IMTS (Intelligent Monitoring And Trending System)
A PC-Based Monitoring, Evaluation And Trending System
For Rotating Machinery

by

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A PC-Based Monitoring, Evaluation And Trending System For Rotating Machinery

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(Abstract)

Analysis of rotating machinery requires the collection and evaluation of large quantities of data. For just one machine, the amount of data may become so overwhelmingly great that a thorough examination of all the data is rendered impractical. **IMTS** (Intelligent Monitoring And Trending System) is a data acquisition system that has been developed to help resolve this problem. **IMTS** is a pc based system which can collect data that is relevant to diagnostic considerations, perform an evaluation by filtering the data through special standards and store the results for later review. The system is flexible because the data is evaluated by user defined, multi-level references called standards. **IMTS** operates in the Microsoft Windows 3.0 operating system, which has the advantage of multitasking two or more programs and thereby allows the data to be collected, evaluated and displayed simultaneously. This means that the user does not experience any temporary periods of system inaccessibility as would be the case in a sequential operating system, such as DOS. This thesis discusses the development of **IMTS** and explains the capabilities of the current system configuration and gives examples of the monitor screen options and trend plotting capabilities.

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1.0 Introduction

Industries that use rotating machinery such as turbines, compressors, fans and pumps often rely on plant engineers or technicians to manually collect and compile large quantities of data (most often vibration data) and then return an evaluation on the performance of the machine. The quality and speed of the evaluation is often compromised due to the voluminous amounts of data and the tedious nature of the task.

A machine's vibration readings may be taken from the bearing caps or directly from the rotating shaft. Although it is easier to acquire data from a bearing cap, it is less reliable as an indicator of the shaft's true vibration. This is due to the fact that the vibration is not always completely transmitted to the bearing cap.

Bearing cap readings are taken with velocity or acceleration transducers that are mounted directly on the bearing cap. Some of the these transducers are portable and require the operator to hold the transducer in place while acquiring data while others use magnetic attraction between the transducer and the bearing cap to keep it in place.

One of the traditional methods of acquiring vibration data directly from the shaft involved the use instruments such as the IRD velocity shaft rider. This device required the user to insert a wooden dowel through an access hole in the bearing cap. The wooden dowel, when completely inserted, rested on the rotating shaft. The vibration of the shaft, which was transmitted through the dowel, was sensed by the IRD velocity transducer which rested on the exposed end of the wooden dowel.

Vibration data from critical path machinery is usually obtained from direct shaft readings. Due to the vital role these machines play in the process of which it is a part, the more accurate shaft readings are opted for over the less reliable bearing cap readings. These shafts readings

are usually obtained from eddy current probes (also called non contact probes) that are permanently mounted on the machine.

Except for the fixed eddy current probes, the other types of transducers are portable, hand held instruments. The collection of data from a variety of locations is accomplished by having the operator physically move the transducer to the points of interest. The more sophisticated instruments are capable of storing the results, which can later be uploaded to a personal computer (pc).

Nevertheless, all of these portable instruments have problems. First, the acquisition of voluminous amounts of data is rarely performed by plant engineers or technicians using these devices due to the long time required in physically moving the instruments from one location to another. Second, because these transducers are not fixed, there is no guarantee that data is consistently collected from the same point every time. Therefore, it is difficult to draw conclusions by comparing previously collected data to current data for a given point. Furthermore, it is not feasible to have an operator continuously collect data. Instead, data can only be collected sporadically, which results in large time gaps in the historical data record. All of these problems preclude the utilization of these devices for large data acquisition tasks.

This inability to process large quantities of data coupled with limited means of data retrieval, means that trending is difficult if not impossible. Trending a rotating machine calls for the storage and retrieval of the collected data and related information in a manner that provides a clear historical perspective of the machines operation.

Plant control rooms contain data acquisition systems that are much more sophisticated than the hand held devices. The control room receives a multitude of data from fixed probes such as the eddy current probe, that describe the conditions of a variety of machines in the plant. The

control room also has limited ability to maintain this data on storage devices such as strip chart recorders. Furthermore, control rooms monitor operations by sounding alarms (annunciators) if the data collected exceeds an alarm value. Nevertheless, only very large operations such as power plants can justify the cost of obtaining the capabilities found inside a control room. In fact, for smaller data collection tasks, power plant engineers and technicians resort to the simpler hand held devices.

Despite its ability to determine alarm conditions, the control rooms are not capable of making more subtle judgements on data. A system capable of performing a more subtle evaluation requires the ability to distinguish between different operating conditions such as warning, unsatisfactory and satisfactory.

Expert systems possess yet a different type of judgement capability. An expert system will determine the most probable cause of the problem associated with the machine and then suggest the most effective solutions. Unfortunately, the majority of expert systems lack flexibility. A flexible system, for the purposes of this discussion, is defined as one which is applicable to more than one class or design of machine. Hegner et al., for example, developed a condition based maintenance system for shipboard high pressure air compressors [1]. This expert system was developed for a specific air compressor design and cannot be applied to other rotating machinery operating in different environments such as a steam turbine in a power plant. Most expert systems also require an operator to manually input any data it may need in order to diagnose problems. Ideally, this data collection and input should be automated.

Although all of the aforementioned devices or systems, i.e., portable instrumentation, control room instrumentation and current expert systems, are capable of performing certain tasks well, they do not perform all of them. Specifically, these tasks include (1) data collection, (2)

data trending, (3) monitoring and (4) evaluation of the performance of any class or design of turbine, compressor, fan or pump.

In an effort to overcome the deficiencies of traditional data acquisition systems, the VPI & SU Rotordynamics Lab has developed a system called **IMTS** that can better perform all of these tasks.

IMTS can be operated independently or in conjunction with a rotating machinery diagnostic expert system. As an independent system, **IMTS** performs the four tasks outlined above. When operating with the expert system, the capabilities are furthered expanded by providing diagnostic information and solutions to problems related to rotating machinery.

This thesis discusses operation of **IMTS**. Specifically, this thesis addresses the following topics: (1) development of **IMTS** in the Windows 3.0 multitasking environment, (2) software issues and problems that were encountered in developing **IMTS**, (3) hardware that comprises **IMTS**, (4) output produced by **IMTS** and (5) the plans for integration of **IMTS** with the expert system.

2.0 General Description

The following general description of **IMTS** gives a brief overview of the data acquisition system capability and will be valuable in facilitating comprehension of the more detailed discussions in later sections of this thesis. Vibration, temperature, and any other type of analog signal from a rotating machine can be collected by transducers mounted at appropriate monitoring locations. Appendix A discusses possible monitoring locations for a variety of rotating machinery.

All of the raw signals produced by the transducers are first received by a remotely controlled signal processing and multiplexing station. Temperature, flow and pressure signals are processed at this remote site and then directly passed to the pc which is located at a central control location. Vibration signals are only multiplexed at this remote site and then sent to signal processing instrumentation that is situated nearby the pc. After being processed, the vibration data is passed to the pc. Figure 1 shows a schematic diagram that describes **IMTS**.

The end result of processing these signals is data of rotordynamic significance. Specifically, the data obtained relate to the following rotordynamic parameters: speed, temperature, flow rate, phase, gap voltage, and the frequency composition of the vibration.

Given these parameters, a rotordynamic evaluation of rotating machinery is made possible by implementing standards. Refer to Appendix B for a discussion of what a rotordynamic evaluation entails. A standard is a data file containing reference values that define varying operational states for rotating machinery such as "excellent", "good", "fair", "poor", and "alarm". An important features of the standard is that they are produced by the user for his particular application which means that the user is not limited to evaluating only a specific class or design of

VIBRATION, TEMPERATURE, FLOW SIGNALS
FROM MACHINERY

↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓

REMOTE LOCATION:
1) MULTIPLEXING
2) TEMPERATURE PROCESSING
3) ANALOG TO DIGITAL CONVERSIONS
   (FLOWS, PRESSURES)

PROCESSED TEMPERATURE
AND FLOW DATA

MULIPLEXED VIBRATION
SIGNALS

PC

VIBRATION SIGNAL
PROCESSING

PROCESSED VIBRATION DATA
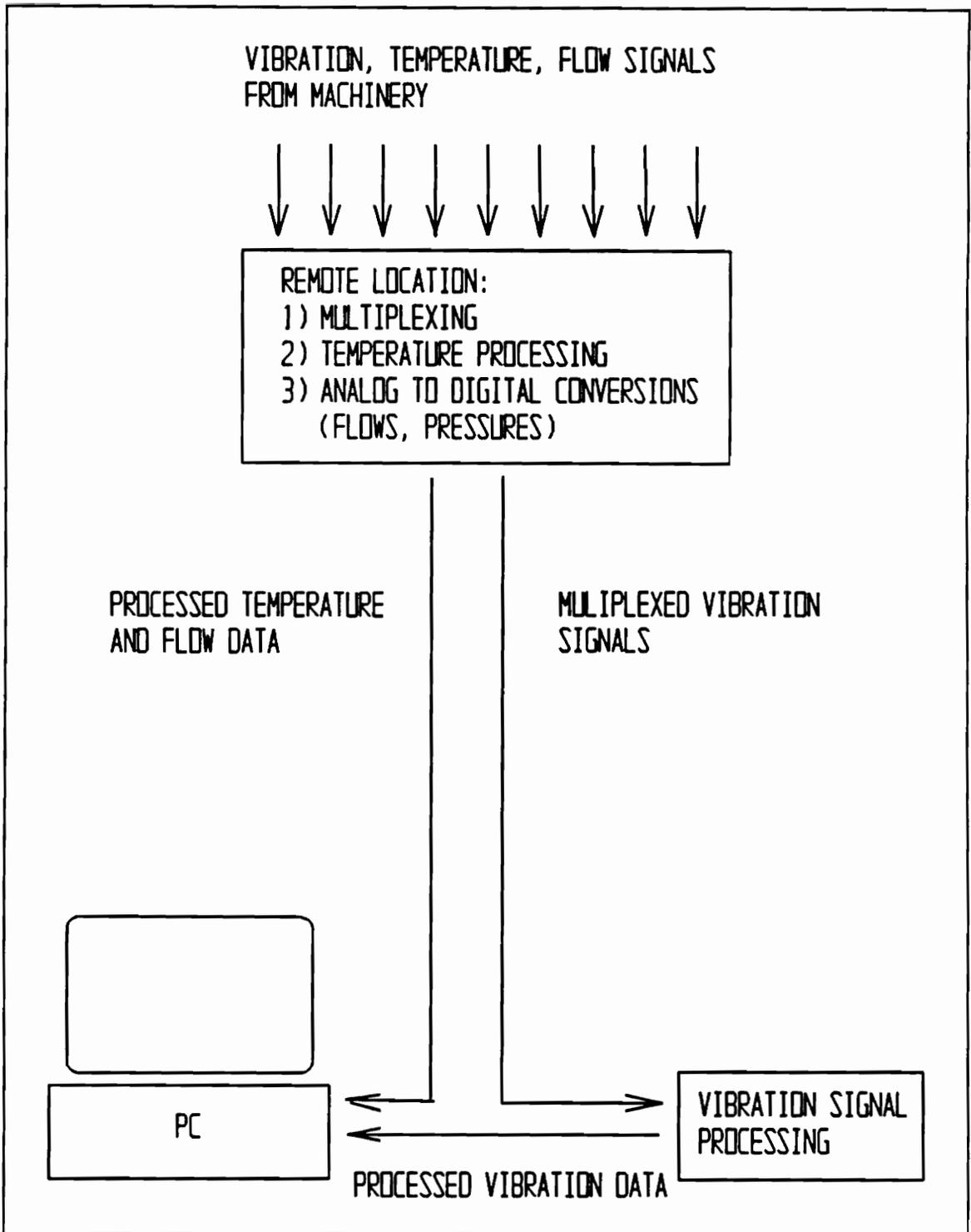
Figure 1   IMTS General Description

rotating machine. Appendix C contains a more detailed explanation of standards and how they are produced. Once the data is collected, evaluated and stored, the results may be selectively displayed upon request from the user.

The Diagnostic Rotating Machinery Expert System will soon have the capability to access the data and evaluations that have been stored. This would allow the expert system to have automatic access to information that would otherwise require an operator to manually input at the keyboard.

Seven programs were written to control the operations of IMTS. These operations involved control of the instrumentation, comparing acquired data to a standard's reference value (i.e., conducting a rotordynamic evaluation) and storing and displaying the results. The software operates in the Windows 3.0 multitasking environment which results in faster operation and essentially uninterrupted access to the system by the operator.

3.0 Windows

Windows, like DOS (Disk Operating System), is an operating system produced by the Microsoft Corporation for the IBM compatible pc. An operating system is a translator which allows communication between the user and the computer, the disk drives, and the printers. However, unlike DOS, Windows takes full advantage of the 80386 and 80486 memory management and manipulation capabilities. One of the most useful and powerful features of Windows is multitasking.

Implementation of multitasking is critical because it allows for the simultaneous operation of the seven programs that control all **IMTS** operations: data acquisition, data evaluation and data display. By allowing these programs to run simultaneously, the overall performance of **IMTS** is improved in terms of speed and user interaction.

The following sections deal with (1) the operating modes of Windows 3.0, (2) a detailed explanation of multitasking, (3) the capabilities and deficiencies of applications designed specifically for Windows 3.0 compared to DOS applications running in Windows 3.0 and (4) the seven computer programs that comprise **IMTS** software.

3.1 Operating Modes For Windows

Windows 3.0 can operate in three modes: real, standard, or 386 enhanced. Real mode will force an 80286, 80386, or 80486 processor to simulate the operation of an 8086 or 8088 processor. Operating Windows 3.0 in this mode permits access to only conventional memory (0 KB – 640 KB), regardless of the presence of expanded (EMS) or extended (XMS) memory which is memory above the 0 KB – 640 KB range. This restriction to memory

access means that fewer programs can be loaded and operated in a multitasking capacity. Another limitation to the real mode is that the limited multitasking which is available, applies only to Windows applications; applications created in the DOS environment are incapable of multitasking in the real mode.

Standard mode is an improvement over real mode because it permits access to extended memory thus permitting larger and more applications to multitask. It runs only on 80286 processors or better (80386 or 80486); the 8086 and 8088 processors cannot support this mode. However, like the real mode, the standard mode will not support DOS applications in a multitasking capacity.

Fortunately, DOS applications can multitask if running Windows 3.0 in the 386 enhanced mode. Like the standard mode, the enhanced mode has access to conventional and extended memory. Multitasking a DOS application in 386 enhanced mode is based on a principle called virtual machines. Windows 3.0 allocates a separate section of extended memory to each DOS application that is multitasking. Each of these sections of memory contain a copy of the operating system and device drivers thus simulating an 8086 machine (virtual machine) for each application. In effect, the 386 enhanced mode allows several computers with the 8086 processor to operate from a single 80386 or 80486 cpu (central processing unit).

The 386 enhanced mode also contains a useful feature that permits the assignment of how much time the processor devotes to each application relative to all other applications.

3.2 Multitasking

IMTS runs in the Windows 3.0 multitasking 386 enhanced computer operating system. This system was selected due to its multitasking capabilities which allow several programs to share time on the computer's processor thus running simultaneously. This type of sharing is done by allotting each program a small amount of time on the computer's cpu. When a program's turn using the cpu is over, another program begins operating. These turns are short enough so that the human user barely notices that the cpu is being shared. Multitasking is advantageous because while some programs, such as the acquisition programs, take a significant amounts of time in sampling data or allowing the data to reach its steady state value, the display or evaluation modules are performing their tasks. This results in faster operation.

In a nonmultitasking system such as the Disk Operating System (DOS), programs must be executed sequentially. They all share the processor, but a program will relinquish its control of the processor only after it is done performing its entire task. For example, the program that acquires data must wait until the evaluation programs and display program release control of the computer's cpu before it can acquire a new set of data. Not only do sequential operations slow down overall execution time, but the quality of the user interface would deteriorate drastically as well. This deterioration is characterized by periods in which the user interface effectively ceases to exist while another program is operating.

3.3 Windows and DOS Windows

Windows 3.0 has the capability of running programs, referred to in Windows 3.0 as *an application*, in a *true window* or a *DOS window* environment. A *true window* environment can support Dynamic Data Links (DDL) and allows a given window to initiate the execution of another window by employing a feature called Event Triggered Execution (ETE). As applied to IMTS, DDL is the method by which the data acquisition programs send data to the data evaluation programs and then, to the program that displays and logs the evaluated data. ETE is the technique in which the evaluation program is triggered to begin execution after the data has been acquired by the acquisition program. The development of these programs requires compilers that will compile the source code to run in this *true windows* environment; Microsoft Corporation makes a BASIC compiler called VISUAL BASIC that will do it. Unfortunately, the libraries containing the subroutines and functions that are used to control the instrumentation interface, namely the IEEE-488 for the Bently Nevada Digital Vector Filter-3 and the Rapid Systems Digital Signal Processor interface, cannot be integrated into the user developed code produced by VISUAL BASIC.

