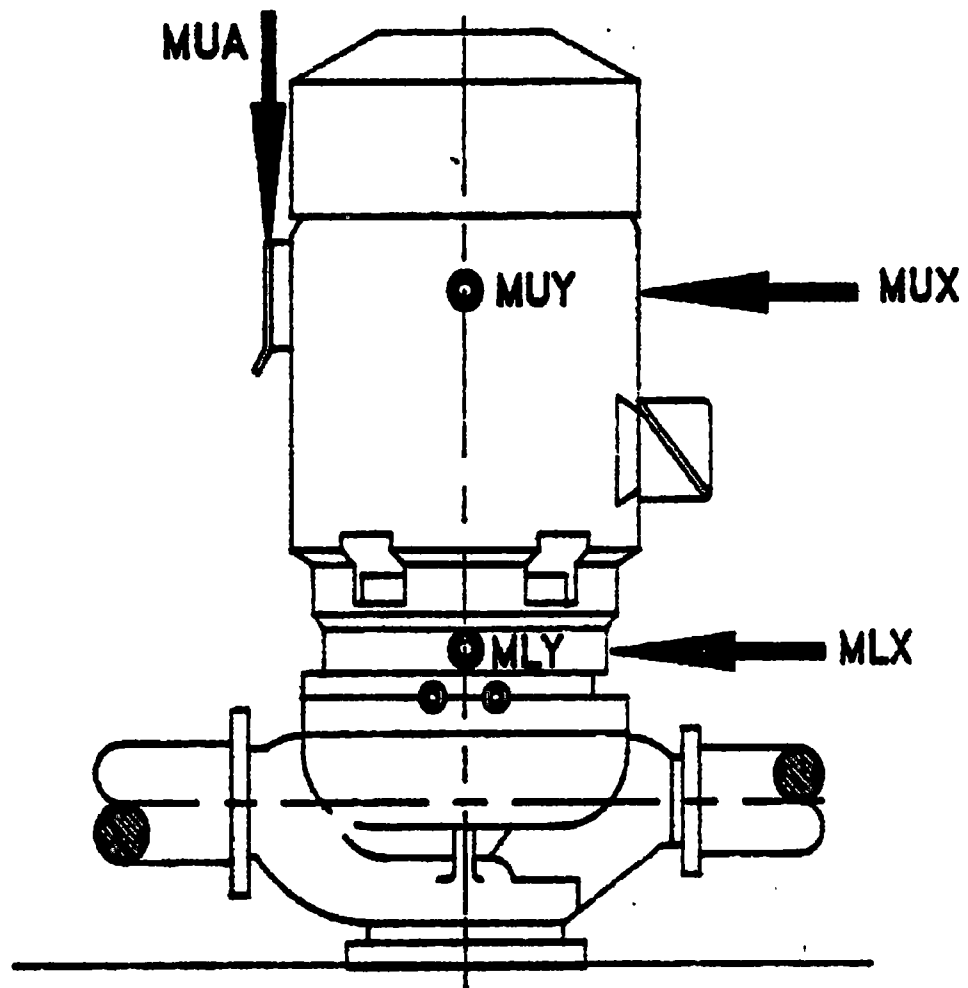


Figure 4: Measurement Point Location and Designation for Typical Vertical Equipment Arrangement

ANALYSIS PARAMETER SETS

Analysis parameter sets identify up to twelve individual frequency bands for each Measuring Point. Each frequency band corresponds to a vibration parameter indicative of certain conditions. For example, a common vibration signature characteristic is a dominant peak in the frequency band corresponding to the turning speed of the machine, known as "1xRPM". The amplitude of this portion of the vibration signature is directly proportional to the degree of rotor balance. Vibration data collected from rotating equipment will contain a complex waveform consisting of many such characteristic frequencies. Figure 5¹ shows a typical analysis parameter set:

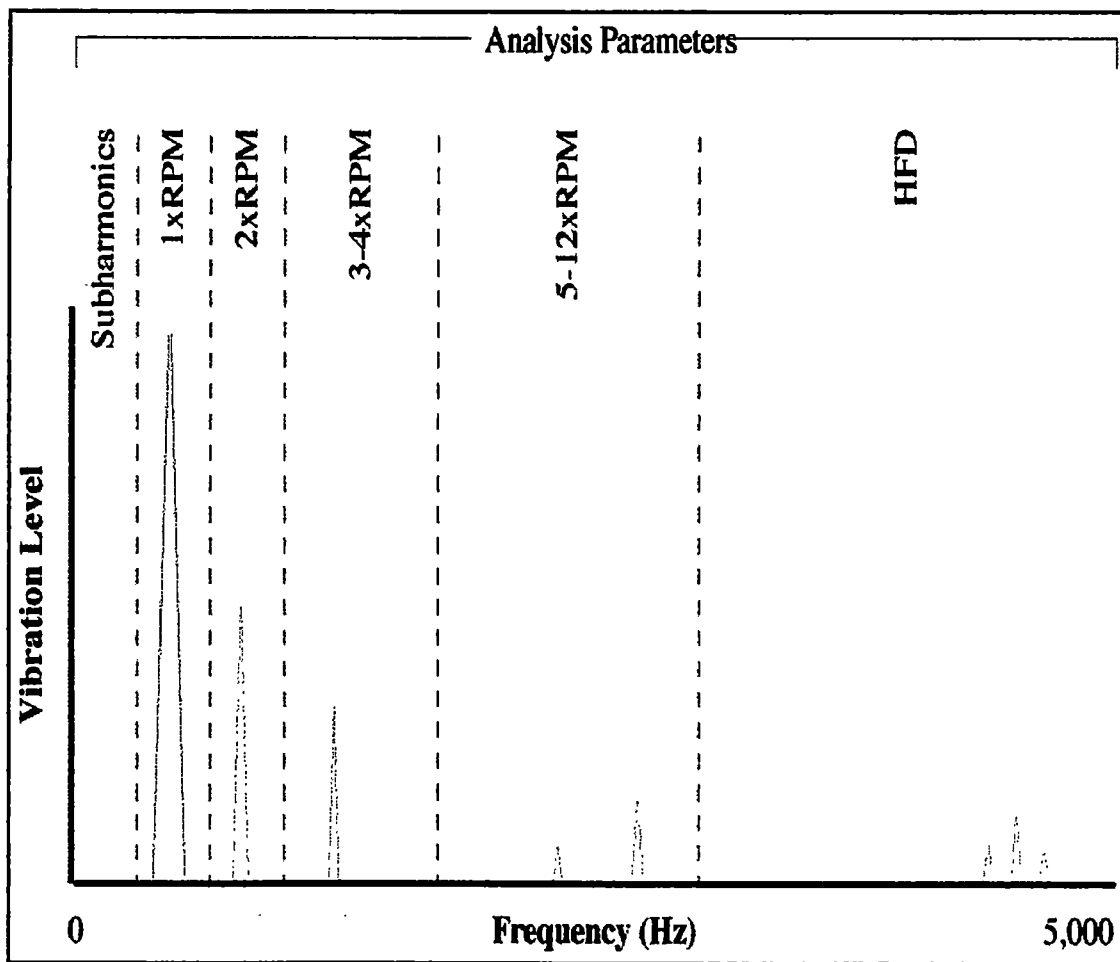


Figure 5¹: Typical Analysis Parameter Set

Table 2 contains a list of the analysis parameter sets available in the HFIR Facility database that are assigned to Measuring Points.

Table 2: Analysis Parameter Sets Assigned to Measuring Points

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#1-AC Motor (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
#2-AC Motor (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
	Rotor Bar Pass	In/Sec	53.00-63.00*RPM
	Stator Slot	In/Sec	67.00-77.00*RPM
#3-AC Motor (3200 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	2xLine Freq.	In/Sec	115.0-125.00 Hz
	1k-20kHz	G's	1000-20000 Hz
#4-Fan (1600 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Blade Pass	In/Sec	7.40-8.40*RPM
#5-Fan (800 rpm)	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#5-Fan (continued)	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Blade Pass	In/Sec	7.40-8.40*RPM
#7-Pump	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	4.40-5.40*RPM
	Vane Pass 2	In/Sec	0.00-0.40*RPM
#8-Pump	30-70xTS	G's	30.40-70.50*RPM
	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	2.40-3.40*RPM
#12-Pump	Vane Pass 2	In/Sec	6000-12000 Hz
	30-70xTS	G's	30.40-70.50*RPM
	Overall	In/Sec	2.00-70.50*RPM
	Subharmonics	In/Sec	0.00-0.80*RPM
	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
#14-Secondary Pump	9-25xTS	In/Sec	8.40-25.40*RPM
	25-70xTS	In/Sec	25.40-70.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Vane Pass 1	In/Sec	5.40-6.40*RPM
	Vane Pass 2	In/Sec	0.00-0.40*RPM
	30-70xTS	G's	30.40-70.50*RPM
	Overall	In/Sec	2.00-70.50*RPM
#14-Secondary Pump	Subharmonics	In/Sec	0.00-0.80*RPM

Analysis Parameter Set	Analysis Parameter	Units	Lower-Upper Range
#14-Secondary Cooling Pump (continued)	1xTS	In/Sec	0.80-1.40*RPM
	2xTS	In/Sec	1.40-2.40*RPM
	3-8xTS	In/Sec	2.40-8.40*RPM
	9-25xTS	In/Sec	8.40-25.40*RPM
	25-75xTS	In/Sec	25.40-75.00*RPM
	1k-20kHz	G's	1000-20000 Hz
	Rotor Bar Pass	In/Sec	53.00-63.00*RPM
	Stator Slot	In/Sec	67.00-77.00*RPM

ALARM LIMITS

Alarm limits are predetermined parameter magnitudes that indicate serious degradation in the health of the monitored component. Alarm limit sets contain an alarm limit for the magnitude of the overall signal as well as individual alarm limits for each analysis parameter. RBMware™ provides four alarm levels:

1. **Fault Level:** This is the most severe alarm level and is indicative of impending component failure. The fault alarm values specified in RBMware™ are based on published standards for applicable Equipment.
2. **Alert Level:** Though less severe than fault levels, alert levels are indicative of significant component degradation. The alert levels specified by RBMware™ are based on component technical specifications and industry standards.
3. **Weak Side Level:** This alarm is set at a level below the normal operating amplitude of the Equipment. The primary purpose of this alarm is to protect against improper data collection.
4. **Early Warning Alarm:** This is a statistical alarm that is based on the amount of deviation from the normal operating amplitude. There are two methods of calculation, including the Baseline Ratio and the Maximum Deviations. The Baseline Ratio establishes alarm levels based on the percent deviation from the normal value. For example, a Baseline Ratio of 1.3 will trigger an alarm if the magnitude of the collected data is greater than 1.3 times the magnitude of normal data. The Maximum Deviations alarm establishes alarm levels based on the number of standard deviations from the calculated mean, or average, value.

