ATTACHMENT 11

AUTOMATED MACHINERY DIAGNOSTICS

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INTRODUCTION

Over the last few years, many segments of industry that operate large rotating machinery have instituted vibration monitoring programs. Displacement, velocity or acceleration sensors are either permanantly installed on machines or are periodically installed while data is taken. Originally, simple overall amplitude was monitored with limits set on the amplitude of the signal. Signals in excess of these limits indicated a dangerous operating condition, and in some cases, the machine was automatically shut down. Machinery protection from catastrophic failure in this manner while valuable, did not provide diagnostic information that could be used in maintenance planning.

It has been convincingly demonstrated that additional insight into machinery condition may be gained if the data from vibration sensors are analyzed using modern Fast Fourier Transform (FFT) techniques. Over the years, individuals have gained skill in relating the appearance and changes in FFT plots to mechanical condition of the machine being monitored. As long as the number of machines to be monitored is limited, a skilled individual can provide diagnostic information by comparing new spectra to past spectra and observing trends in the data. Attempts to expand this manual analysis to whole plants has resulted in problems associated in training more people to analyze the vast amounts of data that can be generated.

This paper describes a system that relieves this problem by:

1. Automatically analyzing and comparing spectra very quickly and only flagging those signals which have shown significant changes from the last analysis.
2. Assigns a probable cause for the signal variation noted and automatically assesses the seriousness of the problem.
3. In cases where automatic assessment of cause and seriousness is not possible, the system efficiently presents the diagnostic engineer with the significant data.

The system development has been funded by the Electric Power Research Institute and is presently installed in the Northeast Utilities Millstone II Nuclear Power Plant.

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SYSTEM REQUIREMENTS

The intent of the system development is to provide a computer controlled system that processes, compares and assigns identifications to the data in much the same way that a skilled analyst would do. To accomplish this, the experience of Shaker Research Corporation engineers who have been involved in machinery troubleshooting for many years was reviewed. The kinds of analysis that have provided diagnostic information in the past have included:

1. Analysis of transient conditions that occur during machinery starts and stops to determine the machine's response as its speed passes through the rotors critical speed(s) and other structural resonances.
2. Demodulation of high frequency resonances which allow the identification of the excitation source of the resonance as a seal or blade rub or in some machines a defective rolling element bearing.
3. Subtraction of runout error from displacement probes. This feature operates in connection with the start/stop operation since runout is memorized either on the first few turns of a start or the last few of a stop.
4. Comparison on a frequency and amplitude basis of the present spectrum with the last and previous spectra. Speed variations must be normalized as part of this comparison.

The system as developed performs all the above analysis. A monitor panel is also included which has warning and alarm indicators for the overall level of each sensor. These indicators are wired into the computer to provide an interrupt so that data may be stored and analyzed during the period of time that signals from any sensor exceed these limits. Some of the aspects of the system operation during transients such as starts, stops or alarms are discussed in References 1 and 2. High frequency vibration techniques and runout correction are discussed in References 3 and 4. This paper will concentrate on the procedures to compare and diagnose the steady state spectra.

SPECTRUM ANALYSIS

Ideally, when the equipment in a plant is new, spectra would be loaded into the computer to provide an as new history. Millstone II Nuclear Power Plant had been in operation for a little over a year when the system was installed so that spectra taken at this time were loaded. These "as new" data are not stored as complete spectra but rather the amplitudes of signals over a given noise level are stored. Table 1 shows a typical set of stored data. If a machine is overhauled during a shutdown, initial runs allow a comparison between before and after overhaul. In most cases, a new "as new" set of data would then be stored for the overhauled pump.

Once the "as new" data are stored for each spectrum, the system starts cycling through all sensors and a new spectrum is obtained from the FFT unit. This spectrum is stored as a complete 400 line spectrum. Figure 1 shows a typical spectrum where the X's are the "as new" points sotred. Several comparisons are now made which may be explained by referring to the sketch in Figure 2. In the top sketch, if a peak has increased over the original "as new" stored peak by a predetermined percentage, this fact is flagged. On subsequent samples of this spectrum it is not desired to continually flag this peak so that when it is first flagged, a new reference "Z" is stored. On the next cycle therefore, the computer recognizes that the peak is over the "as new" stored data but on checking the table of Z's, it finds it has not exceeded the last reference.