VISUAL BASIC will only support Dynamic Link Libraries (DLL) which are another characteristic of the *true windows* environment. A DLL differs from traditional libraries in that a DLL does not link the source code with every library function and subroutine. Instead, when a program written in VISUAL BASIC attempts to call a library function or subroutine, only that function or subroutine is loaded into memory. It remains loaded for as long as the user defined code requires it and is removed from memory after the user defined code is finished with it.

Hewlett Packard Corporation is currently testing a DLL for the IEEE-488 interface and it is scheduled for release in the winter of 1992.

Rapid Systems, on the other hand, has no current plans for developing a DLL for their signal processor. Given the lack of a DLL for the two interfaces required, an alternative had to be found. The *DOS windows* is that alternative. It will allow links between user created programs and the traditional libraries to run in the multitasking mode, but at a cost. *DOS windows* cannot support DDE and ETE which means that another method for data exchange and program triggering must be implemented. This method will be discussed in the Software Development section of this thesis.

3.4 Modules

The software that runs **IMTS** is organized according to the specific task it performs. Software that performs a specific task is called a module and operates independently of all other modules. These specific tasks are: control, data collection, data evaluation, data display and storage.

The **Control Module** opens and closes the relays that allow passage of vibration signals to the DVF-3 (Digital Vector Filter) and the FFT DSP (Fast Fourier Transform Digital Signal Processor). Because the processing times for these instruments may vary, the **Control Module** must keep these relays open long enough to insure that signals are completely processed by all instrumentation. This responsibility also requires that the **Control Module** coordinate the operation of all acquisition modules. Coordination insures that an acquisition module will acquire all of the data passed through the relays.

Acquisition modules exist for vibration data obtained from the DVF-3, for spectrum data obtained from the DSP and for temperature and flow/pressure data obtained from the thermocouple board and analog to

digital convertor board respectively. The **DVF Acquisition Module** retrieves data from the DVF-3 and stores the data in a file. Similarly, the **FFT Spectrum Acquisition Module** retrieves data from the DSP and the **Temperature / AD Acquisition Module** retrieves data from the thermocouple and AD boards and stores the data in files to be read by their respective evaluation modules. The temperature and AD evaluation are paired up due to software and system considerations that are explained in the Software Development section.

Evaluation modules, as their names imply, evaluate and judge the acquired data based on the user defined standards. Despite the necessity of three acquisition modules, one finds only two evaluation modules in the final programs. One of the evaluation modules performs a double duty; it evaluates data from the **DVF Acquisition Module** and **Temperature / AD Acquisition Module**. This evaluation module is called the **DVF-Temp-AD Evaluation Module**. The justification for having the **DVF-Temp-AD Evaluation Module** performing a double duty is similar to the reason the **Temperature / AD Acquisition Module** acquires two types of data and is explained in the **Software Development and Related Issues** section of this thesis. The **Display And Storage Module** presents the data and the corresponding evaluations in a variety of intelligent formats. It displays the data on the monitor and stores the data so that it may be trended and retrieved at a latter time. In addition, the **Display And Storage Module** is the user interface. It provides the user with the ability to display desired data and to control the systems operation such as resetting a standard, triggering the acquisition of spectrum data, or logging data in a log file.

4.0 Software Development and Related Issues

Turbo Pascal (ver 4.0) [2], Microsoft Quick Basic (ver 4.5) [3] and PDC Prolog (ver 3.1) [4] are the languages used to program all of the software that comprise **IMTS**. The **Display And Storage Module** was written in Turbo Pascal. Turbo Pascal is better oriented to the graphic displays as compared to other languages such as BASIC. Turbo Pascal has relatively simple graphics instructions and carries an abundance of predefined graphic subroutines. The **DVF-Temp-AD Module** was written in PDC Prolog so as to take advantage of Prolog's ability to quickly and easily manipulate large quantities of data. All other modules require little data manipulation and no graphic displays thus making them ideally suited for BASIC; a simple language universally understood by most programmers.

4.1 Continuous Loop

IMTS operates indefinitely or until directed to stop by the operator. To achieve this, all modules must be able to return to the beginning of their code once they reach the ends of their respective codes. Several looping or repeating control structures found in BASIC, Pascal and Prolog satisfy this requirement. Table I shows the looping structures available for each language.

Table I

Loop Control Structures For IMTS Languages	
Language	**Control Structure**
BASIC	While .. Do For .. Next Do .. Until Goto

Pascal	While .. Do
	For .. Do
	Repeat .. Until

Prolog	Backtracking Selected Use Of Cuts

4.2 Communications Between Modules

Although each module runs independently of other modules, a given
module requires inputs from other modules to create outputs. For example,
the **FFT-Evaluation Module** will not produce its output containing spectrum
data and the corresponding evaluations unless the unevaluated spectrum
data is read in as an output from the **FFT Acquisition Module**. If inputs
are not available, then the module waits until they become available.

Data is passed between modules by way of data files. When module **A**
finishes processing data, it creates a file containing all of the results
of the process and necessary information for use by module **B**. This file
is then duplicated, but the new copy is given a different name. The new
name is one recognized only by module **B**. This duplication step prevents
sharing conflicts that arise in Windows 3.0 when two or more multitasking
programs attempt to access the same file at the same time.

Programming languages may provide several methods to accomplish the
required duplication, but one should be cautious. It was discovered in
development that the **DVF-Temp-AD Module**, which was written in Prolog,
performs the duplication process in two distinct steps. It first creates
an empty file under the new name, and then transfers data from the old
file to the new file. In between the two steps, a new file exists, but
contains no data. The time between these two steps permits the **Display
and Storage Module** to successfully open the file. However, because only
the first step of the two step procedure has been completed, the **Display
And Storage Module** will not find any data to read. The solution was the
implementation of a one-step renaming procedure in which the old data file
is simply given a new name. Figures 2a and 2b illustrate the differences
between the two methods.

If module **B**, shown in Fig. 3, attempts to access a file that does

1. Transfer evaluated data from DVF-TEMP-AD EVALUATION
   module to a file named "EVL.PLG"
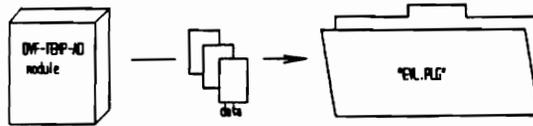
2. Create a file named "EVL.DSP" that will later
   contain evaluated data from "EVL.PLG"
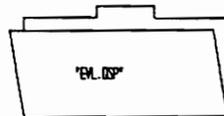
3. DISPLAY AND STORAGE module attempts to read
   data from "EVL.DSP". This file is empty !

Figure 2a. Copying Files
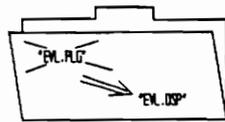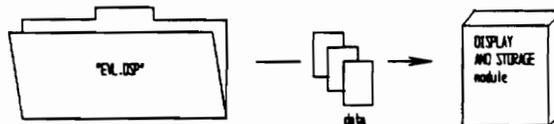
Figure 2b.   Renaming Files
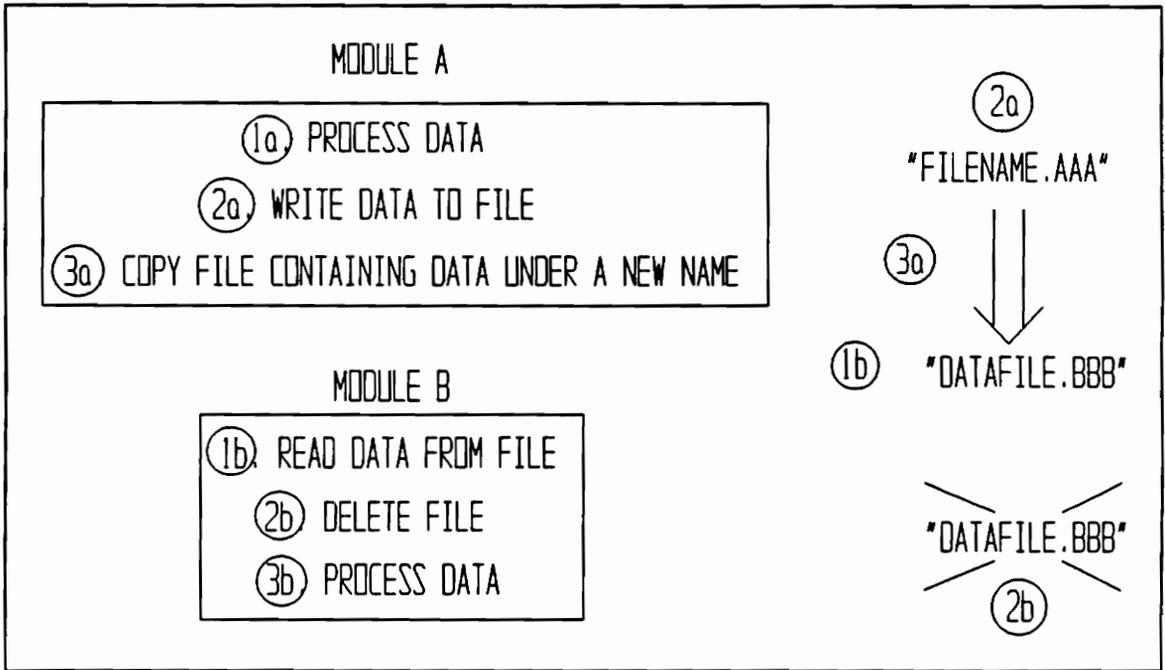
Figure 3   Communication Between Two Modules

not yet exist, an error code may be produced depending on the programming language. Error code 53 in QuickBasic and error code 2 in Turbo Pascal indicate that an I/O (input/output) attempt, such as opening a file for input, was made on a nonexistent file. If this error code is generated, then the program is designed to continue the I/O attempt until error code 0 is obtained indicating a successful I/O attempt (successfully opened the file) for both Turbo Pascal and QuickBasic. Once an error code 0 is obtained, module **B** reads the contents of the newly created data file, deletes it when done reading, and then processes the data. If module **B** were written in Prolog, then error messages would not apply. Prolog, unlike QuickBasic and Pascal, have a function designed to check for the existence of a data file.

The module that creates the data file, **A**, must also perform file operations to insure proper communications between modules. If the attempt to duplicate a file produces error code 58 in QuickBasic, it is an indication that a file with this name already exists. This file should be deleted after being read by module **B** thus allowing module **A** to create a more recent file with the same name. Again, these error messages are only applicable to modules written in QuickBasic and Pascal.

Figure 3 illustrates the communication process between two modules. In step 1a, module **A** may perform a processes on the data such as the evaluation of data. When the process is complete, the results are transferred to a temporary data file named "FILENAME.AAA" as shown in step 2a. This is the first step necessary in transferring data from module **A** to module **B**. Step 3a renames "FILENAME.AAA" as "FILENAME.BBB". At this point, module **B** recognizes the name "FILENAME.BBB" and reads its contents as shown in step 1b. Step 2b requires that when all of the data is read from "FILENAME.BBB", it is deleted. At this point the transfer of data is complete and module **B** can display the data as shown in step 3b.

4.3 Combining Acquisition and Evaluation Modules

In the prototype designs, **IMTS** was comprised of modules that performed distinct tasks – more distinct than they currently perform. As more modules were introduced to perform a greater variety of tasks, the complexity of **IMTS** grew because more communications between the modules were required. This growth not only increased the complexity of **IMTS**, but also became limited by the pc's RAM memory. Given these two factors, an effort was made to collapse several modules into a more general module, thereby reducing the system complexity and the strain on computer RAM memory.

Two peculiar results of these consolidations are the **Temp-AD Acquisition Module** and **DVF-Temp-AD Evaluation Module**. They both seem to perform more than one specific task especially if compared to the other modules in **IMTS**. This may be true, but the benefits are worth it. Temperature and AD data are both obtained from the Metrabyte system via the RS-232 interface. Instead of transferring control of the RS-232 to a temperature acquisition module and then to an AD acquisition module, one module performs both tasks. The result is a reduction in memory requirements and in the need for more memory. These results are also achieved by consolidating evaluation modules for DVF data, temperature data and AD data.

4.4 Protecting IEEE-488 Address

The IEEE-488 allows data transfer between the DVF-3 to the software which manipulates the data. The pc's main processor routes the data to the **DVF Acquisition Module** via memory. At a specific location in upper memory, DC00-E000 HEX, the data from the DVF-3 is stored for retrieval by the **DVF Acquisition Module**. If this location is not protected, Windows 3.0 will use this location and thus destroy the contents of this memory area. The result will either be the entire system locks up or only the **DVF Acquisition Module** will stop running. To prevent this from occurring, the user protects this location in the *config.sys* file by declaring the following statement:

EMM386 NOEMS X=DC00-E000

Exactly what this command means will be explained in the **System Configuration** section of this thesis.

4.5 System Configuration

When starting **IMTS** by resetting or turning on the computer, the computer reads the **CONFIG.SYS** file (see Appendix - A for listing of the **CONFIG.SYS** file). This file contains commands that load installable drivers and reserve space in system memory for information processing. An installable driver is the instruction set that allows the computer to interact with peripheral hardware such as a Bernoulli Drive and mouse. Furthermore, these device drivers also allow access to upper, expanded, and extended memory if available. Despite the variety of commands that one may find in the **CONFIG.SYS** file, this thesis explains only those

command lines that of particular interest to the operation of **IMTS** as
listed below:

      [A]   **DEVICE=C:DOS HIMEM.SYS**

      [B]   **DEVICE=C:DOS EMM386.EXE NOEMS X=DC00-E000**

      [C]   **DOS=HIGH**

      [D]   **DEVICE=C:DOS RAMDRIVE.SYS 1024/E**

Line [A] loads the memory manager that permits Windows 3.0 to gain
access to extended memory. Without this command, Windows 3.0 could not
function in 386 enhanced mode because this mode requires at least 1024 KB
of extended memory. Line [B] loads another type of memory manager which
actually performs two functions. The *EMM386* command is the expanded
memory manager for those applications requiring expanded memory. However,
none of the programs found in **IMTS** require expanded memory. Instead,
EMM386's second function is utilized which permits access to the upper
memory block. By gaining access to the upper memory block, it is possible
to protect vital memory locations from being corrupted by routine Windows
3.0 operations. The memory area DC00 - E000 is protected. Line [C] loads
a portion of DOS into high memory which permits more space in conventional
memory for DOS applications. Line [D] creates a ramdrive. A ramdrive is
identical to a disk or hard drive with the exception that it exists in
RAM. Since a ramdrive exists in memory, I/O (Input and Output) to
ramdrives are much faster than I/O to a traditional floppy or hard disks
which requires the physical movement of a reading head to specific
locations of the storage medium.

4.6 PIF Files

PIF stands for [P]rogram [I]nformation [F]ile. It is used by Windows 3.0 to determine where the application is located, establish a DOS application's memory requirements and the amount of time the application has on the computer's processor relative to other applications. There are two pages in the PIF file editor as shown in Figs. 4a and 4b.

On the first page (standard), the *KB Required* value refers to the size of the virtual machine that is created by Windows 3.0 enhanced mode for that particular application. The *Background* and *Exclusive* switches determine whether other programs can operate while this particular application operates. All applications in IMTS operate in the *Background* mode which permits multitasking. The *Full Screen* switch is selected only for the Display and Control Module which means that it is the only application that appears on the monitor. All other applications, while not visible on the monitor, are running in the background.