There are two types of alarms employed in the HFIR Vibration Analysis Program: the dual upper alarm level alarm and the dual upper delta alarm. Figure 6 provides descriptions of these types of alarms¹:

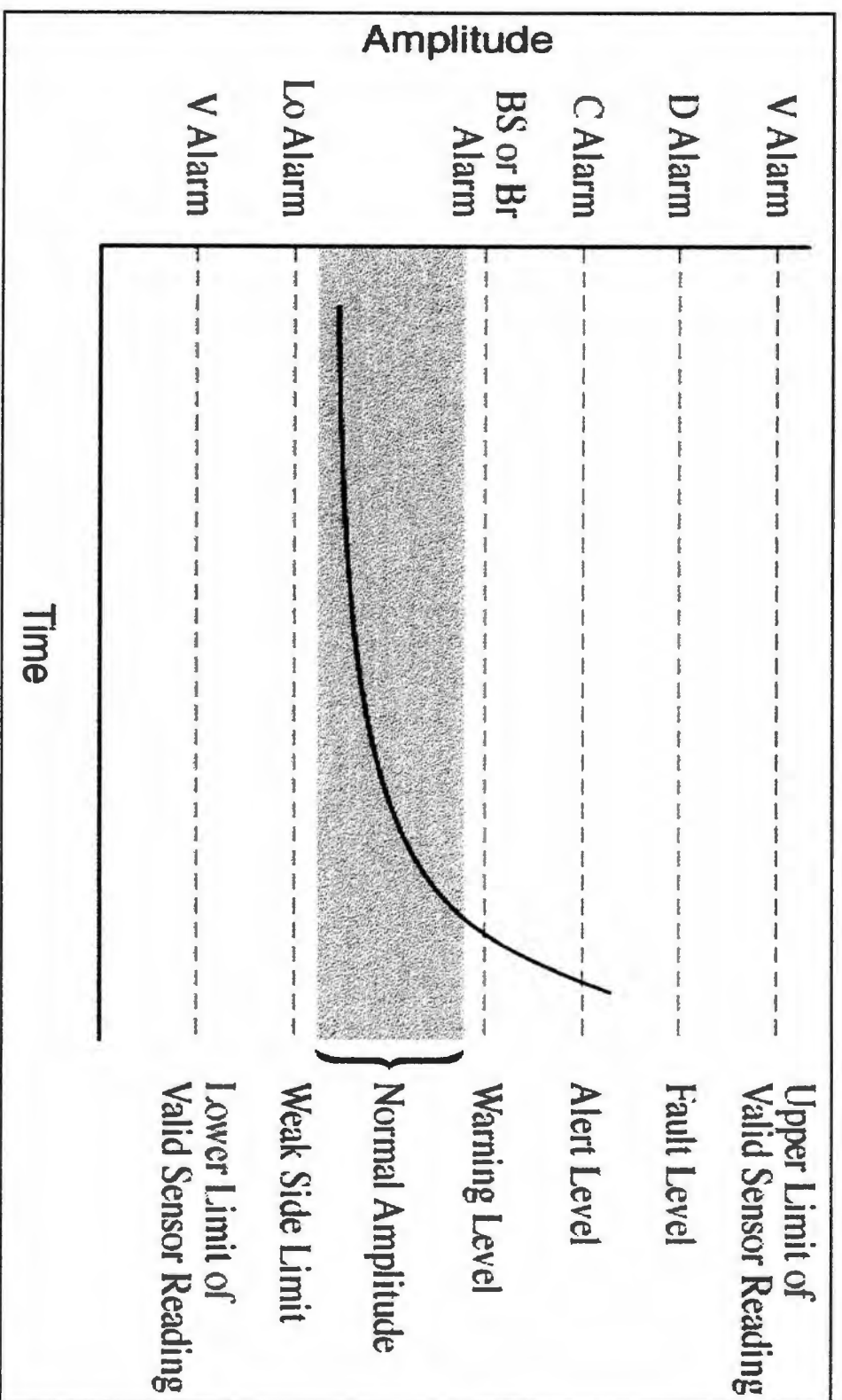


Figure 6¹: Dual Upper Level and Delta Alarm Description

Table 3 provides a description of the alarm codes used by RBMware™ when generating reports:

Table 3: Alarm Codes Used By RBMware™

Alarm Code	Alarm Limit
A	The measured parameter is expected to exceed the absolute fault level within three measurement intervals.
Br	An Early Warning Alarm calculated using the Baseline Ratio method.
Bs	An Early Warning Alarm calculated using the Maximum Deviations method.
C	Alert Level Alarm
D	Fault Level Alarm
L	The measured parameter is below the weak side value for a Dual Upper Alarm type.
V	The measured parameter is above the maximum or below the minimum sensor validity alarm.

The “A” alarm code is generated as a result of a trend analysis on the measured parameters, with the goal of early indication of developing faults. Table 4 contains a listing of the alarm limit sets available in the HFIR Facility database that are assigned to Measuring Points.

Table 4: Alarm Limit Sets Assigned to Measuring Points

Alarm Limit Set	Signal Parameter	Fault Level	Alert Level	Baseline Alert Ratio
#1-AC Motor	0	.354	.283	2.00
	1	.141	.071	2.00
	2	.283	.248	2.00
	3	.212	.177	2.00
	4	.177	.141	2.00
	5	.141	.106	2.00
	6	.106	.071	2.00
	7	.283	.212	2.00
	8	2.00	1.00	2.00
	9	.283	.177	2.00
	10	.283	.177	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00
#2-Secondary Pump Motor	0	.530	.354	2.00
	1	.141	.071	2.00