It is also important from a diagnostic standpoint to know if a given peak increases in amplitude quickly or over a long period of time. If the peak in qestion is the unbalance signal for example, a slow increase could indicate contaminate buildup while a sudden increase could indicate a sudden mass shift that could occur if a blade had broken or a coupling shifted. In the third sketch, the solid line would indicate the last spectrum taken while the dashed peak is the latest. This rapid increase is also flagged and identified as a rapid increase.

Finally, a new peak might appear over the predetermined noise level. This fact is also flagged and identified as a different type of occurrence from the previous two discussed. Flags are also set when signals decrease in amplitude by the predetermined percentage. Every time a flag is set, a new reference is stored along with the spectral data and this value is also stored along with the data and time in a trend area identified by the spectrum number.

To achieve the frequency resolution needed in the low frequency area as well as to observe high frequency resonances more than one spectra are often taken and stored for a given sensor. In the case of high frequency accelerometers, as many as 5 spectra can be taken, one low frequency (0-500 Hz), one medium frequency (0-5000 Hz), one high frequency (0-50 KHz) and two spectra generated by demodulating two different high frequency resonances. The high frequency spectra are treated differently than the low frequency discrete spectra in that the energy of the resonance is monitored rather than the peak amplitude alone. A typical high frequency spectrum is shown in Figure 3.

If the discrete spectrum being analyzed is from a machine which can operate at variable speeds much as a steam turbine driven pump, the system must recognize the influence of a speed change so that proper peaks are compared. For these pumps, a reference speed is selected that is approxiamtely in the center of the expected speed variation. Frequencies of peaks in the spectra are converted to this reference speed by measuring the actual speed just prior to taking the spectrum and calculating a correct factor. Limits must be set on how much the correction factor may deviate from 1.0 and still compare amplitude directly. There may be some spectra peaks that are due to resonances or simple electrical noise which should not be shifted as a function of speed and provisions must be made in the program to allow certain spectral peaks to be excluded from the speed correction process.

All of the above data comparison functions are those that the analyst must consider as he compares present spectral data to the past records. The chance for error is great and even so, a very large record keeping system must be developed if many machines are to be monitored periodically. It is readily apparent why the diagnostic engineer quickly loses interest in this respective data comparison process and why it is ideally suited to computer processing.

The process described to this point is the data analysis function, but has introduced very little in the area of diagnosing the machinery problem and variations in the data are observed. Diagnosis should not be made for a machine on the basis of one spectrum from one sensor but rather by comparing out of tolerance signals for all spectra from all its sensors. Therefore, the data analysis function continues until all the data from all the sensors have been analyzed.

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As flags are raised for significant variations in the amplitudes of a spectral peak, the kind of occurrence (i.e., rapid increase) is coded along with the amplitude and frequency of the peak and these data are stored in temporary diagnostic tables. When all spectra for a given machine have been analyzed, there will be one diagnostic table for each spectrum that showed a significant variation. For the feedwater pump which has six sensors (4 accelerometers and 2 displacement transducers), 22 spectra are possible and thus if all contained significant variations, there could be 22 diagnostic tables.

The next step is to identify each of the frequencies and to consolidate all the information into one table that facilitates comparisons. Each machine type that is being analyzed by the computer has an identification table stored for it. Table II is the identification table for the condensate pump. Each of the identification numbers down to the -1 in the second column identifies a discrete frequency vibration signal that can be generated by the machine. Those below the -1 are ranges of frequencies excluding those discrete frequencies already identified above. For instance, identification 27 includes all those signals between 200 and 500 Hz except for those at 240 and 300 Hz.