The second page of the PIF file editor (advanced) contains information related to the particular application's priority on the computer's processor relative to other applications. If an application is running in the foreground, then the *Foreground Priority* is used to determine what proportion of the processor time it receives relative to the sum of all other applications' *Background Priority* values. For example, the Display And Control Module may operate with a *Foreground Priority* value of 150 while all other application have a combined *Background Priority* value of 850. This means that 15% [150/(150+850)] of the processor's time is allocated to the Display And Control Module.

```
┌──────────────────────────────────────────────────────────────┐
│ ▬    PIF Editor - SWCONT4.PIF                           ▼│▲   │
├──────────────────────────────────────────────────────────────┤
│ File   Mode   Help                                           │
│                                                              │
│  Program Filename:    ┌─────────────────────────────────┐   │
│                       │ SWCONT4.EXE                     │   │
│                       └─────────────────────────────────┘   │
│  Window Title:        ┌─────────────────────────────────┐   │
│                       │ swcont4                         │   │
│                       └─────────────────────────────────┘   │
│  Optional Parameters: ┌─────────────────────────────────┐   │
│                       │                                 │   │
│                       └─────────────────────────────────┘   │
│  Start-up Directory:  ┌─────────────────────────────────┐   │
│                       │                                 │   │
│                       └─────────────────────────────────┘   │
│  Memory Requirements:   KB Required │0│   KB Desired │640│   │
│                                                              │
│  Display Usage:  ○ Full Screen     Execution:  ⊠ Background  │
│                  ◉ Windowed                     □ Exclusive  │
│  ⊠ Close Window on Exit          ┌──────────────┐           │
│                                  │ Advanced...  │           │
│                                  └──────────────┘           │
└──────────────────────────────────────────────────────────────┘
```
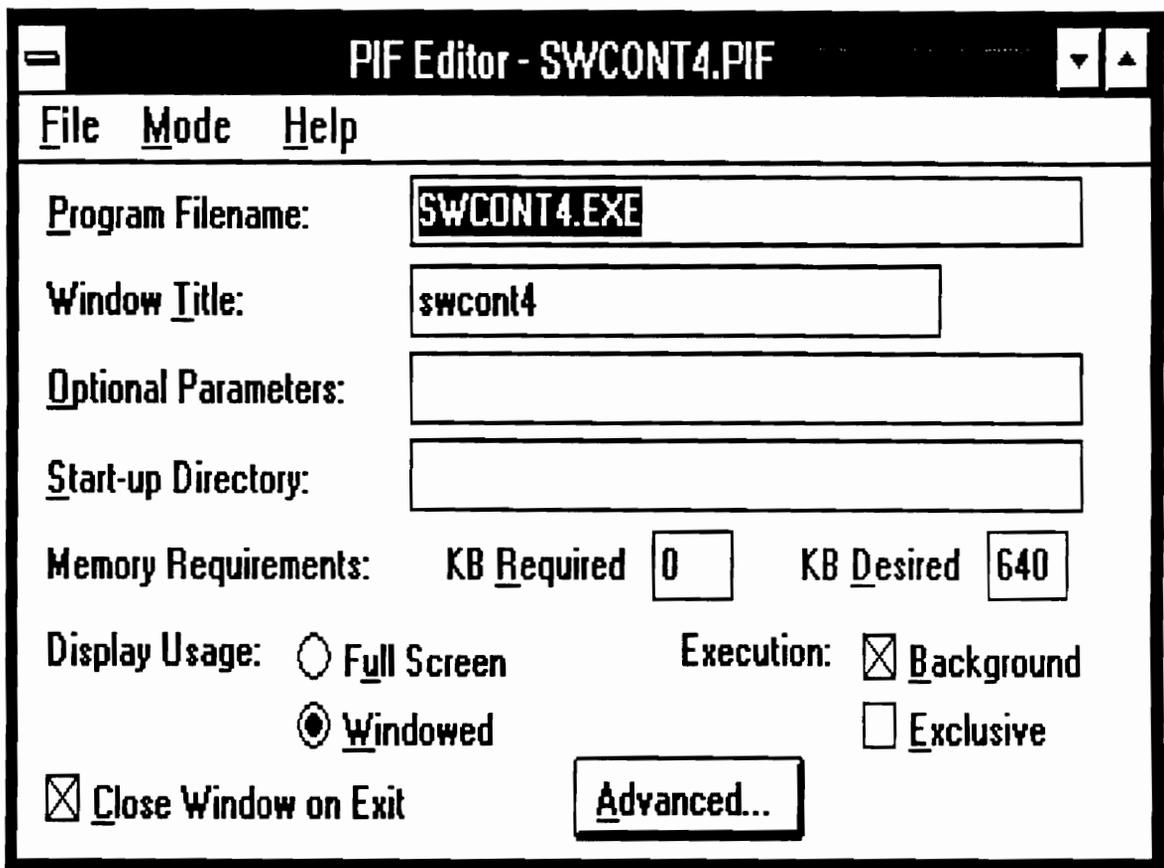
Figure 4a   Standard PIF Files Editor

```
┌─────────────────────────────────────────────────────────────────────┐
│ ▬                        Advanced Options                            │
├─────────────────────────────────────────────────────────────────────┤
│ ┌─Multitasking Options──────────────────────────────┐  ┌──────────┐ │
│ │ Background Priority:   │50    │  Foreground Priority: │100   │     │  OK    │ │
│ │                 ☒ Detect Idle Time                │  └──────────┘ │
│ └───────────────────────────────────────────────────┘  ┌──────────┐ │
│ ┌─Memory Options─────────────────────────────────────────│ Cancel  ││
│ │ EMS Memory:    KB Required  │0    │   KB Limit │1024  │ ☐ Locked ││
│ │ XMS Memory:    KB Required  │0    │   KB Limit │1024  │ ☐ Locked ││
│ │          ☒ Uses High Memory Area      ☐ Lock Application Memory   ││
│ └──────────────────────────────────────────────────────────────────┘│
│ ┌─Display Options────────────────────────────────────────────────────┐│
│ │ Video Memory:    ◉ Text    ○ Low Graphics    ○ High Graphics      ││
│ │ Monitor Ports:   ☐ Text    ☐ Low Graphics    ☒ High Graphics      ││
│ │          ☒ Emulate Text Mode      ☐ Retain Video Memory           ││
│ └──────────────────────────────────────────────────────────────────┘│
│ ┌─Other Options──────────────────────────────────────────────────────┐│
│ │ ☒ Allow Fast Paste                ☐ Allow Close When Active        ││
│ │ Reserve Shortcut Keys:  ☐ Alt+Tab  ☐ Alt+Esc   ☐ Ctrl+Esc         ││
│ │                         ☐ PrtSc    ☐ Alt+PrtSc ☐ Alt+Space        ││
│ │                         ☐ Alt+Enter                                ││
│ │ Application Shortcut Key:   │None                           │       ││
│ └──────────────────────────────────────────────────────────────────┘│
└─────────────────────────────────────────────────────────────────────┘
```

Figure 4b Advanced PIF Files Editor

5.0 Hardware

A basic discussion of the data acquisition system was given in Chapter 2. This chapter gives a more detailed description of the actual hardware employed in this particular project. A schematic if IMTS's hardware is given in Fig. 5. It includes a SWAN pc, a printer, two Bernoulli drives, the Rapid Systems FFT Spectrum Analyzer (also called digital signal processor - DSP), Bently Nevada's Digital Vector Filter-3 (DVF-3), Frequency Devices' 2 channel low pass filter and Metrabyte's 32 channel relay board (MEM-32), 20 channel thermocouple board (THERM-20), 16 channel AD converter board (MAI-16), the controller board (REM-64) and the power supply.

5.1 Personal Computer And Peripherals

The pc plays a central role in the operation of IMTS. It includes a Windows 3.0 supported VGA monitor with at least 640 pixel by 480 pixel resolution. In addition, other standard equipment such as a 25 pin connector (RS-232) or a 9 pin connector (RS-422) serial port and parallel port are required. The serial port is used to communicate with the Metrabyte system.

A printer is accessible via either a serial or parallel port, but the fastest method of transferring data to a printer is through a parallel port. Note that like the monitor, the printer must be supported by Windows 3.0.

The pc must have at least an 80386 processor to support the Windows 3.0's multitasking capabilities. IMTS currently runs on an 80486 processor with a clock rate of 33MHz. Under this processor, IMTS reacts
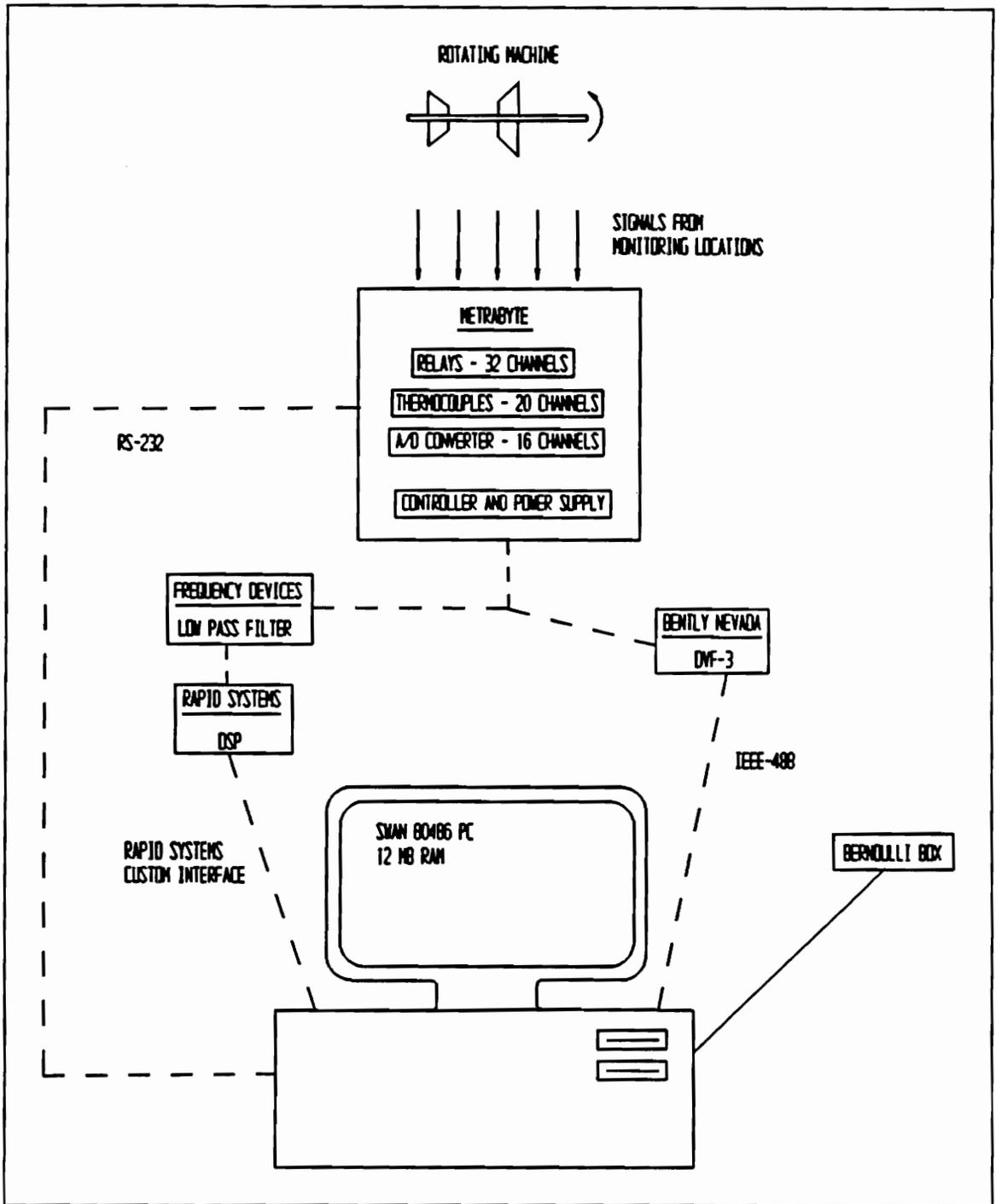
Figure 5 Hardware

quickly to user commands and updates to the screen are seemingly instantaneous. Previous versions of **IMTS** ran on an 80386 processor with a clock rate of 20 MHz and were noticeably sluggish. This sluggishness was characterized by long reaction times to user commands and updates to the screen were painstakingly slow.

The minimum memory requirements to operate Windows 3.0 in the 386 enhanced mode is 2 Megabytes. However, given the memory requirements of the code for each of **IMTS**'s seven modules, 12 Megabytes of extended memory are necessary.

A hard disk is needed to store the Windows 3.0 execution code. Also **IMTS** uses the hard disk to store historical data before it is periodically transferred to the Bernoulli drive. Because the size of these data files can grow quickly, a hard disk with a high storage capacity (60 Megabytes) is recommended so as to avoid frequent transfers of data to the Bernoulli drive.

Should the hard drive be too full to store more data, two 20 Megabyte Bernoulli drives are used to handle the overflow data. In addition, the Bernoulli drives back up data on the hard drive to prevent the loss of data in the event of a hard disk failure.

An IEEE-488 interface card and a Rapid Systems interface card are required for communication with the DVF-3 and Rapid Systems DSP respectively. These cards rest in expansion slots inside the computer as do the serial and parallel interface cards, the graphics card, the Bernoulli Drive interface card, and the mouse interface card. Additional expansion slots may be desired for interface with additional printers or Bernoulli Drives.

5.2 Metrabyte Boards

The Metrabyte boards are the REM-64, MEM-32, MAI-16, THERM-20 and the power supply. Control of these boards from the pc occurs over the RS-232 or RS-424 serial communications line. The REM-64 is where the actual pc-Metrabyte interfacing occurs. The software that controls the Metrabyte boards are written in BASIC although Pascal or C may also be used. Commands issued from software operating in the pc are interpreted by the REM-64 which then performs the requested action on the desired Metrabyte board. A 50 conductor ribbon cable (bus) interfaces all of the Metrabyte boards to the REM-64. A set of DIP switches on the REM-64 allow the user to set RS-232 or RS-422 operation, Baud rates, parity and board address.

The MEM-32 is a 32 channel electro-mechanical relay board which multiplexes the signals from the vibration transducers to the DVF-3. Since the DVF-3 limits the entire system to processing two channels at once, the MEM-32 is used to pass only two signal to the DVF-3 and DSP at a time. Once the DVF-3 and DSP finish processing the two signals, the MEM-32 will allow passage of two new signals. The MEM-32 has mercury wetted contacts rated at 2 amps. Because of its wetted contact configuration, the MEM-32 must be mounted ± 30 degrees of vertical.

The THERM-20 is a thermocouple input board employing 20 input channels. Seven industry standard thermocouples (J, K, T, R, S, B, or E) are supported via DIP switch selections. Results may be reported in degrees Celsius or Fahrenheit. An on-board microcomputer calculates the temperature from the measured input voltage, applies Cold Junction Compensation and stores the results in 256 bytes of internal RAM. When allowed to collect data continuously, THERM 20's RAM is updated every 1.25 seconds.

The MAI-16 is a 16 channel, 8 or 12 bit analog to digital convertor.

DIP switches allow for gain settings of ± 10V, ± 5V, ± 2.5V or ± 1.25V. These gains can also be set via software. The MAI-16 may be used to monitor flow rates and pressures from measuring instruments that have analog output.

5.3 Digital Vector Filter - 3

The Digital Vector Filter (DVF-3) from Bently Nevada Corporation receives vibration signals on two channels from displacement transducers. It receives a
single once-per-revolution signal from a displacement probe, optical pickup, or other suitable transducer.

The DVF-3 computes the speed, overall amplitude, synchronous amplitude, gap volts (refer to Appendix B for an explanation of gap volts) and phase for each of the vibration signals. Processing time for all parameters is instantaneous except for gap volts. Computation of the gap voltage requires up to 15 seconds.

Calibration values and scaling units are selectable directly through the keys on the front panel of the DVF-3. The synchronous filter bandwidth of 12 RPM or 120 RPM is also selectable via the DVF-3's front panel. The DVF-3 supports the IEEE-488 interface which allows the transfer of data from the DVF-3 to the pc.

5.4 Rapid Systems DSP and AD Convertor, Frequency Devices Low Pass Filter

The Rapid Systems FFT Spectrum Analyzer (DSP) calculates a 1024 point fast fourier transform to determine the harmonic and subharmonic frequency content and associated amplitudes of vibration signals.

The DSP card inside the pc is connected to the AD convertor via a custom cable developed by Rapid Systems. The AD - DSP configuration can simultaneously process four channels of vibration signal inputs. However, only two signals are monitored simultaneously because of the limitation imposed by the DVF-3.

Gain and sampling rate settings for the AD convertor and DSP are controlled by software commands. **IMTS** permits the initial selection of gain and sampling rate values with the setup program. The sampling rate may also be adjusted during operation.

When selecting sample rates, one must be sure to adhere to the Nyquist sampling criteria which requires that sampling be performed at a rate that is at least twice the frequency of the signal of interest. Furthermore, application of a low pass filter to the vibration signal is required to prevent aliasing. The Frequency Devices two channel low pass filter acts as the anti-aliasing filter.

6.0 IMTS Operation

This section describes the operation of IMTS. In order to begin operation, the user must first establish all of the operating parameters by using the setup program. The next step requires the user to start all of the seven programs. Once IMTS is running, the user may select displays that show the results of data collection and evaluation. Furthermore, a discussion is provided on safety features that prevent the loss of data due to power outages and hardware failures.

6.1 Setup Program

The user operates the menu driven setup program prior to running IMTS. The setup program (1) establishes the active channels on the relay, thermocouple and AD boards, (2) assigns the active channels to a specific machine, (3) labels the active locations for identification purposes, (4) sets the initial sample rate and gain value for the Rapid Systems AD convertor, (5) sets the FFT acquisition frequency, (6) establishes logging frequency and (7) sets the DVF-3 settling time.

Establishment of active channels allows IMTS to keep track of which channels require attention and which channels can be ignored. The MEM-32 relay board can handle up to 28 vibration signals, however some applications may have fewer signals. In such instances, only the channels that have signals passing through them should be multiplexed. Multiplexing all channels at all times is unnecessary, would be time consuming, and thus is avoided by multiplexing only the channels that are active.

Active channels for the THERM 20 board are selected to determine

which of the 20 thermocouple inputs are actually connected to thermocouples. If only 2 thermocouples are connected, then there is no need to spend time processing the remaining 18 nonexistent input signals. Similarly, there is no need to process nonexistent inputs on the AD board.