Alarm Limit Set	Signal Parameter	Fault Level	Alert Level	Baseline Alert Ratio
#2-Secondary Pump Motor (continued)	2	.283	.248	2.00
	3	.212	.177	2.00
	4	.177	.141	2.00
	5	.141	.106	2.00
	6	.106	.071	2.00
	7	.283	.212	2.00
	8	2.00	1.00	2.00
	9	.283	.177	2.00
	10	.283	.177	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00
#7-Pump	0	.283	.212	2.00
	1	.141	.071	2.00
	2	.248	.177	2.00
	3	.212	.141	2.00
	4	.212	.141	2.00
	5	.177	.106	2.00
	6	.141	.071	2.00
	7	2.00	1.00	2.00
	8	.248	.141	2.00
	9	.248	.141	2.00
	10	.248	.141	2.00
	11	4.00	2.00	2.00
	12	6.00	4.00	2.00

FAULT FREQUENCIES

Fault Frequencies identify specific frequencies, or ranges of frequencies whose amplitude is indicative particular faults. The primary function of the fault frequency lines is to provide the analyst with assistance in identifying component faults. Fault frequencies are represented as lines on spectral plots and indicate the position of a peak that may be associated with a well-defined fault. The position of these lines is calculated by RBMware™ using component technical specifications. Figure 7¹ shows a typical fault frequency set:

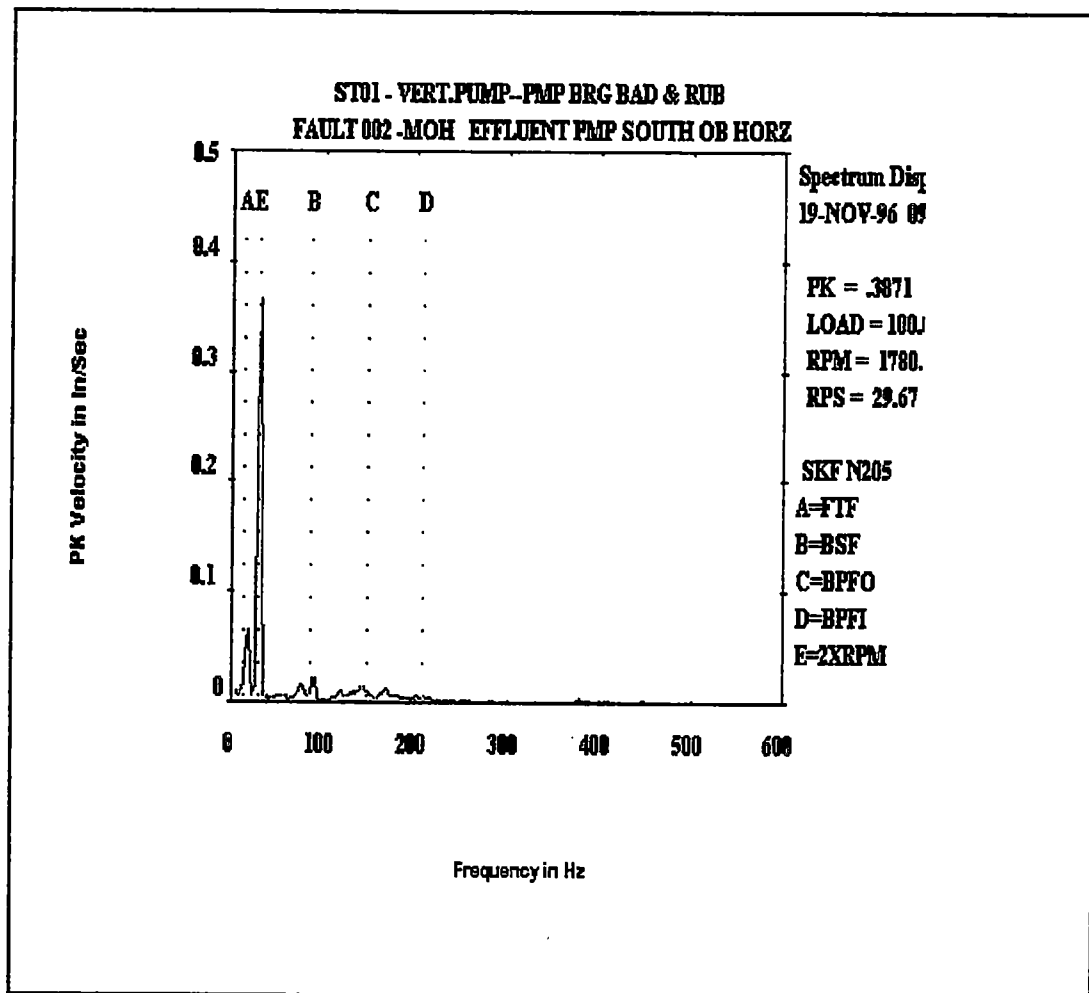


Figure 7¹: Typical Fault Frequency Set

Table 5 contains a listing of the fault frequency sets available in the HFIR Facility database that are currently assigned to Measuring Points. The first and second modifiers indicate the multiples of turning speed with which a fault frequency is associated.

Table 5: Fault Frequency Sets Assigned to Measuring Points

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
Cooling Tower Fan Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	6.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Gear Mesh	1.00	3.00

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
HOG FN Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
HOG FN Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00
SBHE FN-1, 2 Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
SBHE FN-1, 2 Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00
SBHE FN-3 Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
SBHE FN-3 Fan	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Blade Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	2.00	3.00

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
Pressurizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
Pressurizer Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
	Belt Frequency	1.00	3.00
Cleanup Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	3.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Cleanup Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	3.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Pool Coolant Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Pool Coolant Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Auxiliary Pressurizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00

Fault Frequency Set	Fault Frequency	First Modifier	Second Modifier
Auxiliary Pressurizer Pump Motor (continued)	Vane Pass	8.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Demineralizer Pump Motor	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Demineralizer Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00
Primary Coolant Pump	Unbalance	1.00	1.00
	Misalignment	1.00	3.00
	Looseness	1.00	10.00
	Vane Pass	5.00	3.00
	OB Bearing	0.00	4.00
	IB Bearing	0.00	4.00

Table 6 provides a summary of the Measuring Points and the analysis parameter and alarm limit sets assigned to each.