Warning and alarm levels are given for each signal that is identified. The numbers shown are in engineering units multiplied by 100 so that the warning level IW1 (sensor 1) for ID 7 is 0.2g's while IW3 is 1 Mil; sensor 3 is a displacement probe. The zeros indicate that there are not spectra in the frequency range noted for a given sensor (high frequency spectra are not taken for displacement sensors). The number in the INO column refers to a specific fault listed in a stored fault identity table, Table III.

Finally a printout is displayed on the screen, (Figure 4), that includes the frequency, those sensors that showed a significant variation of the signal, the amplitude of the signal for each sensor and the warning and alarm levels for each sensor as well as the identification of the source of the signal. The type of signal change is listed, i.e., rapid increase over last reading as well as a recommendation for action to be taken. If the actual level exceeds the warning or alarm level, then a hard copy is automatically produced.

The diagnostic engineer may now spend his time considering those indications of serious degradations. He can now interrogate the system to obtain additional information such as a spectrum plot or he can observe the time history of a given sensor by observing a trend plot, Figure 5. He may also change several of the system variables such as warning and alarm levels or the percentages used to flag signal variations. If a sensor is replaced, new calibration data may easily be entered. The options available to the engineer are shown in the menu, Figure 6, that is presented to him when he interrogates the system. Note one option is to conduct diagnostic tests on the system itself.

CONCLUSIONS

The system accomplishes the two objectives set for it. It takes the drudgery out of data analysis of vast amounts of spectra generated from many sensors on many machines. It makes an initial diagnosis and retains historical trend data to allow the diagnostic engineer to conduct a further investigation if he so desires.