In addition to selecting active channels, the user needs to match vibration signals with speed reference signals. This matching is necessary for the DVF-3 which requires a speed reference signal for the two input vibration signals. Without matching, the DVF-3 may process a given vibration signal with the incorrect speed reference signal. IMTS can support up to 4 speed reference signals. In displaying the results of the evaluations, there must be a method of identifying the different signals. Labelling requires the user to give descriptive names to the various active channels on the MEM-32 relay board, the THERM-20 thermocouple board and the MAI-16 AD convertor board. For example, channel 3 on the MEM-32 board may be labelled "BFP, BRG #1, x" which signifies that this channel contains vibration data from the x probe on the #1 bearing of the boiler feed pump.

Establishing the sample rate and gain for the Rapid Systems AD convertor is explained in greater detail in the chapter devoted to hardware. Note, however, that FFT acquisition frequency and FFT sample rate are not the same parameter. The FFT sample rate is a parameter used by the FFT processor's AD convertor to determine the number of samples taken per second - sample rates of 20 Hz up to 500 Hz are common. The FFT acquisition frequency is a time value that determines how often an FFT is performed - once every 10 minutes, 30 minutes, or hour are typical values.

Logging frequency refers to how often data is stored on a file. The DVF-3 settling time refers to the amount of time given to the DVF-3 to compute the gap volts of the vibration signal.

6.2 Start Up

After running the setup program, the operator must load the Windows 3.0 operating system. Once in Windows 3.0, a variety of icons will appear. These icons represents the different modules that comprise **IMTS**. To start a module, the operator simply double clicks its icon. Likewise to start another module, its icon must be double clicked. Once all of the icons have been started, **IMTS** is operating. There are seven modules and therefore seven icons that must be double clicked: *Cont*, *FFTAcq*, *DVFAcq*, *TADAcq*, *DVFTADE*, *FFTEv*, *Disp* (Fig. 6).

Once started, **IMTS** presents the user with a variety of options to the user. Due to the large quantities of data and evaluations that are processed by **IMTS**, the system displays information in a variety of screens so as to eliminate confusion and clutter on the monitor. These screens are organized according to individual machines and to the nature of the data: vibration, temperature or data obtained from the AD convertor (flow and pressure). A user selects a particular screen for display by hitting the corresponding key as shown in the menu at the lower portion of the monitor.

The user selects control options in the same way; he or she hits the key that corresponds to the desired control option. A control option, however, does not display data. Instead, control options permits the user to store data in files for future reference, reset any reference values
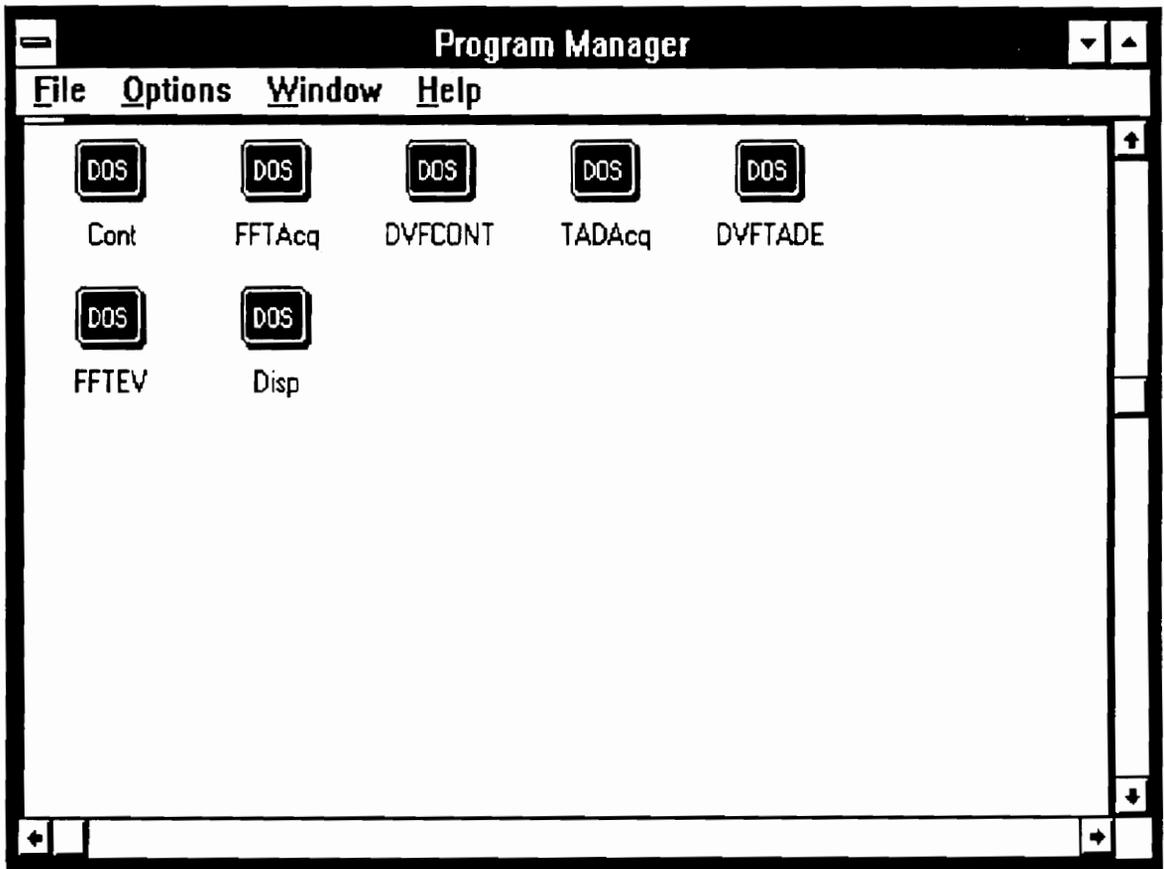
Figure 6   IMTS Icons

that may be processed by deviation standards, trigger the acquisition and evaluation of FFT spectrum data and quit the operation of IMTS.

6.3 System and Machine Summary

The **SYSTEM SUMMARY [F1]** option provides general information on all of the machinery undergoing analysis. As shown in Fig. 7, each box contains the name of the machine and the current maximum and minimum overall vibration value (in mils) present on that the machine.

The green or red light in the upper right corner of each box indicates an acceptable or alarm condition respectively for that machine. The number appearing above each box is for identification purposes.

The **MACHINE SUMMARY [F2]** option displays all of the current overall vibration, temperature, and AD data relative to the machine chosen by the user as shown in Fig. 8. An identification number for each monitoring location is given adjacent to its corresponding description.

Both the **SYSTEM SUMMARY** and **MACHINE SUMMARY** displays are intended as a quick reference for determining the performance of the entire system or a particular machine respectively. If a particular machine appears to operate in an unacceptable status, additional and more specific information is available to determine the trouble spot and the parameter that is in violation of acceptable operating conditions.

```
MASTER SCREEN

        1                  2                  3                  4
┌──────────────┐  ┌──────────────┐  ┌──────────────┐  ┌──────────────┐
│BFP-1A     ▬  │  │BFP-1B     ▬  │  │IDF-1A     ▬  │  │IDF-1B     ▬  │
│HI:   8.1     │  │HI:   6.9     │  │HI:   8.1     │  │HI:   8.1     │
│LO:   2.8     │  │LO:   2.8     │  │LO:   2.8     │  │LO:   2.8     │
└──────────────┘  └──────────────┘  └──────────────┘  └──────────────┘
```

F1....SYSTEM SUMMARY	F6....AD SUMMARY	sF1...FFT TRIGGER	TIME: 08:10:59
F2....MACHINE SUMMARY	F7....VIBRAT RESET	sF2...LOG DATA	DATE: 1-15-1992
F3....VIBRAT SUMMARY	F8....TEMP RESET	sF3...TREND DATA	
F4....FFT SUMMARY	F9....AD RESET	sF4...LOG [ON/OFF]	LOG: 08:10:47
F5....TEMP SUMMARY	F10...FFT SPECTRUM	sF5...QUIT	
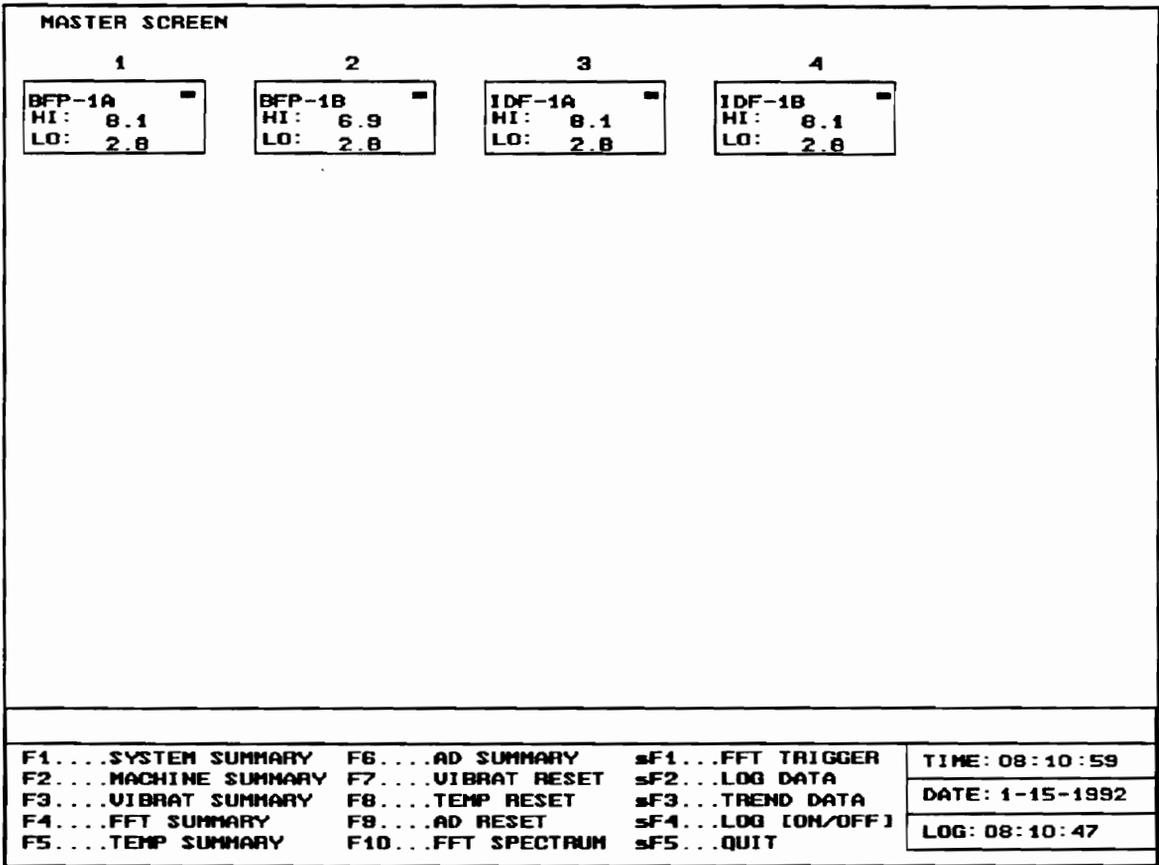
Figure 7   [F1] System Summary

```
MACHINE SUMMARY                    BFP-1A
┌─────────────────────┬─────────────────────────┬──────────────────────────┐
│ Vibration           │ Temperature             │ A/D                      │
│ Location      MILS  │ Location      DEGREES F  │ Location         A/D     │
│ 19 BFP-1A #19  2.8  │ temp #1         75.1     │ ad #1        33544.2     │
│ 23 IDF-1A #23  6.9  │ temp #3         54.3     │                          │
│ 27 IDF-1B #27  6.3  │ temp #5        132.2     │                          │
│ 31 IDF-1A #31  8.1  │ temp #11       -76.4     │                          │
└─────────────────────┴─────────────────────────┴──────────────────────────┘




┌─────────────────────────────────────────────────────────┬───────────────────┐
│ F1....SYSTEM SUMMARY   F6....AD SUMMARY    sF1...FFT TRIGGER │ TIME: 08:21:20  │
│ F2....MACHINE SUMMARY  F7....VIBRAT RESET  sF2...LOG DATA    ├───────────────────┤
│ F3....VIBRAT SUMMARY   F8....TEMP RESET    sF3...TREND DATA  │ DATE: 1-15-1992 │
│ F4....FFT SUMMARY      F9....AD RESET      sF4...LOG [ON/OFF]├───────────────────┤
│ F5....TEMP SUMMARY     F10...FFT SPECTRUM  sF5...QUIT        │ LOG: 08:10:47   │
└─────────────────────────────────────────────────────────┴───────────────────┘
```

Figure 8 [F2] Machine Summary

6.4 Vibration, FFT, Temperature, and AD Summary

The **VIBRAT[ION] SUMMARY [F3]**, **FFT SUMMARY [F4]**, **TEMP[ERATURE] SUMMARY [F5]**, and **AD SUMMARY [F6]** displays together provide specific information on all of the most recent data on all of the rotordynamic parameters and their associated evaluations. The **VIBRAT[ION] SUMMARY [F3]** display shown in Fig. 9 provides overall vibration, synchronous vibration, phase, gap volts, and speed values for a specific location.

A description of this location is given in the upper portion of the display. The first column, *CURRENT VALUE,* contains the most recently acquired data. The adjacent column, *CURRENT STATUS*, is the evaluation of the data values given in the *CURRENT VALUE* column. The third and fourth columns, Δ *VALUE* and Δ *STATUS*, contain the difference between the most recently obtained data and the reference value for that particular parameter, and the evaluation based on this difference respectively. In the lower right corner of the display is the time and date of when the data appearing on this screen was acquired.

The **FFT SUMMARY [F4]** , shown in Fig. 10, displays data based on the decomposition of the overall vibration into its frequency content. This breakdown is done by displaying the frequency zones that were defined in the FFT standard. The first and second column, jointly taken as *SPEED RANGE*, define the frequency zone limits. The third column, *MAX AMPLITUDE*, contains the most current maximum amplitude occurring within the corresponding frequency zone. The third and fourth zone, taken together as *REFERENCE*, define the three operating regions for the associated frequency zone. The low value is the threshold between the "good" and "fair" region. The high value is the threshold between "fair" and "poor" region. The sixth column, *STATUS*, contains the actual evaluation: "good", "fair" or "poor".

```
┌─────────────────────────────────────────────────────────────────────────────┐
│ VIBRATION SUMMARY                                                             │
│   ┌─────────────────────────────────────────────────────────────────┐        │
│   │                        IDF-1A #23                                 │        │
│   │                                                                   │        │
│   │                        CURRENT      CURRENT    ▲ VALUE   ▲ STATUS  │        │
│   │                        VALUE        STATUS                        │        │
│   │ OVERALL AMPLITUDE        6.9        acceptab    -8.1     trip      │        │
│   │ SYNCHRONOUS AMPLITUDE    6.8        acceptab    -8.2     trip      │        │
│   │ PHASE                    176                     131     bye-bye   │        │
│   │ SYNCHRONOUS AMPLITUDE & PHASE                            trip      │        │
│   │ GAP VOLTS [-]            8.1        Nominal      0.1     Nominal   │        │
│   │ SPEED [RPM]              1345                                      │        │
│   │                                           DVF TIME: 20:03:36      │        │
│   │                                           DVF DATE: 01-15-1992    │        │
│   └─────────────────────────────────────────────────────────────────┘        │
│                                                                               │
│                                                                               │
├─────────────────────────────────────────────────────────────────────────────┤
│ F1....SYSTEM SUMMARY   F6....AD SUMMARY     sF1...FFT TRIGGER │ TIME: 08:23:33 │
│ F2....MACHINE SUMMARY  F7....VIBRAT RESET   sF2...LOG DATA    ├────────────────┤
│ F3....VIBRAT SUMMARY   F8....TEMP RESET     sF3...TREND DATA  │ DATE: 1-15-1992│
│ F4....FFT SUMMARY      F9....AD RESET       sF4...LOG [ON/OFF]├────────────────┤
│ F5....TEMP SUMMARY     F10...FFT SPECTRUM   sF5...QUIT        │ LOG: 08:10:47  │
└─────────────────────────────────────────────────────────────────────────────┘
```

Figure 9   [F3] Vibration Summary

```
FFT INFORMATION SCREEN

                         IDF-1A #23
        SPEED RANGE          MAX         REFERENCE
        LOW      HIGH     AMPLITUDE    LOW     HIGH     EVALUATION

         0.0     899.0      0.0       0.9      1.0        good

       900.0    1099.0      0.1       1.0      1.0        good

      1100.0    1799.0      6.3       1.1      1.8        poor

      1800.0    2199.0      0.0       2.1      3.1        good

      2200.0    2899.0      0.2       1.5      3.5        good

      2900.0    3099.0      0.0       1.0      2.0        good

      3100.0    3999.0      0.0       0.3      0.5        good

      4000.0    5000.0      0.1       0.2      0.4        good




                                  FFT TIME: 20:03:46
                                  FFT DATE: 01-15-1992




F1....SYSTEM SUMMARY    F6....AD SUMMARY      sF1...FFT TRIGGER     TIME: 08:24:43
F2....MACHINE SUMMARY   F7....VIBRAT RESET    sF2...LOG DATA
F3....VIBRAT SUMMARY    F8....TEMP RESET      sF3...TREND DATA      DATE: 1-15-1992
F4....FFT SUMMARY       F9....AD RESET        sF4...LOG [ON/OFF]
F5....TEMP SUMMARY      F10...FFT SPECTRUM    sF5...QUIT            LOG: 08:10:47
```

Figure 10   [F4] FFT Summary

The TEMP[ERATURE] SUMMARY [F5] and AD SUMMARY [F6], Figs. 11 and 12 respectively, both display data in the same format. The first column of each display, *LOCATION*, contains a location identification number and a description of that location. The second column, either *TEMP ^oF* or *AD VALUE*, contains the most recent temperature or data obtained from the thermocouple or AD board respectively. The third column, *STATUS*, contains the evaluation of the corresponding data value in the column left of it. The fourth column, *△ TEMP ^oF* or *△ AD VALUE*, is the difference between the most recently obtained data and the reference value. The final column, *STATUS*, is an evaluation of the values in the *△ TEMP ^oF* or *△ AD VALUE* column.