Table 6: Measuring Points and Analysis Parameters

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Primary Coolant Pumps	PU-1A	Motor Upper Y (N/S)	MUY	3	1
		Motor Upper X (E/W)	MUX	3	1
		Motor Upper Axial	MUA	3	1
		Motor Lower Y (N/S)	MLY	3	1
	PU-1B	Motor Lower X (E/W)	MLY	3	1
		Motor Upper Y (N/S)	MUY	3	1
		Motor Upper X (E/W)	MUX	3	1
		Motor Upper Axial	MUA	3	1
	PU-1C	Motor Lower Y (N/S)	MLY	3	1
		Motor Lower X (E/W)	MLY	3	1
		Motor Upper Y (N/S)	MUY	3	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Primary Coolant Pumps (continued)		Motor Upper X (E/W)	MUX	3	1
		Motor Upper Axial	MUA	3	1
		Motor Lower Y (N/S)	MLY	3	1
		Motor Lower X (E/W)	MLY	3	1
	PU-1D	Motor Upper Y (N/S)	MUY	3	1
		Motor Upper X (E/W)	MUX	3	1
		Motor Upper Axial	MUA	3	1
		Motor Lower Y (N/S)	MLY	3	1
		Motor Lower X (E/W)	MLY	3	1
	PU-1E	Motor Upper Y (N/S)	MUY	13	13
		Motor Upper X (E/W)	MUX	13	13
		Motor Upper Axial	MUA	13	13
		Motor Lower Y (N/S)	MLY	13	13
		Motor Lower X (E/W)	MLY	13	13
	PU-1F	Motor Upper Y (N/S)	MUY	13	13
		Motor Upper X (E/W)	MUX	13	13
		Motor Upper Axial	MUA	13	13
		Motor Lower Y (N/S)	MLY	13	13
		Motor Lower X (E/W)	MLY	13	13
	PU-1G	Motor Upper Y (N/S)	MUY	13	13
		Motor Upper X (E/W)	MUX	13	13
		Motor Upper Axial	MUA	13	13
		Motor Lower Y (N/S)	MLY	13	13
		Motor Lower X (E/W)	MLY	13	13
	PU-1H	Motor Upper Y (N/S)	MUY	13	13
		Motor Upper X (E/W)	MUX	13	13
		Motor Upper Axial	MUA	13	13
		Motor Lower Y (N/S)	MLY	13	13
		Motor Lower X (E/W)	MLY	13	13
Chiller Water Pumps	PU-1	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Pump Inboard Vertical	PIV	11	7
		Pump Inboard Horizontal	PIH	11	7
		Pump Outboard Vertical	POV	11	7
		Pump Outboard Horizontal	POH	11	7
		Pump Outboard Axial	POA	11	7

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Chilled Water Pumps (continued)	PU-2	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Pump Inboard Vertical	PIV	11	7
		Pump Inboard Horizontal	PIH	11	7
		Pump Outboard Vertical	POV	11	7
		Pump Outboard Horizontal	POH	11	7
		Pump Outboard Axial	POA	11	7
Demineralizer Pumps	PU-18A	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	12	7
		Pump Inboard Horizontal	PIH	12	7
		Pump Outboard Vertical	POV	12	7
		Pump Outboard Horizontal	POH	12	7
		Pump Outboard Axial	POA	12	7
	PU-18B	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	12	7
		Pump Inboard Horizontal	PIH	12	7
		Pump Outboard Vertical	POV	12	7
		Pump Outboard Horizontal	POH	12	7
		Pump Outboard Axial	POA	12	7
Primary Cleanup Pump	PU-2A	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Primary Cleanup Pumps (continued)		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	8	7
		Pump Inboard Horizontal	PIH	8	7
		Pump Outboard Vertical	POV	8	7
		Pump Outboard Horizontal	POH	8	7
		Pump Outboard Axial	POA	8	7
	PU-2B	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	8	7
		Pump Inboard Horizontal	PIH	8	7
		Pump Outboard Vertical	POV	8	7
		Pump Outboard Horizontal	POH	8	7
		Pump Outboard Axial	POA	8	7
Pressurizer Pumps	PU-4A	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Pump Inboard Vertical	PIV	7	7
		Pump Inboard Horizontal	PIH	7	7
		Pump Inboard Axial	PIA	7	7
		Pump Outboard Vertical	POV	7	7
		Pump Outboard Horizontal	POH	7	7
	PU-4B	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Pump Inboard Vertical	PIV	7	7
		Pump Inboard Horizontal	PIH	7	7
		Pump Inboard Axial	PIA	7	7
		Pump Outboard Vertical	POV	7	7

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Pressurizer Pumps (continued)	PU-4B	Pump Outboard Horizontal	POH	7	7
Auxiliary Pressurizer Pump	PU-11	Motor Upper Y (N/S)	MUY	3	1
		Motor Upper X (E/W)	MUX	3	1
		Motor Upper Axial	MUA	3	1
		Motor Lower Y (N/S)	MLY	3	1
		Motor Lower X (E/W)	MLY	3	1
Pool Cleanup Pumps	PU-7A	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	8	7
		Pump Inboard Horizontal	PIH	8	7
		Pump Outboard Vertical	POV	8	7
		Pump Outboard Horizontal	POH	8	7
		Pump Outboard Axial	POA	8	7
	PU-7B	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	8	7
		Pump Inboard Horizontal	PIH	8	7
		Pump Outboard Vertical	POV	8	7
		Pump Outboard Horizontal	POH	8	7
		Pump Outboard Axial	POA	8	7
Pool Coolant Pumps	PU-9A	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	7	7
		Pump Inboard Horizontal	PIH	7	7
		Pump Outboard Vertical	POV	7	7
		Pump Outboard Horiz.	POH	7	7