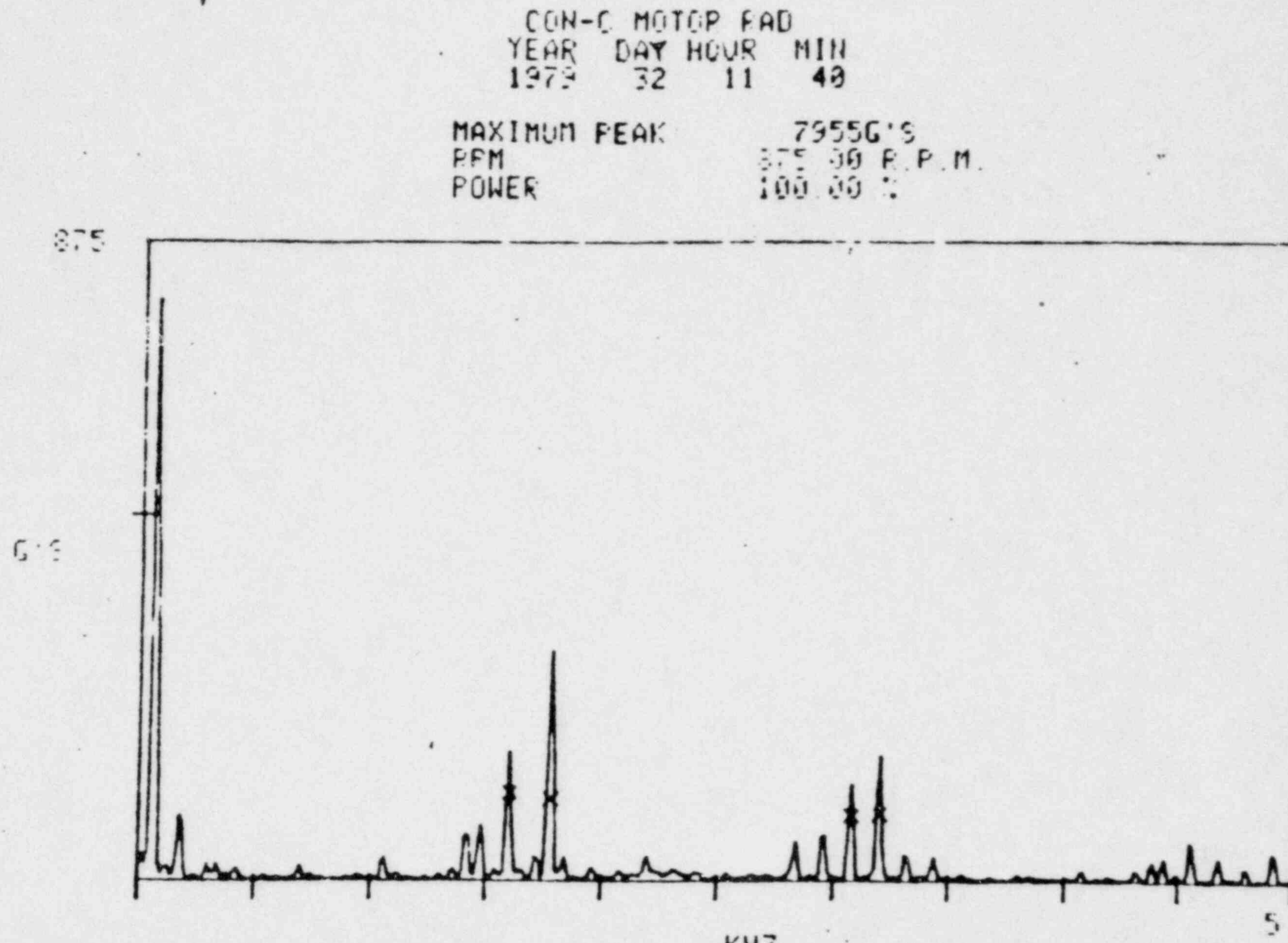

Figure 1

Spectrum with Y's

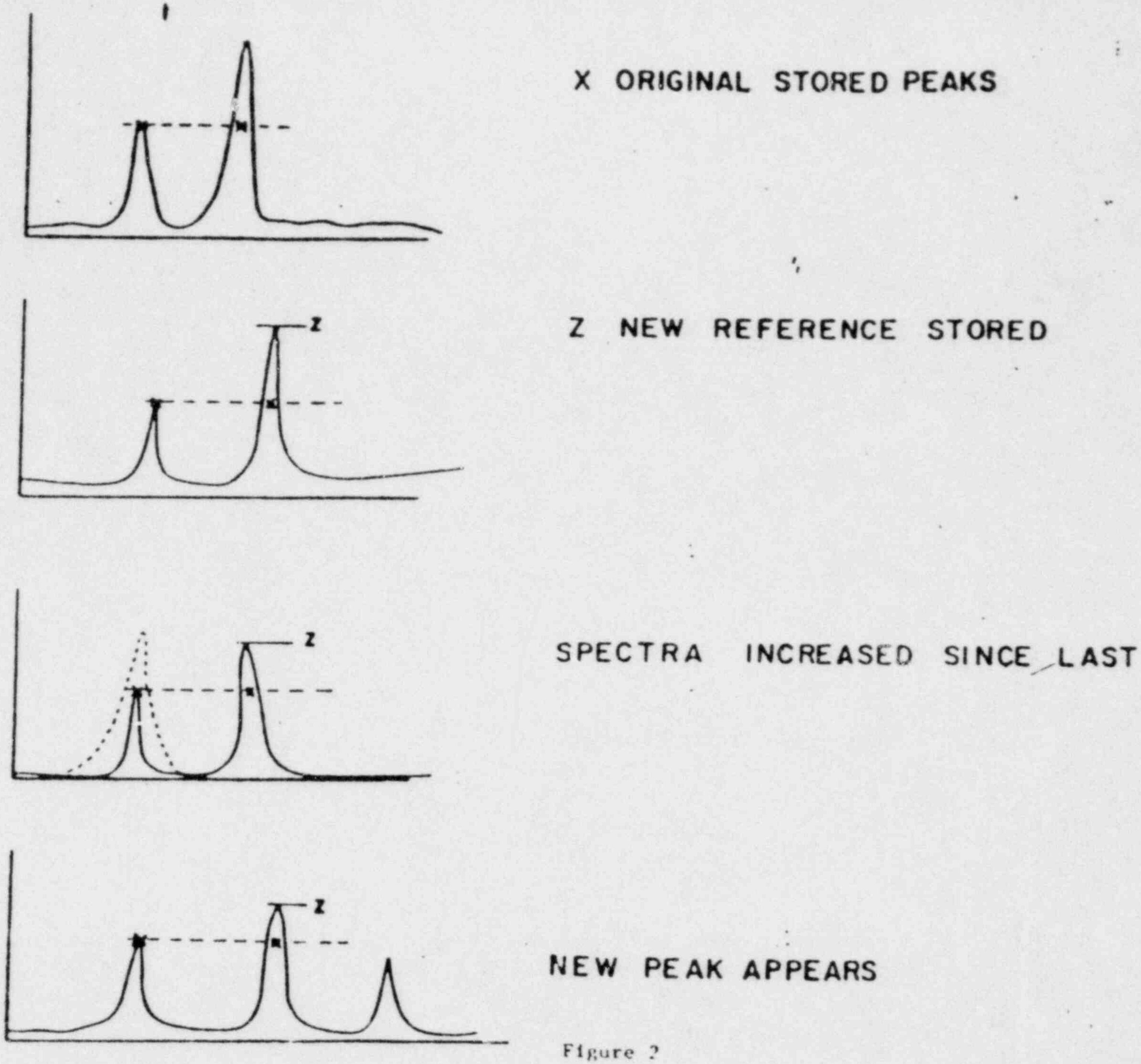
X ORIGINAL STORED PEAKS
Z NEW REFERENCE STORED
SPECTRA INCREASED SINCE LAST
NEW PEAK APPEARS
Z
Z
Z