6.5 FFT Spectrum

The FFT SPECTRUM [F10] display provides a 400 point plot of an FFT performed on any vibration signal. The amplitude is given in mils and the frequency is given in RPMs. The user is prompted to select between a *current* or *previous* plot. The *current* plot is a plot of the most recent data available, whereas *previous* plot is any plot obtained prior to the current plot. The title has the name of the vibration location and the time and date of when the FFT was computed as shown in Fig. 13.

6.6 Trend Data

One of the most useful and frequently used options is TREND DATA [sF3]. By selecting this option, IMTS provides the operator with a historical perspective of the machine's operation. By selecting the

```
                          BFP-1A
     LOCATION      TEMP °F      EVALUATION     ▲ TEMP °F    EVALUATION
     temp #1        75.1        alarm            60.1       trip
     temp #3        54.3        alarm            38.3       trip
     temp #5       132.2        alarm           117.2       trip
     temp #11      -76.4        alarm           -91.4       trip

                                                TIME:  20:04:00
                                                DATE:  01-15-1992




     F1....SYSTEM SUMMARY    F6....AD SUMMARY      sF1...FFT TRIGGER     TIME:08:26:14
     F2....MACHINE SUMMARY   F7....VIBRAT RESET    sF2...LOG DATA        DATE:1-15-1992
     F3....VIBRAT SUMMARY    F8....TEMP RESET      sF3...TREND DATA
     F4....FFT SUMMARY       F9....AD RESET        sF4...LOG [ON/OFF]    LOG:08:10:47
     F5....TEMP SUMMARY      F10...FFT SPECTRUM    sF5...QUIT
```

Figure 11 [F5] Temperature Summary

```
                          BFP-1B

     LOCATION     AD VALUE    EVALUATION    ▲ AD VALUE   EVALUATION

     ad #11       33800.2     alarm          33785.2     trip
     ad #15       32776.0     alarm          32761.0     trip


                                            TIME:  20:04:12
                                            DATE:  01-15-19



  F1....SYSTEM SUMMARY   F6....AD SUMMARY     sF1...FFT TRIGGER   │ TIME: 08:27:18
  F2....MACHINE SUMMARY  F7....VIBRAT RESET   sF2...LOG DATA      │
  F3....VIBRAT SUMMARY   F8....TEMP RESET     sF3...TREND DATA    │ DATE: 1-15-1992
  F4....FFT SUMMARY      F9....AD RESET       sF4...LOG [ON/OFF]  │
  F5....TEMP SUMMARY     F10...FFT SPECTRUM   sF5...QUIT          │ LOG: 08:10:47
```

Figure 12   [F6] AD Summary
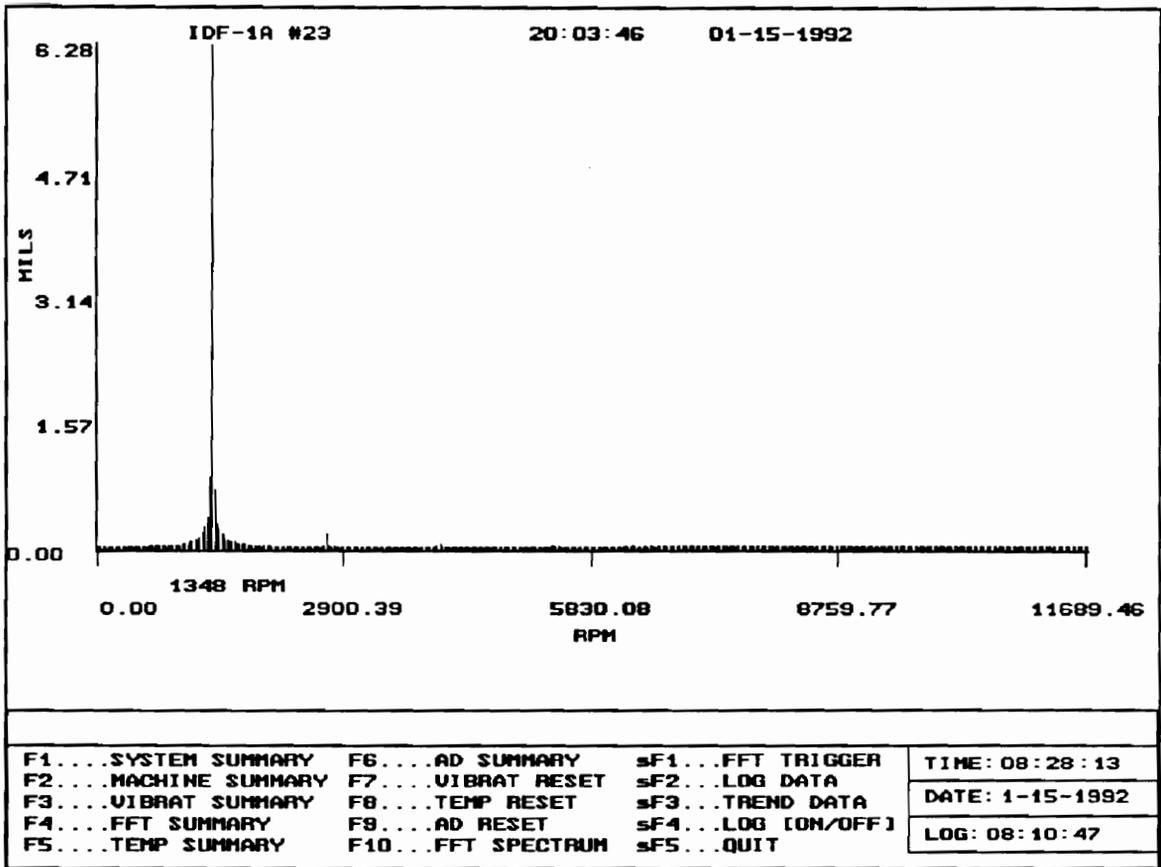
Figure 13 [F10] FFT Spectrum

parameter, the machine and the location ID, the user can view the values of speed, overall vibration, synchronous vibration, phase, gap volts, temperature, AD data and all the associated deviation values as a function of time. The user selects the starting time and the finishing time for the time axis (x-axis) and a maximum and a minimum value for the parameter value (y-axis). Scaling can be performed automatically as well. Two plots can also be displayed simultaneously which is useful in determining relationships that exists between two parameters. If desired, the operator can choose to display a grid at either hourly, daily or weekly intervals to provide more time references in addition to the two end points. Refer to Fig. 14 for a sample of the trend display.

6.7 Vibration, Temperature, and AD Reset

The **VIBRAT[ION] RESET [F7]**, **TEMP[ERATURE] RESET [F8]** and **AD RESET [F9]**, allow the user to reset the reference parameters used by the deviation standard. When the user resets a parameter's reference value, the reference parameter is given the value of the next data that is acquired.

The **VIBRAT[ION] RESET** option permits the user to perform a *global* or *channel* reset. The *global* option resets all resetable values for a particular machine. The *channel* option allows the user to reset specific parameters for within a particular location, to reset all parameters within a particular location, or to cancel the reset option. Figure 15 shows the options available under the *channel* option.

The **TEMP[ERATURE] RESET** and **AD RESET** have similar formats. A list of temperature or AD locations is given. Options to select specific locations for reset are shown in Figs. 16 and 17.
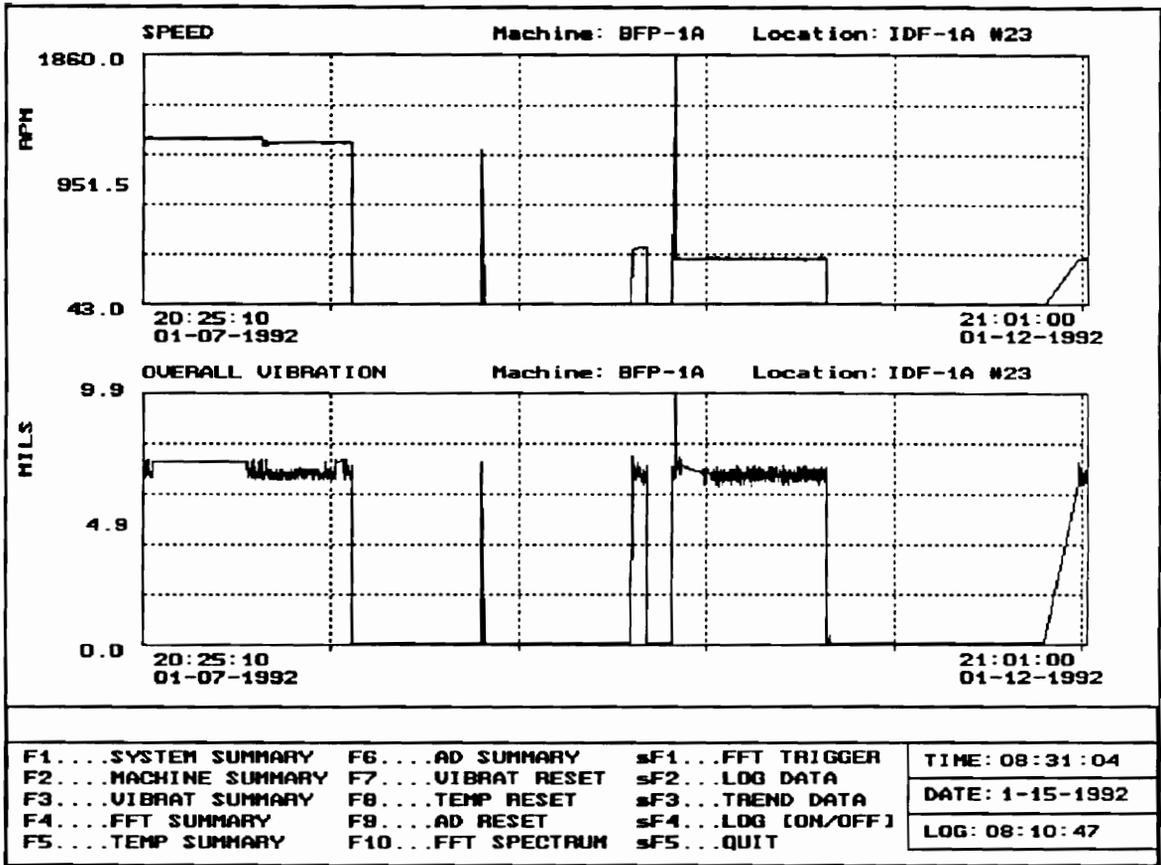
Figure 14   [sF3] Trend Data

```
VIBRATION SUMMARY

                              IDF-1A #23


                          CURRENT    CURRENT    ▲ VALUE    ▲ STATUS
                          VALUE      STATUS
OVERALL AMPLITUDE          6.9       acceptab     -8.1       trip

SYNCHRONOUS AMPLITUDE      6.8       acceptab     -8.2       trip

PHASE                      176                     131     bye-bye

SYNCHRONOUS AMPLITUDE & PHASE                                trip

GAP VOLTS [-]              8.1       Nominal       0.1     Nominal

SPEED [RPM]               1345
                                           DVF TIME: 20:03:36

   NOTE:  TO RESET PARAMETERS FOR ANOTHER LOCATION    1  overall
          SELECT CANCEL [8] AND THEN VIB RESET [F7].  2  synch and phase
                                                      3  synch
    TO SELECT PARAMETER FOR RESET:                    4  phase
    1. HIT [ENTER] AFTER ENTERING THE NUMBER THAT     5  gapvolts
       CORRESPONDS TO THE PARAMETER TO BE RESET.      6  all
    2. HIT "7" and [ENTER] WHEN DONE WITH INPUT.      7  done
                                                      8  cancel


  Make selection here →
  F1....SYSTEM SUMMARY    F6....AD SUMMARY     sF1...FFT TRIGGER    TIME: 08:31:55
  F2....MACHINE SUMMARY   F7....VIBRAT RESET   sF2...LOG DATA
  F3....VIBRAT SUMMARY    F8....TEMP RESET     sF3...TREND DATA     DATE: 1-15-1992
  F4....FFT SUMMARY       F9....AD RESET       sF4...LOG [ON/OFF]
  F5....TEMP SUMMARY      F10...FFT SPECTRUM   sF5...QUIT           LOG: 08:10:47
```

Figure 15   [F7] Vibration Reset

```
┌─────────────────────────────────────────────────────────────────────┐
│    Thermocouple Channels:                                             │
│                                                                       │
│  ①②③④⑤⑥⑦⑧⑨⑩⑪⑫⑬⑭⑮⑯⑰⑱⑲⑳                                          │
│    21   done                                                          │
│    22   all                                                           │
│    23   cancel                                                        │
│                                                                       │
│    Select the channels[s] you wish to reset                          │
│    Hit [ENTER] key after each entry                                   │
│                                                                       │
│                                                                       │
│                                                                       │
└─────────────────────────────────────────────────────────────────────┘


───────────────────────────────────────────────────────────────────────
 Make selection here   →
───────────────────────────────────────────────────────────────────────
 F1....SYSTEM SUMMARY    F6....AD SUMMARY      sF1...FFT TRIGGER   │ TIME: 11:23:35
 F2....MACHINE SUMMARY   F7....VIBRAT RESET    sF2...LOG DATA      ├────────────────
 F3....VIBRAT SUMMARY    F8....TEMP RESET      sF3...TREND DATA    │ DATE: 1-26-1992
 F4....FFT SUMMARY       F9....AD RESET        sF4...LOG [ON/OFF]  ├────────────────
 F5....TEMP SUMMARY      F10...FFT SPECTRUM    sF5...QUIT          │ LOG:
```

Figure 16   [F8] Temperature Reset

```
AD Channels:
(1)(2)(3)(4)(5)(6)(7)(8)(9)(10)(11)(12)(13)(14)(15)(16)
17   done
18   all
19   cancel

Select the channels[s] you wish to reset
Hit [ENTER] key after each entry
```

```
Make selection here   →

F1....SYSTEM SUMMARY     F6....AD SUMMARY       sF1...FFT TRIGGER      TIME: 11:26:36
F2....MACHINE SUMMARY    F7....UIBRAT RESET     sF2...LOG DATA
F3....UIBRAT SUMMARY     F8....TEMP RESET       sF3...TREND DATA       DATE: 1-17-1992
F4....FFT SUMMARY        F9....AD RESET         sF4...LOG [ON/OFF]
F5....TEMP SUMMARY       F10...FFT SPECTRUM     sF5...QUIT             LOG:
```

Figure 17   [F9] AD Reset

6.8 Logging Data

The **LOG DATA [sF2]** function stores data to a file that can latter be reviewed. The file is stored in the ASCII format which is an easily readable format requiring no interpreter program. Data is sent to a log files under three circumstances: an alarm condition exists, it is time for a periodic log of data to file, or the user requests a data log. Note, however, that only one log will occur per data set. This means that if data were logged due to an alarm condition, a user cannot log the same data again by hitting the **sF2** key. In addition, only the data appearing in the **VIBRATION SUMMARY, TEMPERATURE SUMMARY,** and **AD SUMMARY** screen are logged. FFT spectrum data is not available through log files.

6.9 FFT Trigger

Hitting the **FFT TRIGGER [sF1]** key starts the acquisition and evaluation of FFT spectrum data for all vibration locations. Although FFT spectrum data is collected and evaluated periodically, the time before the next acquisition cycle may be too long to wait. By hitting **sF1**, a new acquisition cycle may be initiated without a waiting for the next scheduled acquisition. This option also permits the user to change the sample rate as shown in Fig. 18.