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Pool Coolant Pumps (continued)	PU-9A	Pump Outboard Axial	POA	7	7
	PU-9B	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Pump Inboard Vertical	PIV	7	7
		Pump Inboard Horizontal	PIH	7	7
		Pump Outboard Vertical	POV	7	7
		Pump Outboard Horizontal	POH	7	7
		Pump Outboard Axial	POA	7	7
Air Compressor	C-1B	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
Plant Air Compressor	Plant Air	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
Secondary Coolant Pumps	PU-6A	Motor Upper Y (N/S)	MUY	14	2
		Motor Upper X (E/W)	MUX	14	2
		Motor Lower Axial	MLA	14	2
		Motor Lower Y (N/S)	MLY	14	2
		Motor Lower X (E/W)	MLY	14	2
	PU-6B	Motor Upper Y (N/S)	MUY	1	1
		Motor Upper X (E/W)	MUX	1	1
		Motor Lower Axial	MLA	1	1
		Motor Lower Y (N/S)	MLY	1	1
		Motor Lower X (E/W)	MLY	1	1
	PU-6C	Motor Upper Y (N/S)	MUY	1	1
		Motor Upper X (E/W)	MUX	1	1
		Motor Lower Axial	MLA	1	1
		Motor Lower Y (N/S)	MLY	1	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Secondary Coolant Pumps (continued)	PU-6C	Motor Lower X (E/W)	MLY	1	1
Emergency Secondary Coolant Pump	PU-14	Motor Upper Y (N/S)	MUY	1	1
		Motor Upper X (E/W)	MUX	1	1
		Motor Lower Axial	MLA	1	1
		Motor Lower Y (N/S)	MLY	1	1
		Motor Lower X (E/W)	MLY	1	1
Cooling Tower Fans (High Speed)	4A-1	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4A-2	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4B-1	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
	4B-2	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4C-1	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
	4C-2	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Cooling Tower Fans (High Speed); (cont.)	4C-2	Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4D-1	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
	4D-2	Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
Cooling Tower Fans (Low Speed)	4A-1L	Motor Inboard Horizontal	MIH	2	1
		Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4A-2L	Motor Inboard Horizontal	MIH	2	1
		Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4B-1L	Motor Inboard Horizontal	MIH	2	1
		Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
	4B-2L	Motor Inboard Horizontal	MIH	1	1
		Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4C-1L	Motor Inboard Horizontal	MIH	2	1
		Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Cooling Tower Fans (Low Speed); (cont.)	4C-1L	Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
	4C-2L	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
	4D-1L	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
	4D-2L	Motor Outboard Vertical	MOV	2	1
		Motor Outboard Horizontal	MOH	2	1
		Motor Outboard Axial	MOA	2	1
		Motor Inboard Vertical	MIV	2	1
		Motor Inboard Horizontal	MIH	2	1
HOG Fans	FN-3	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Fan Inboard Vertical	FIV	4	4
		Fan Inboard Horizontal	FIH	4	4
		Fan Inboard Axial	FIA	4	4
		Fan Outboard Vertical	FOV	4	4
		Fan Outboard Horizontal	FOH	4	4
		Fan Outboard Axial	FOA	4	4
	FN-4	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Fan Inboard Vertical	FIV	4	4
		Fan Inboard Horizontal	FIH	4	4

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
HOG Fans (continued)		Fan Inboard Axial	FIA	4	4
		Fan Outboard Vertical	FOV	4	4
		Fan Outboard Horizontal	FOH	4	4
		Fan Outboard Axial	FOA	4	4
	FN-5	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Fan Inboard Vertical	FIV	4	4
		Fan Inboard Horizontal	FIH	4	4
		Fan Inboard Axial	FIA	4	4
		Fan Outboard Vertical	FOV	4	4
		Fan Outboard Horizontal	FOH	4	4
		Fan Outboard Axial	FOA	4	4
	FN-6	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
		Fan Inboard Vertical	FIV	4	4
		Fan Inboard Horizontal	FIH	4	4
		Fan Inboard Axial	FIA	4	4
		Fan Outboard Vertical	FOV	4	4
		Fan Outboard Horizontal	FOH	4	4
		Fan Outboard Axial	FOA	4	4
Special Building Hot Exhaust Fans (SBHE)	FN-1	Motor Outboard Vertical	MOV	6	1
		Motor Outboard Horizontal	MOH	6	1
		Motor Outboard Axial	MOA	6	1
		Motor Inboard Vertical	MIV	6	1
		Motor Inboard Horizontal	MIH	6	1
		Fan Inboard Vertical	FIV	5	4
		Fan Inboard Horizontal	FIH	5	4
		Fan Inboard Axial	FIA	5	4
		Fan Outboard Vertical	FOV	5	4
		Fan Outboard Horizontal	FOH	5	4
		Fan Outboard Axial	FOA	5	4
	FN-2	Motor Outboard Vertical	MOV	6	1