Figure 2

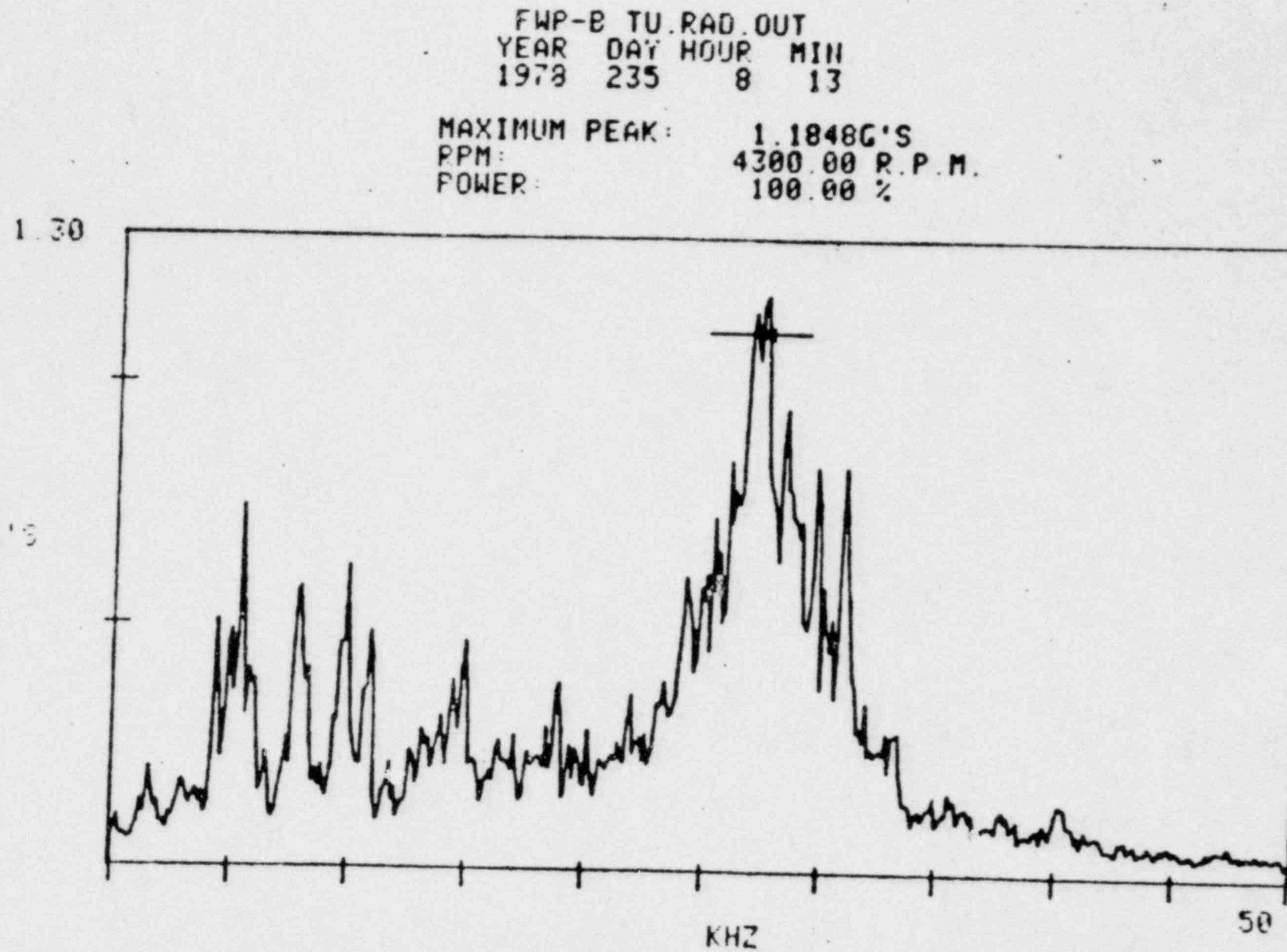

Figure 3

High Frequency Spectra

DATE 7-24-1978 TIME 0)40

SENSOR	FREQ HZ	CHANGE CODE	PRES	LEVEL WAR	ALA	MESSAGE
1	15	203	15	23	35	UNBALANCE
3	15	203	12	23	35	

SLOW DECREASE OVER REFERENCE SET
CONTINUE OPERATION

4	13	203	160	300	600	SUB HARMONIC

SLOW DECREASE OVER REFERENCE SET
CONTINUE OPERATION

SENSOR # 1 IS RCP-C PUMP AX.
SENSOR # 2 IS RCP-C PUMP RAD
SENSOR # 3 IS RCP-C MOTOR RAD
SENSOR # 4 IS RCP-C PUMP DISP
SENSOR # 5 IS RCP-C MOTOR DISP