By increasing the sample rate, a large frequency range may be obtained. However, one pays the price for obtaining a greater frequency range because frequency resolution deteriorates. Similarly, one improves the frequency resolution by decreasing the sample rate, but looses the ability to achieve the high end frequency content of the signal. When the sample rate is changed, the corner frequency of the anti-aliasing filter

```
┌─────────────────────────────────────────────────────────────────────┐
│                                                                       │
│    ┌──────────────────────────────────────────────┐                   │
│    │ FFT TRIGGER                                   │                   │
│    │ CURRENT SAMPLE RATE IS:500 Hz                 │                   │
│    │                                               │                   │
│    │   1.  10 Hz     4.  100 Hz    7.  1000 Hz     │                   │
│    │   2.  20 Hz     5.  200 Hz    8.  2000 Hz     │                   │
│    │   3.  50 Hz     6.  500 Hz    9.  DONE        │                   │
│    └──────────────────────────────────────────────┘                   │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│                                                                       │
│ Set the corner frequency to 200 Hz.  Hit [Enter] to continue          │
├───────────────────────────────────────────────────────┬───────────────┤
│ F1....SYSTEM SUMMARY   F6....AD SUMMARY     sF1...FFT TRIGGER │ TIME: 08:33:28 │
│ F2....MACHINE SUMMARY  F7....VIBRAT RESET   sF2...LOG DATA    ├───────────────┤
│ F3....VIBRAT SUMMARY   F8....TEMP RESET     sF3...TREND DATA  │ DATE: 1-15-1992│
│ F4....FFT SUMMARY      F9....AD RESET       sF4...LOG [ON/OFF]├───────────────┤
│ F5....TEMP SUMMARY     F10...FFT SPECTRUM   sF5...QUIT        │ LOG: 08:10:47  │
└───────────────────────────────────────────────────────┴───────────────┘
```

Figure 18   [sF1] FFT Trigger

must also be changed. As per the Nyquist sampling criterion, the sampling rate is twice the maximum frequency one wishes to observe. If the signal contains any frequencies greater than the Nyquist frequency, then they must be filtered by a low pass filter so as to prevent aliasing.

6.10 Log [ON/OFF]

IMTS logs vibration, temperature and AD when any one of three conditions is true. Logging always occurs at a predefined interval such as once every half hour. In addition, this data is logged whenever the user requests a log by selecting the **Log Data [sF2]** command. Finally, data may be logged whenever the
most recently acquired set of data contains at least one parameter that is in an alarm condition. If one parameter of an acquired data set contains an alarm, then all of the data corresponding to that data set is stored. If these alarms persist, then files may rapidly grow to the point of making data retrieval a slow process. Granted that it is sometimes necessary to collect all of this data when an alarm condition exists, however these alarms may often be initially acknowledged and then ignored.

For example, assume a very high (alarm) gap voltage produced by a probe that monitors a bearing location in the x direction. If other probes (such as the probe that monitors the same bearing but in the y-direction) show no abnormal conditions, then it may be reasonable to say that the probe has failed and that the machine is continuing to operate acceptably. In such cases it is unnecessary to collect data in order to capture some alarm machine condition for later review since no such conditions exist. A desirable feature would be the ability to turn this alarm triggered log off and on as the operator finds necessary. The **Log**

alarm triggered log off and on as the operator finds necessary. The **Log Data [sF5]** option does just that. By putting the **Log Data [sF4]** in the off condition, the user can deactivate alarm triggered logging, but does not disable the periodic or user triggered data log.

6.11 Quit

The **QUIT [sF5]** command, as the name would suggest, stops operation of **IMTS**. The system closes all log and trend files. Note that only the **Display And Storage** Module is terminated by the **QUIT [sF5]** command. Other modules must be terminated by typing a capital letter "C" when it is made the active application in Windows 3.0.

6.12 Power Outages, Backing Up Data and Previous Runs

Arguably, the most valuable feature of **IMTS** is its ability to provide trend information. The time and effort spent collecting the data would truly be wasted if all of this information were rendered inaccessible or lost due to unfortunate events such as an accidental unplugging of the computer or a power outage created by an electrical storm. Although the system will terminate operation due to these misfortunes, **IMTS**'s ability to recall the data collected up to the time of the disturbance is not lost. Every time **IMTS** reads a new data set, critical information is stored in the *restart file* . This file contains the total number of data points and the time and date of the initial and final points that were collected. This is all of the information required to restart **IMTS** in the same state prior to the disturbance. Note that

trend files and the *restart file* are not destroyed by a disruption in power and thus remain in tact after power is restored.

This ability to restart after a power outage also means that the user can intentionally stop operation by selecting the **QUIT [sF4]** option. Should the user stop data collection for any reason such as to check if a sensor is functioning properly, then the system can be restarted later and still have access to data collected prior to interruption.

Since **IMTS** does not destroy old data to make room for the newer data, a method of saving the old data is essential. When the combined size of any of the trend files approaches 20 Megabytes, **IMTS** displays a message to the operator to copy all of the trend files to the Bernoulli Drive and delete the trend files on the hard drive. By deleting the trend files, more space is created on the hard drive.

7.0 Integration with the Expert System

The ability to perform diagnostics and deliver remedies for rotating machinery requires **The Diagnostic Rotating Machinery Expert System.** Currently it is an off-line system which means that it is not capable of accessing necessary information without the operator manually typing information at keyboard. As an on-line system, The Diagnostic Rotating Machinery Expert System will automatically access required information.

To operate in the on-line mode, it is necessary to transfer the results of **IMTS** operations to **The Diagnostic Rotating Machinery Expert System.** This is accomplished by the having the expert system read the log files and trend files created by **IMTS.**

If **The Diagnostic Rotating Machinery Expert System** were to operate as another module, which would bring the total number of multitasking programs to 8, then it would need to apply the same techniques used by the other modules in transferring data, i.e. renaming data files. However, it would also be possible, and simpler, to allow **The Diagnostic Rotating Machinery Expert System** to run in DOS. This would entail running **IMTS** only long enough to collect and evaluate data. After terminating execution of **IMTS, The Diagnostic Rotating Machinery Expert System** could be started in the DOS environment. Since it would be operating in the DOS environment, it would be the only program that was running and thus would not need to perform the file renaming procedure that is required for multitasking programs in the Windows 3.0 environment.

8.0 Conclusions And Recommendations

The effort to produce a pc-based flexible data acquisition system capable of evaluating and trending data has been successful. IMTS acquires the relevant rotordynamic data and evaluates the data based on user defined references called standards. Flexibility arises from the fact that these standards are created by the user for his or her particular application. This means that the evaluations provided by IMTS are not restricted to one type or class of rotating machinery such as a specific pump model; IMTS can be used for a variety of rotating machinery.

IMTS operates in the Windows 3.0 operating system by using DOS applications called modules. Unfortunately, Windows 3.0 does not permit the transfer of data between these modules due to the fact that they are DOS applications which cannot utilize Windows 3.0 's dynamic data exchange (DDE) capabilities. To resolve this problem a sub-operating system was developed. This sub-operating system permits transfer of data between DOS application by writing the data to a file and then reading from it in a manner which prevents simultaneous reading and writing. This is the first known successful attempt at transferring data between multitasking DOS applications in the Windows 3.0 operating system.

With the most challenging technical issues resolved, efforts may now be geared to fine tuning IMTS. This includes reducing the time required to access the large trend files. Currently, IMTS must make a pass to determine the initial trend point's starting time and date and another pass to determine the final trend point's time and date. The third pass reads in the actual data points that are plotted. An algorithm should be developed to performs all of these reads in one pass instead of three and thus reducing the time associated with retrieving trend information.

Another improvement is the implementation of a more sophisticated file backup system. The new backup system is intended to protect against a hard disk crash which would result in losing all of the trend data. The new design would automatically copy all of the trend data after a 24 hour period to a Bernoulli disk. This would insure that no more than 24 hours of data would be lost should the hard drive become inaccessible.

Perhaps the most difficult technical undertaking will be the resolution of the problems associated with downloading code to the DSP board. The **FFT Acquisition** module which is responsible for executing the download will only work if it is the first or second module started. If it is started as the third or any later module, then the code will not download. Furthermore, once the **FFT Acquisition** is begun, no other modules may start until it has successfully performed the download which takes about 3 seconds.

Other remaining tasks include the conclusion of the on-line Diagnostic Rotating Machinery Expert System (DRMES). At this point DRMES will read the log files generated by **IMTS** to obtain the required data. The next step will be to run DRMES as another module in a multitasking configuration with **IMTS**. This task will be the subject of another master's thesis, which will be completed before summer, 1992.

References

[1]   Hegner, H. R. et al, <u>System Study Of Condition Based Maintenance Systems For Shipboard High-Pressure Air Compressors</u> Focus On Mechanical Failures: Mechanisms And Detection, Proceedings Of The 45th Meeting Of The Mechanical Failures Prevention Group, April 9-11, 1991, Annapolis Maryland.

[2]   Turbo Pascal Owner's Handbook Version 4.0, Borland International, Scotts Valley Ca. 95066, 1987.

[3]   Microsoft Quick BASIC, Programming In QuickBASIC Version 4.5, Microsoft Corporation, Redmond, Wa., 1988.

[4]   Microsoft Windows User's Guide Version 3.0, Microsoft Corporation, Redmond, Wa. 1990.

Appendix A Machinery Monitoring Locations

Before evaluating the data, one must determine from where the data should be collected. Typically, vibration data is obtained by placing transducers close to the bearing, at axial locations, and occasionally at midspan and coupling locations. However, the number of transducers used on a machine is determined by its importance in the process or how expensive it is to replace or repair it. Table A-I shows some typical applications.

Table A-I
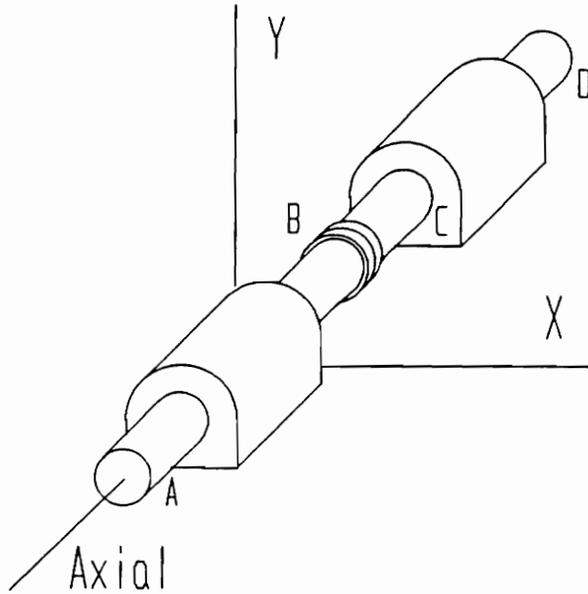
Recommended Monitoring Locations [5]	
Machine Description	**Location**
Steam turbine/large pump or compressor with fluid film bearings.	Radial horizontal and vertical at A, B, C, D. Redundant at A and D.
Gas turbine or medium size pump.	Radial horizontal and vertical at A and B.
Motor/fan, both with fluid film bearings.	One radial at each bearing. One axial to detect wear.
Motor/pump or compressor with rolling element bearings.	One radial at each bearing. One axial, usually on motor, to detect thrust wear.
Gearbox with rolling element bearings.	Transducers mounted as close to each bearing as possible.
Gearbox shafts with fluid film bearings.	Radial horizontal and vertical at each bearing. Axial to detect thrust wear.

[5]   Vance, J. M., _Rotordynamics of Turbomachinery_, John Wiley & Sons, New York, 1988, p 329

Appendix B   Rotordynamic Evaluation

A rotordynamic diagnostic evaluation relies primarily on the collection of vibration data.   The term *vibration data* is actually a classification for several parameters: overall vibrations, synchronous vibrations, harmonic and sub harmonic vibrations, phase, and gap volts. Each of these parameters are significant because of what they can reveal about a rotating machine.

B.1   Parameters

Overall vibration is an indication of the total magnitude of vibration the shaft is undergoing at a particular location.   The overall vibration is the combined effect of the synchronous, harmonic and subharmonic components.   Decomposition of the overall vibration into its synchronous, harmonic and subharmonic components may help reveal the source(s) of the vibration.   For example, an imbalance is manifested as a synchronous vibration, while oil whip shows up at 43% to 49% of running speed.   However, a dry rub may also show up as a subharmonic vibration and great care must be taken to avoid improper conclusions from vibration data.   A misalignment or bent shaft is usually characterized by a frequency component occurring at twice the running speed.   However, a cracked shaft can also cause a twice speed vibration component.   Figure B-1 shows the axial forces experienced at the bearings locations for a bent rotating shaft.

Phase data is required when balancing the machine and is useful in determining a change in vibration in which the amplitude remains constant but shifts in phase.   Phase data can also detect alignment problems.   The
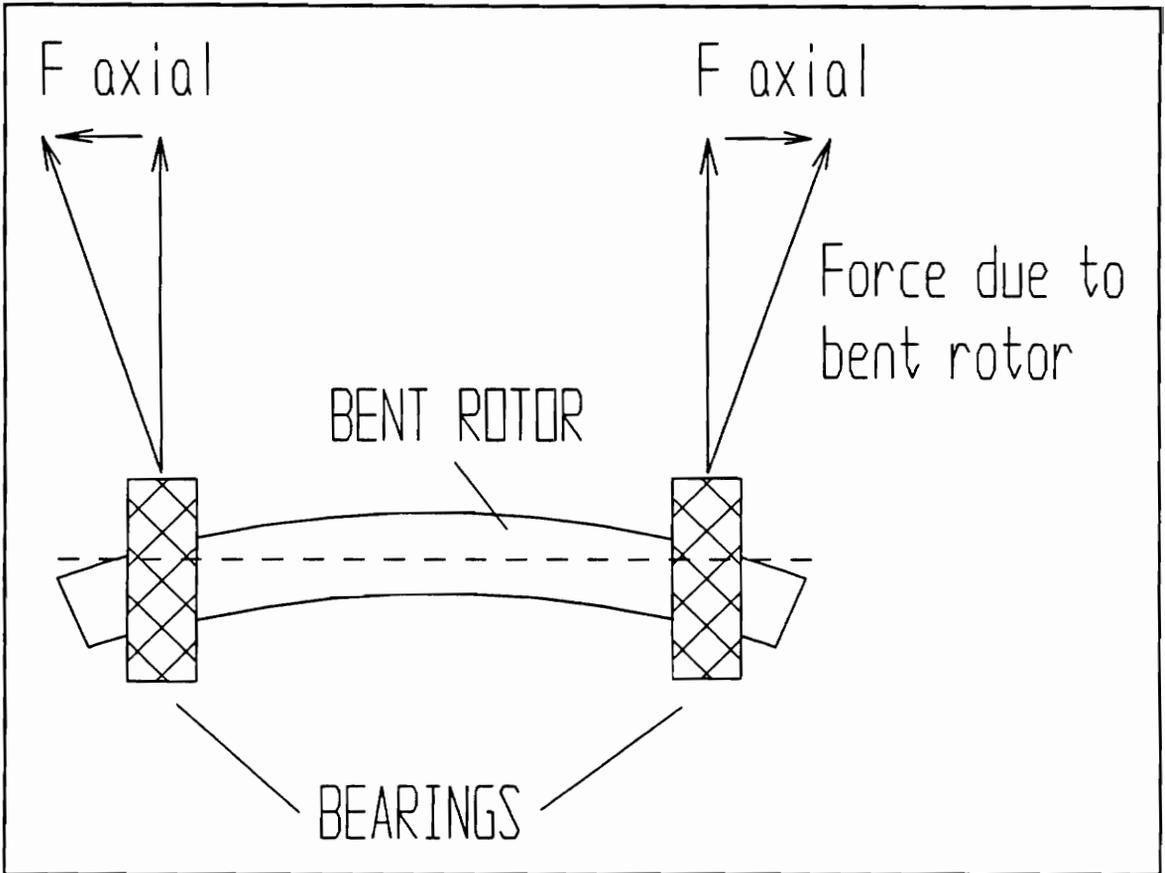
Figure B-1   Axial Forces For a Bent Shaft

relative phase angle of axial vibration due to misalignment, measured at the ends of the shaft, is about 180° as indicated by the opposite directions of the axial force vectors in Fig. B-1. Note that the actual relative phase angles may differ somewhat due to machine dynamics. A properly aligned machine would have a relative phase of 0° [6]

The combination of synchronous amplitude and phase as a single parameter is worth considering as well since it is a better description of the machine's vibration than the two parameters taken independently. If a phase shift of 180° accompanied by 0.1 mil (a mil is equivalent to 0.001 in. or 0.025 mm) decrease in amplitude occurred with time, it would be cause for concern. Such large changes in phase are significant despite the small change in vibration.

Gap voltage is a measure of the physical distance between the face of a noncontact probe tip and the observed surface. The distance can be expressed in terms of voltage which is the value of the dc output signal of the noncontact probe [7]. Gap voltage may be used to measure the static shaft position and may be used to determine if the shaft is seriously misaligned, has shifted during operation or if the transducer is malfunctioning. Note that due to the serious nature of a rotor shift (usually warranting a shutdown), two transducers are normally used in axial measurements for redundancy. Should one transducer fail, the other will continue monitoring and thus reduce the probability of an unnecessary shutdown.