Component	Component ID	Measuring Point	Point ID	AP Set	AL Set
Special Building Hot Exhaust Fans (SBHE); (continued)	FN-2	Motor Outboard Horizontal	MOH	6	1
		Motor Outboard Axial	MOA	6	1
		Motor Inboard Vertical	MIV	6	1
		Motor Inboard Horizontal	MIH	6	1
		Fan Inboard Vertical	FIV	5	4
		Fan Inboard Horizontal	FIH	5	4
		Fan Inboard Axial	FIA	5	4
		Fan Outboard Vertical	FOV	5	4
		Fan Outboard Horizontal	FOH	5	4
		Fan Outboard Axial	FOA	5	4
	FN-3	Motor Outboard Vertical	MOV	1	1
		Motor Outboard Horizontal	MOH	1	1
		Motor Outboard Axial	MOA	1	1
		Motor Inboard Vertical	MIV	1	1
		Motor Inboard Horizontal	MIH	1	1
		Fan Inboard Vertical	FIV	5	4
		Fan Inboard Horizontal	FIH	5	4
		Fan Inboard Axial	FIA	5	4
		Fan Outboard Vertical	FOV	5	4
		Fan Outboard Horizontal	FOH	5	4
		Fan Outboard Axial	FOA	5	4
Air Compressors	C-1A	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1
	C-1C	Motor Outboard Vertical	MOV	3	1
		Motor Outboard Horizontal	MOH	3	1
		Motor Outboard Axial	MOA	3	1
		Motor Inboard Vertical	MIV	3	1
		Motor Inboard Horizontal	MIH	3	1

HARDWARE

NOTE

To ensure compatibility with RBMware™, all vibration-monitoring equipment is manufactured by CSI.

DATA ANALYZER

A CSI Model 2120 Analyzer is used to collect vibration data from machinery.

TRANSDUCER AND MOUNTS

CSI Model 320 quick thread accelerometers are used in combination with stud-type accelerometer mounts. This configuration provides good frequency response up to 16,000 Hz, which is more than adequate for HFIR applications.

ROUTINE DATA COLLECTION

To facilitate regularity in data collection, redundant components are switched during each refueling outage. Data is collected prior to, and immediately following refueling outages, with the exception of the Primary Coolant Pumps. Due to their inaccessibility during full-power operations, vibration data is collected from these components only during periods of shutdown. The first step in the data collection process is to download the pre-specified routes from the RBMware™ database to the CSI-2120 analyzer. A route is a list of measuring points and equipment from which data is sequentially collected. Once the route(s) have been downloaded, data collection may begin.

NOTE

It is essential that data be collected and stored properly. Each individual is responsible for ensuring that they collect and identify all data correctly. Adherence to the sequence outlined by the route information will facilitate consistency on the data and minimize the occurrence of incorrectly assigned data.

When all available data has been collected it is transferred to the HFIR Facility database. At this time, the analyst will generate a Last Measurement Survey Report, shown in Figure 8.

Last Measurement Survey Report

Database: HFIR Facility.rbm
Area: Cooling Tower
Route No. 1: COOLING TOWER
Report Date: Aug-24-99 12:37

* SUSPECT EQUIPMENT LIST *

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM

Sec. Coolant Pump PU-6C					
PU-6C	-	(Aug-17-99) (RPM = 1188.)	(LOAD = 100.0)		
	MUY --- 3-8xTS	.136 In/Sec	.071 .250	Br	110
	MUX --- 3-8xTS	.117 In/Sec	.068 .250	Br	154
Cooling Tower Fan 4C-1H					
4C-1	-	(Aug-16-99) (RPM = 1800.)	(LOAD = 100.0)		
	MOH --- ROTOR BAR PASS	.157 In/Sec	.080 .400	Br	89
	MOH STATOR SLOT	.157 In/Sec	.080 .400	Br	106
	MOA --- 25-75xTS	.042 In/Sec	.031 .150	Br	229
	MIV --- 25-75xTS	.070 In/Sec	.036 .150	Br	81
	MIH --- 25-75xTS	.068 In/Sec	.045 .150	Br	116
	MIH ROTOR BAR PASS	.148 In/Sec	.080 .400	Br	86
	MIH STATOR SLOT	.148 In/Sec	.142 .400	Br	159
Cooling Tower Fan 4D-1H					
4D-1	-	(Aug-16-99) (RPM = 1800.)	(LOAD = 100.0)		
	MOH --- ROTOR BAR PASS	.273 In/Sec	.250 .400	C	15
	MOH STATOR SLOT	.273 In/Sec	.250 .400	C	16
	MOA --- ROTOR BAR PASS	.148 In/Sec	.080 .400	Br	79
	MOA STATOR SLOT	.148 In/Sec	.080 .400	Br	81
	MIV --- 25-75xTS	.046 In/Sec	.041 .150	Br	246
	MIV ROTOR BAR PASS	.152 In/Sec	.080 .400	Br	89
	MIV STATOR SLOT	.152 In/Sec	.084 .400	Br	122
	MIH --- ROTOR BAR PASS	.247 In/Sec	.080 .400	Br	26
	MIH STATOR SLOT	.247 In/Sec	.080 .400	Br	27
Cooling Tower Fan 4D-2H					
4D-2	-	(Aug-16-99) (RPM = 1800.)	(LOAD = 100.0)		
	MIH --- SUBHARMONICS	.111 In/Sec	.100 .200	C	???
Cooling Tower Fan 4A-1L					
Fan 4A-1	-	(Aug-16-99) (RPM = 900.)	(LOAD = 100.0)		
	MOH --- 2xTS	.108 In/Sec	.060 .300	Br	127
	MOA --- 2xTS	.087 In/Sec	.067 .300	Br	244
	MIH --- 2xTS	.108 In/Sec	.060 .300	Br	126

Exceptional Point Total:		14			
Exceptional Equipment Total:		5			

Figure 8: Last Measurement Survey Report

DATA ANALYSIS

Data analysis relies not only on the automated features provided by RBMware™, but on the expertise of HFIR maintenance personnel as well. The alarms provided by RBMware™ are based on industry standards, and must be continuously evaluated for appropriateness to HFIR applications. Familiarity with the equipment and an understanding of the fundamentals of vibration analysis and RBMware™ are the tools used by the analyst to perform this evaluation. For this reason, it is essential that personnel involved in the collection and analysis of vibration data be trained to a level commensurate with their responsibilities.

Once the analyst determines that vibration data collected from a component is indicative of a potential problem, a case history is initiated using RBMware™. This case history will contain a description of the symptoms, diagnoses, and maintenance recommendations associated with a given vibration signal. Once a problem has been corrected, the case history is closed and stored for later reference. The data taken before and after the repair are associated with the case history.

RECORDS

VIBRATION DATA

All vibration data will be backed up once per quarter. The files will be stored on Iomega Ditto media and located in the HFIR PdM office.

USER'S MANUALS

Manuals associated with all HFIR vibration analysis equipment will be maintained in the HFIR PdM office.

Attachment 3: Thermography

SCOPE

The following sections describe the organization and operations of the HFIR Thermography Program. The HFIR Thermography Program is inextricably linked to the equipment used to implement and support it. A working knowledge of the software and associated hardware is required for all personnel involved in the program.

INSTRUMENTATION AND SOFTWARE

NOTE

This manual is intended to provide an overview of the structure and organization of the HFIR Thermography Program; specific concerns regarding thermography equipment should be addressed by referring to the applicable user's manual.

SOFTWARE

Thermonitor 95 is a windows-based image processing software package designed to support periodic thermographic monitoring. Produced by Inframetrics, Inc., Thermonitor 95 provides both analytical and programmatic support for the HFIR Thermography Program.

HARDWARE

An Inframetrics Model PM290 thermographic camera is used to collect infrared images of selected plant components at established intervals.

COMPONENTS MONITORED

The components selected for routine monitoring are classified as either safety-related or non-safety related.

DATA COLLECTION AND ANALYSIS

Considerations for the proper collection of thermographic images are many; only those personnel trained on the principles of thermography and image processing should be involved. Once the data have been collected, they are downloaded to the Thermonitor 95 database. The analysis of thermographic data is concerned with the identification of thermal anomalies. Any areas that exhibit significant temperature differences should be noted and examined further.

RECORDS

THERMOGRAPHIC IMAGES

All thermographic images will be backed up biannually. The files will be stored in the HFIR thermography office.

USER'S MANUALS

Manuals associated with all HFIR thermography equipment will be maintained in the HFIR Thermography Program office.

Attachment 4: Tribology

SCOPE

The following sections describe the organization and operations of the HFIR Tribology Program.

COMPONENTS MONITORED

The components selected for routine monitoring are classified as either safety-related or non-safety related.

SAMPLE COLLECTION AND ANALYSIS

All lubricating oil analysis is performed by outside contractors. HFIR personnel are responsible for the following:

1. Collection of sample in accordance with applicable HFIR procedures
2. Collection of samples in accordance with the guidelines established by the outside laboratory
3. Storage and shipment of samples in accordance with the guidelines established by the outside laboratory
4. Review and storage of the analysis results
5. Determination of the most effective monitoring frequency

The sample is tested for the following attributes:

1. Viscosity-a measure of a lubricant's flow rate at certain temperatures (40°C and 100°C).
2. Viscosity Index-a measure of a lubricant's resistance to thinning with increases in temperature.
3. Contamination-a measure of the amount and size of particulate matter entrained in a lubricant sample.
4. Additives-a measure of the content of additives in a lubricant sample. Additives are chemical compounds used to enhance the performance of a lubricant.
5. Wear Metals-a measure of the amount of wear metals in a lubricant sample.
6. Oil Condition-a measure of the amount of water and the degree of oxidation and nitration in a lubricant sample.

RECORDS

ANALYSIS RESULTS

All analysis results will be stored on file in the HFIR PdM office.

Attachment 5: Motor Current Signature Analysis

SCOPE

The following sections describe the organization and operations of the HFIR Motor Current and Signature Analysis (MCSA) Program.

EQUIPMENT

The data is collected using a CSI AC Current Probe Model 341B and an Astromed Dash 10 High Speed Recorder.

COMPONENTS MONITORED

Motor current data is routinely collected from Limatorque electric actuators on primary and secondary system isolation valves to heat exchangers HX-1A, 1B, 1C, and 1D. All of the monitored components are classified as non-safety related.

DATA COLLECTION AND ANALYSIS

Collection of motor current data is to be performed in accordance with ORNL-RRD-PMI-4.2, "Maintenance Instruction for Current Signature Analysis Data Gathering for Limatorque Electric Actuators".

RECORDS

ANALYSIS RESULTS

All analysis results will be stored on file in the Bldg. 7910 File Room.

VITA

Scott Brame was born in Mayfield, Kentucky on July 28, 1969. He attended Mayfield City Schools, graduating from Mayfield High School in 1987. He spent three years at Murray State University in Murray, Kentucky before enrolling at the University of Tennessee, Knoxville January of 1994. After receiving a Bachelor's degree in Nuclear Engineering May of 1998 he accepted a position as a graduate research assistant in the Nuclear Engineering department. The Master of Science degree in Nuclear Engineering was received in December of 1999.

Recently married to the girl next door, he is currently pursuing a Doctor of Philosophy degree in Nuclear Engineering at the University of Tennessee. His current research is focused on the application of Bayesian statistical techniques to radiation dosimetry