Conditions other than vibration are important for proper evaluation of machinery performance. Flow rate, which is a measure of load, is necessary because a machine's vibration characteristics are often a function of load. Temperature of either the system working medium or bearing elements is always useful in detecting an abnormal operating condition or failure of the support system, respectively. Speed is

required in evaluating the machines performance relative to design point and for proper separation from critical frequencies.

Data may be evaluated according to a fixed standard or a deviation standard. Both types of standard will be explained in this section and will be accompanied with examples.

B.2 Fixed Evaluations

A fixed evaluation is based solely on the most recently acquired data; it is not taken relative to some other previous reading. Fixed evaluations are applicable to overall, harmonic and subharmonic amplitudes, gap voltages, temperatures and flow rates. These evaluations are meaningless for parameters involving phase since evaluations for phase can be made only on a relative basis. Fixed evaluations determine the machine's operation relative to an absolute standard which remains constant throughout the operation of the machine.

Figures B-2a and B-2b show the ISO STD 3945 (International Organization for Standards) support vibration severity references for a soft and hard supported rotor with mils peak to peak readings taken off the bearing cap respectively. A soft support is defined as a support with its fundamental natural frequency that lies below the operating frequency of the rotor. In contrast, a hard support is defined as a support with its natural frequency that lies above the rotor operating frequency.[8] Tables B-Ia and B-Ib show the same standard (ISO STD 3945) with bearing cap readings given in velocity [mm/s and in./s] for a hard and soft supported rotor respectively.

Another frequently used standard is the IRD Mechanalysis Machinery Severity Vibration Chart. This is similar to the ISO STD 3945 in that
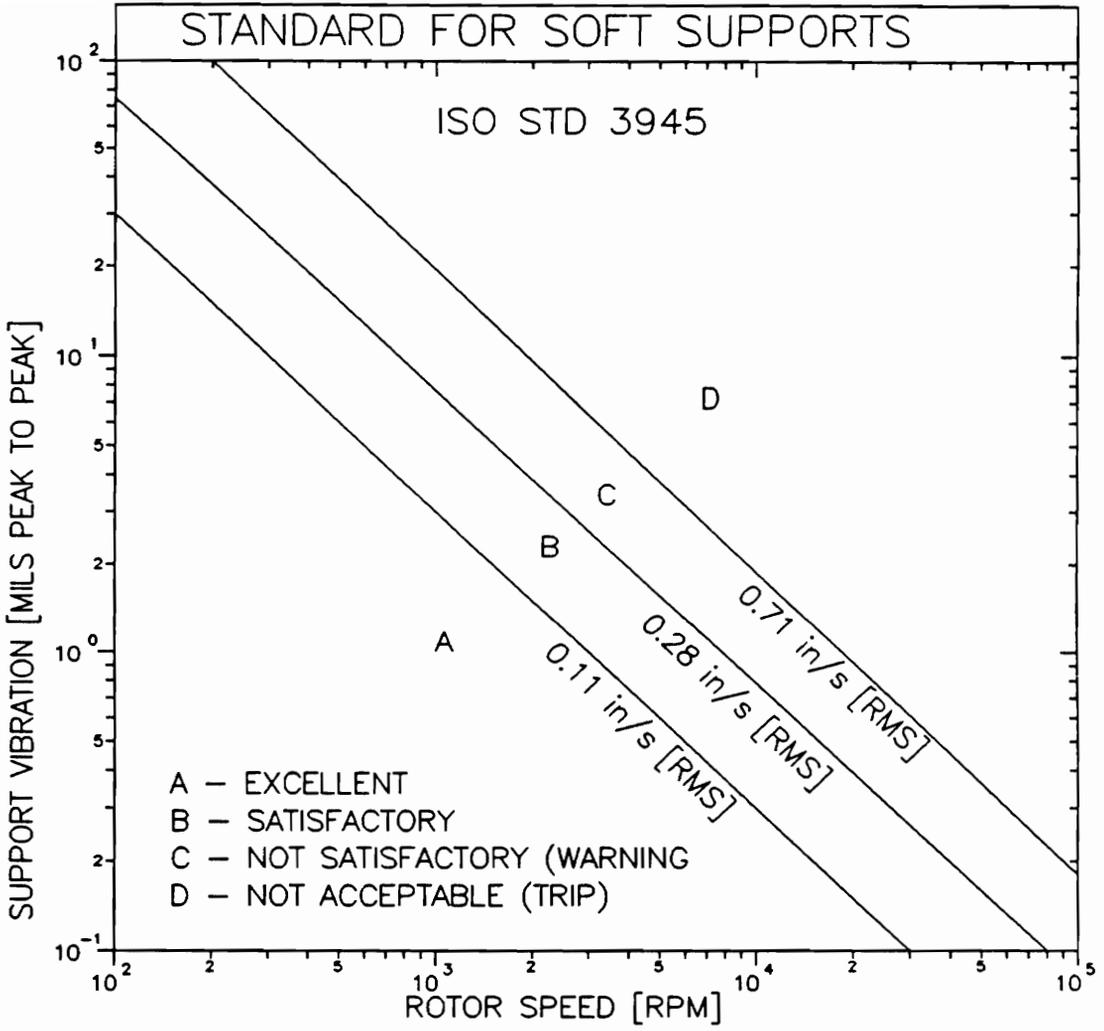
Figure B-2a ISOSTD 3945 - Soft Supports

Table B-Ia

ISO STD 3945				
VIBRATION SEVERITY FOR SOFT SUPPORTED ROTOR				
V_{RMS}		V_p		Severity
mm/s	in./s	mm/s	in./s	
0.45	0.018	0.64	0.03	GOOD
0.71	0.028	1.00	0.04	
1.12	0.044	1.58	0.06	
1.8	0.071	2.55	0.10	
2.8	0.11	3.96	0.16	
4.5	0.19	6.36	0.27	SATISFACTORY
7.1	0.28	10.04	0.40	
11.2	0.44	15.84	0.62	UNSATISFACTORY
18.0	0.71	25.46	1.00	
28.0	1.10	39.60	1.56	UNACCEPTABLE
71.0	2.80	100.41	3.96	
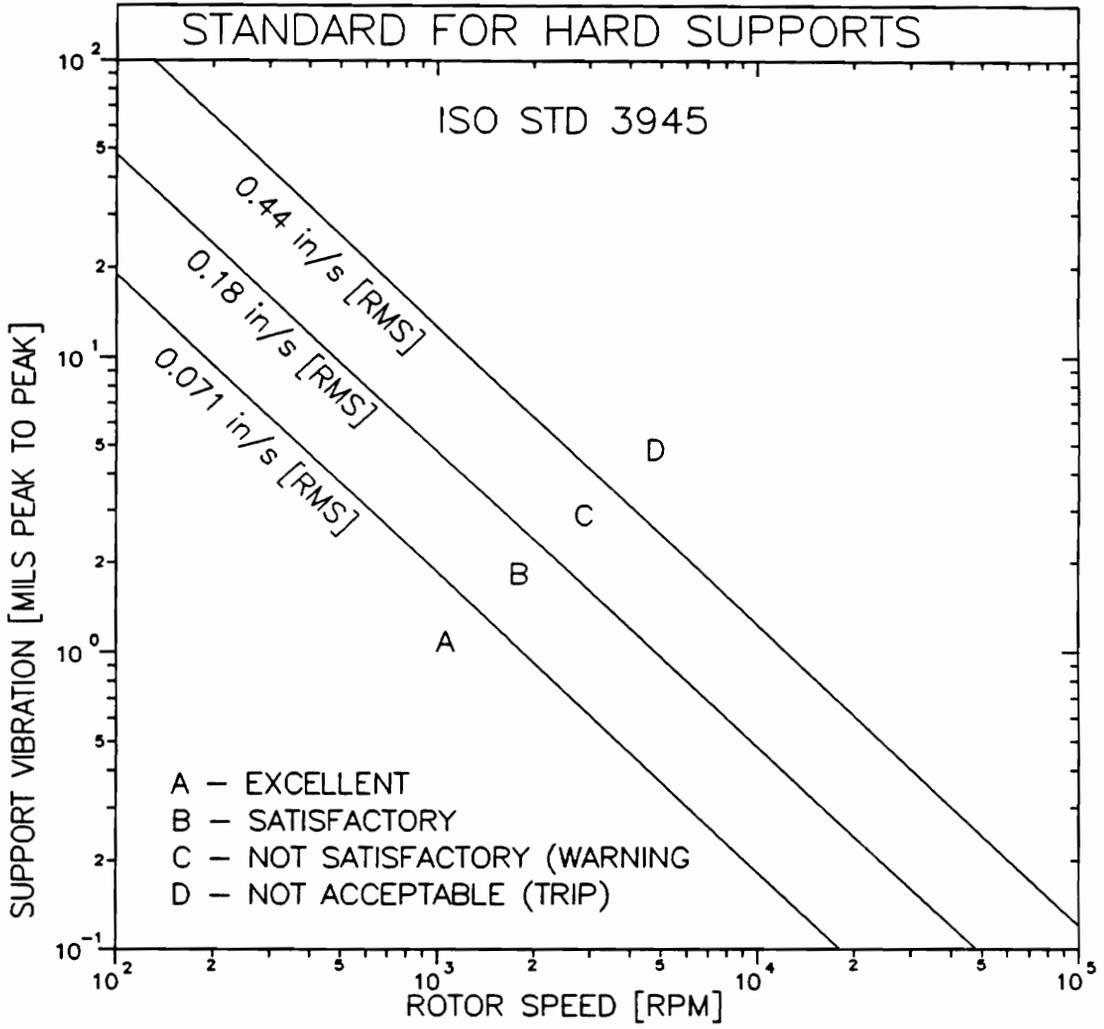
Figure B-2b   ISOSTD 3945 - Hard Supports

Table B-Ib

ISO STD 3945 VIBRATION SEVERITY FOR HARD SUPPORTED ROTOR				
V_{RMS}		V_p		Severity
mm/s	in./s	mm/s	in./s	
0.45	0.018	0.64	0.03	GOOD
0.71	0.028	1.00	0.04	GOOD
1.12	0.044	1.58	0.06	GOOD
1.8	0.071	2.55	0.10	GOOD
2.8	0.11	3.96	0.16	SATISFACTORY
4.5	0.19	6.36	0.27	SATISFACTORY
7.1	0.28	10.04	0.40	UNSATISFACTORY
11.2	0.44	15.84	0.62	UNSATISFACTORY
18.0	0.71	25.46	1.00	UNACCEPTABLE
28.0	1.10	39.60	1.56	UNACCEPTABLE
71.0	2.80	100.41	3.96	UNACCEPTABLE

readings are taken off the bearing caps, but notice that the IRD standards defines 9 operating zones whereas the ISO STD 3945 defines only four. The IRD standard is shown if Fig. B-3 and is given in tabular form in Table B-II

API (American Petroleum Institute) also has a widely used specification for absolute shaft vibration [9]. The limited specification is given as

$$Amplitude \ (mils \ p\text{-}p) < \sqrt{12000/N}$$

$$where$$

$$N = maximum \ continuous \ operating \ speed, \ RPM$$

An allowance of up to 0.25 mils peak to peak can be taken for shaft runout.

B.3 Deviation Evaluations

A deviation evaluation, however, does take into account earlier data and requires the storage of historical data for comparison. Furthermore, the deviation evaluation is based on the difference between the acquired data value and the deviation reference value. In other words, the deviation evaluation evaluates the time rate of change of the acquired data.
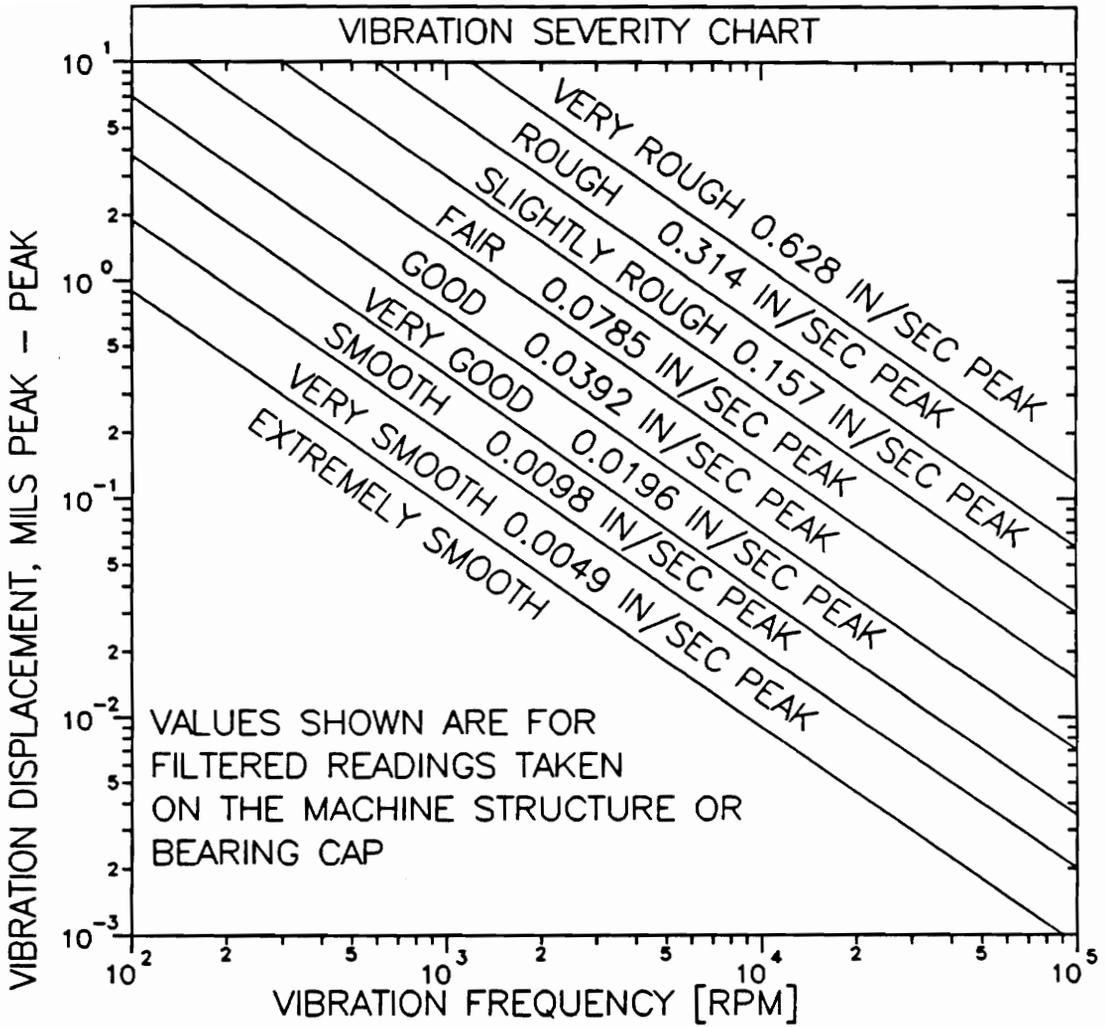
Figure B-3   IRD Mechanalysis General Machinery Vibration Severity Chart

Table B-II

IRD MECHANALYSIS VIBRATION SEVERITY CHART				
V_{RMS}		V_p		
mm/s	in./s	mm/s	in./s	Severity
0.0889-	0.0035-	0.1245-	0.0049-	EXTREMELY SMOOTH
0.1753	0.0069	0.2489	0.0098	VERY SMOOTH
0.3531	0.0139	0.4978	0.0197	SMOOTH
0.7036	0.0277	0.9957	0.0392	VERY GOOD
1.4097	0.0555	1.9939	0.0785	FAIR
2.8194	0.1110	3.9878	0.1570	SLIGHTLY ROUGH
5.6413	0.2221	7.9756	0.3141	ROUGH
11.2801+	0.4441+	15.9512+	0.6280+	VERY ROUGH

The parameters involving phase data, namely phase and synchronous amplitude - phase, are always taken relative to a value that was obtained earlier. The earlier value is called the deviation reference value. Overall amplitude, synchronous amplitude, gap volts, temperature and flow rate can also be evaluated relative to a deviation reference values.

The deviation reference values can be reset at any time during operation to the current values. For example, if load conditions change, the user would want to reset all of the reference values from the previous load condition to those values that exist under the new operating conditions. Figure B-4 shows the CAGI (Compressed Air and Gas Institute) standard for a change in vibration which is an example of a reference which may be used in making deviation evaluations for shaft displacement probe data.

CAGI Change in Vibration Standard
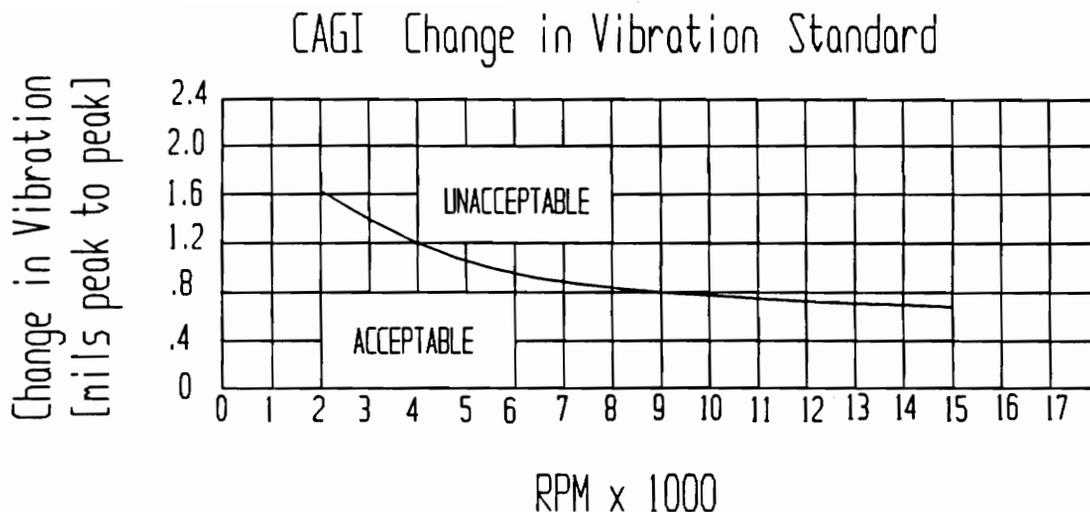
Figure B-4   CAGI STD   Change in Vibration

[6] Vance, J. M., Rotordynamics Of Turbomachinery, John Wiley & Sons, New York, 1988, p 348.

[7] Bently Book One - Bently Nevada Application Notes, Minden, Nevada, USA 1985.

[8] International Organization For Standardization, Mechanical Vibration of Large Rotating Machines With Rotational Operating Speeds From 10 to 200 rev/s - Measurement and Evaluation of Vibration Severity in situ., " Machine Support System", 1976.

[9] API Standard 617 2.8.2.5 - Centrifugal Compressors for General Refinery Services, 4th edition, November, 1979, 2101 L Street, Northwest, Washington D.C.

Appendix C   Standards

Standards are user defined references used in evaluating the variety of parameters involved in a rotordynamic evaluation. Standards provide **IMTS** with a comprehensive and flexible evaluation capability [10] [11]. Four types of standards exist: scalar, vector, graphic and spectrum. These standards may be accepted industrial guidelines (refer to Figs. B-2a, B-2b, B-3 and B-4) and safety requirements, or customized criteria for a particular machine based on personal familiarity and experience. Setup programs exist that allow easy creation of these standards. The following section discusses the concepts and uses of particular types of standards available in **IMTS**.

C.1 Scalar Standards

The scalar standard requires only a single piece of data, such as a rotor speed or gap voltage at the probe. The standard is set by defining an acceptable median value for the data and a series of one or more regions around the median.

Figure C-1 shows a typical scalar standard for gap volts. Here, the median value is -8.0, volts, and any value within 0.5 volts of the median (-7.5 volts to -8.5 volts) is considered "nominal". Any value greater that 0.5 volts but less than 1.0 volt from the median (-7.0 volts to -9.0 volts) is considered to be in a "warning" condition. Deviations greater than 1.0 volt are considered an "alarm" condition. These values are for illustration purposes only and would provide for an alarm condition if the gap changed by more than 5 mils. This assumes a vibration probe sensitivity of 200 mv/mil.
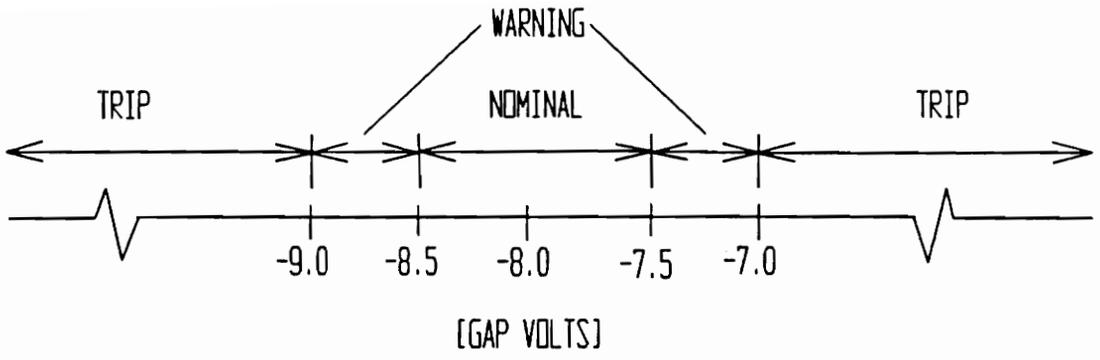
Figure C-1   Scalar Standard for Gap Volts

Because the scalar standard is used in performing fixed and deviation evaluations, the median values are constant or variable, respectively. Note, however, that in both cases the magnitudes of the deviation and median values must be defined by the user before IMTS has begun operation. Nevertheless, for the scalar standard which performs a deviation evaluation, the median value may be reset while IMTS is operating. The median value after a reset is equal to the value of the most recently acquired value of the parameter that it evaluates. For example, assume a scalar standard is applied to the overall vibration parameter. If the current overall vibration is 5 mils and the current median value is 7 mils, then the median value after a reset would be equal to the current overall vibration, 5 mils. A reset effectively shifts the center of the scalar standard to the current parameter's value.

C.2 Vector Standard

Vector standards involve two variables that can be used to define a two dimensional vector, such as vibrational amplitude and its corresponding phase. The standard is set by defining the nominal magnitude and phase angle of the vector formed by the two variables, and a series of one or more allowable deviations by which the magnitude of the measured vector is allowed to vary from the nominal one.

An illustration of this type of standard for synchronous vibration and phase is given in Fig. C-2. The nominal vector is 2 mils at a phase of 40°. Actual vectors whose tips fall within a 1 mil circle of this vector are considered "nominal". Those greater than 1 mil and less than 2 mils are considered "marginal", greater than 2 mils and less than 3 mils
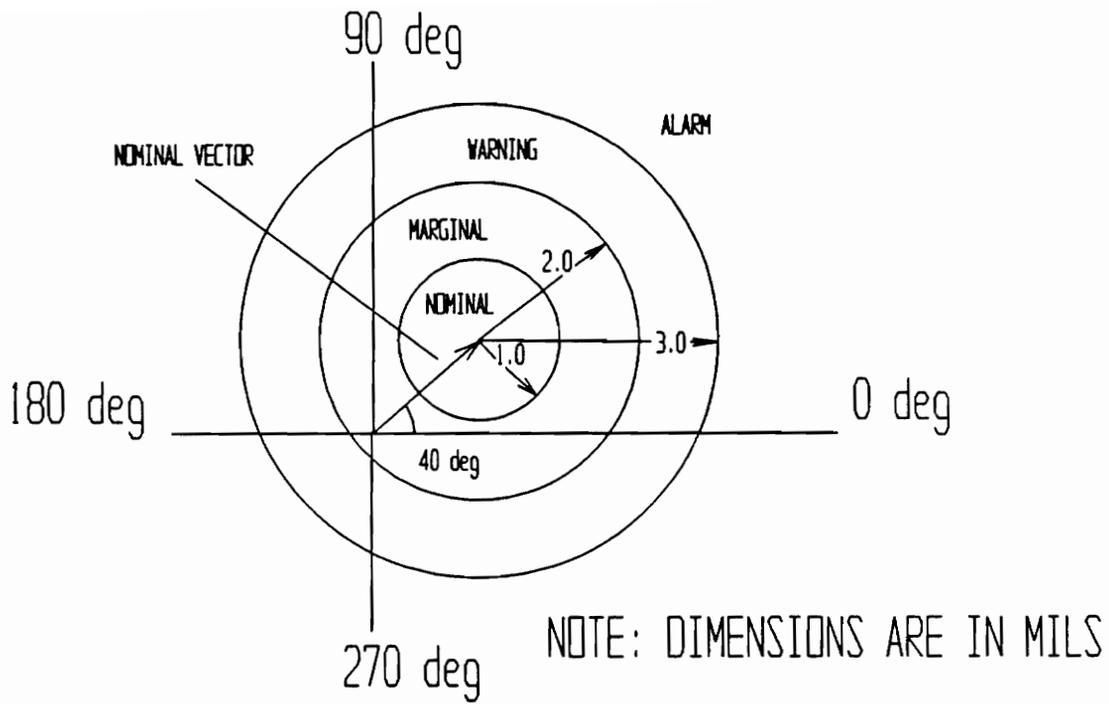
Figure C-2 Vector Standard

are taken as a "warning", and greater than 3 mils are in an "alarm" condition.

Like scalar standards, the nominal magnitude and phase with the corresponding deviations are set before starting operation. The nominal vector can be reset to the most recent set of acquired data during operation of the system.

C.3 Graphic Standard

Like many published standards, the graphic standard is created by selecting one variable as a function of another in a cartesian plane.

Figure C-3 shows a typical graphic standard with amplitude versus rotor speed. The standard is divided into regions marked by curves which are a function of the abscissa variable (speed). These regions represent different operational states of the machine. These standards must be created and set before IMTS can be activated.

C.4 Spectrum Standard

The spectrum standard is used to evaluate FFT spectrum data. It is similar in appearance to a graphic standard since the amplitude is a function of the frequency in the cartesian plane. Also, the curves are actually horizontal lines that indicate various regions of machine operation. Exactly three regions of operation are permitted: "good", "fair", and "poor" as shown in Fig. C-4. Furthermore, the frequency axis (abscissa) must be divided into no more than 10 zones. Evaluations yielded with the spectrum standard are based on the maximum amplitude
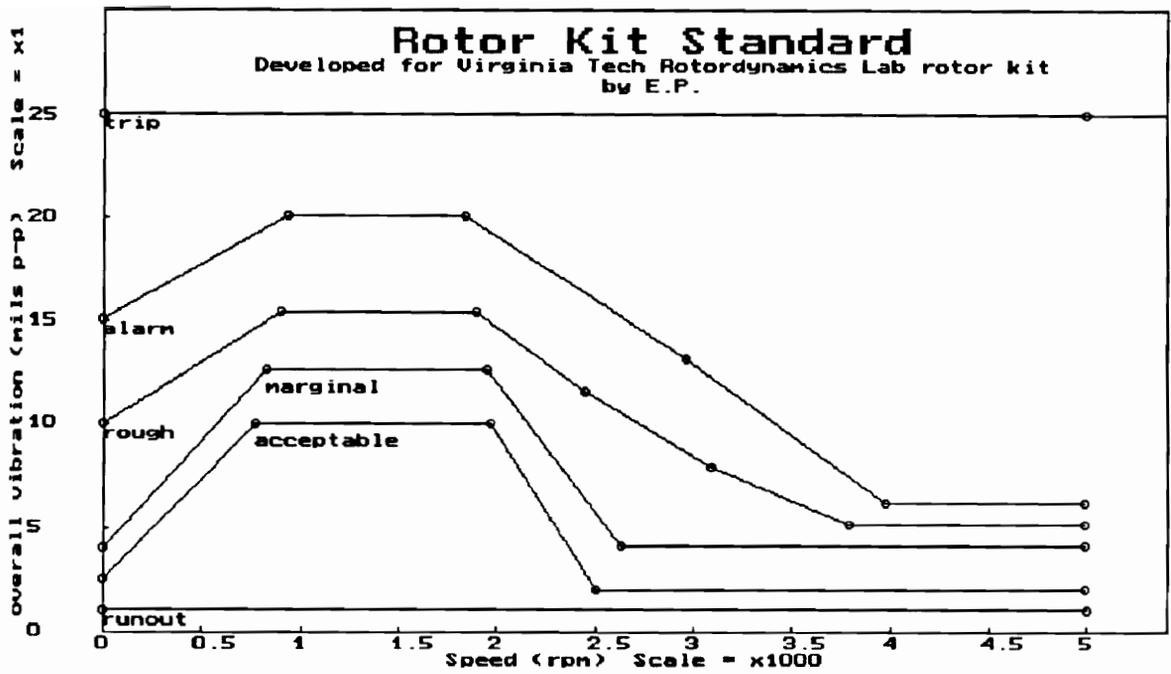
Figure C-3   Graphics Standard for Overall Amplitude Vs. Speed
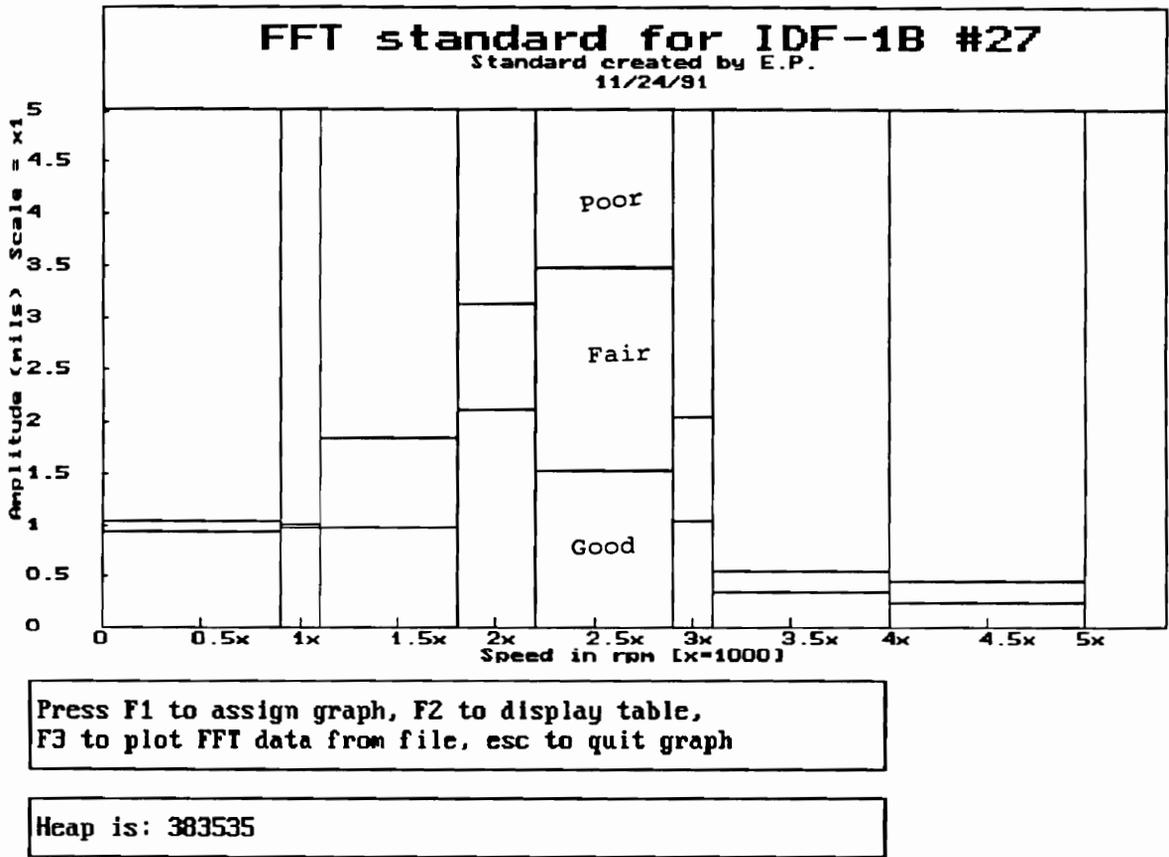
Figure C-4   FFT Standard

found within each defined zone. These standards must also be created and

set before **IMTS** is activated.

[10] Pawtowski, E., Typrin, M., Kirk, R. G., "An Intelligent Standards Filter For A PC-based Expert System", <u>Focus Of Mechanical Failures: Mechanisms And Detection, Proceeding of the 45th Meeting of The Mechanical Failures Prevention Group</u>, Annapolis, Md., April 9-11, 1991. pp. 109-116.

[11] Typrin, M. Pawtowski, E., Kirk, R. G., "A PC-based Evaluation And Monitoring System For Rotating Machinery", <u>Proceedings of Conference Rotordynamics '92</u>, Venice, Italy, April 28-30, 1992.

Appendix - D CONFIG.SYS

```
DEVICE=C:\DOS\SETVER.EXE
DEVICE=C:\DOS\HIMEM.SYS
DEVICE=C:\DOS\EMM386.EXE NOEMS X=DC00-E000
DOS=HIGH,umb
FILES= 100
BREAK=ON
BUFFERS=20
LASTDRIVE=F
SHELL=C:\DOS\COMMAND.COM C:\DOS\ /E:4092 /p
DEVICE=C:\DOS\ramdrive.sys 1024 /e
DEVICEHIGH=RCD.SYS /F /P
```

Vita

Marcello Typrin was born on December 18, 1966 in Rio de Janeiro, Brazil. At the age of four, he and his parents moved to the Washington D.C. area. He graduated high school from the Fairfax County public schools system in June, 1985 and entered Virginia Polytechnic Institute and State University in the fall of the same year. He received his Bachelor of Science Degree in Mechanical Engineering in June, 1990. In February, 1992, Marcello successfully defended his thesis and received his Master of Science Degree in Mechanical Engineering. Marcello has accepted a position with Cooper Industries in the Engineering Management Training Program.