Figure 4

Diagnostic Printout

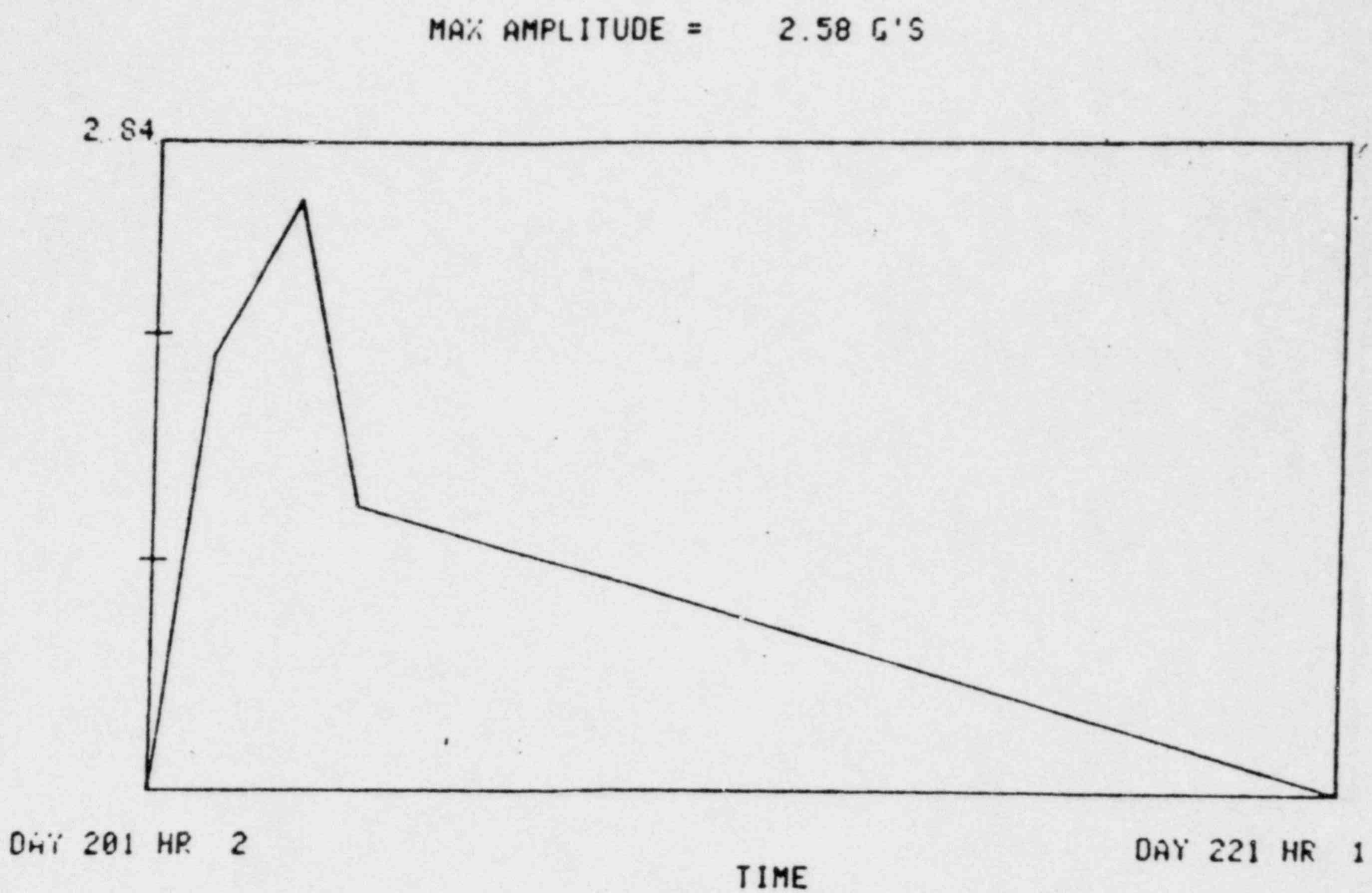

Figure 5
Trend

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**********MENU*****************

 1 CHANGE PROBE TYPE
 2 CHANGE NOISE & PEAK DIFFERENCE LEVELS
 3 EDIT DIAGNOSTIC IDENT TABLE
 4 EDIT CONDITION & RECOMMENDATION FILE
 5 EDIT SENSOR NAME FILE
 6 CHANGE % LEVEL FOR FLAGS
 7 CHANGE STORED PEAKS
    INCLUDES OPTION TO GET NEW SPECTRA
 8 PLOT DATA
 9 EDIT MESSAGE FILE
10 RUN HARDWARE DIAGNOSTICS
11 RUN EXERC
12 GET LIST OF SENSOR INFO FOR A GIVEN MACHINE
13 LOOK AT STORED DATA FOR A GIVEN SPECTRUM
14 LOOK AT TRENDS FOR A GIVEN SPECTRUM
99 EXIT

ENTER YOUR CHOICE
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Figure 6

Menu

Table 1

Stored Data

DATE 2- 1-1979

NO. OF PEAKS IS 4 FREQM = 5000.00

BIN	FREQUENCY	PEAK VALUE
128	1600	1208
142	1775	1122
246	3075	.0892
256	3200	.0911

DATE = 1-24-[illegible]8 [illegible]

MACHINE = 4 (Condensate Pump)

SECTOR = 3280

INX	ID	IFREQ	INO	IW1	IA1	IW2	IA2	IW3	IA3
1	1	12	1	20	40	20	40	200	500
2	2	15	2	23	35	23	35	500	1000
3	3	30	3	20	35	20	35	100	500
4	4	44	4	35	20	35	100	500	0
5	5	60	5	50	100	15	30	100	500
6	6	59	6	50	100	15	30	100	500
7	7	74	7	20	30	20	30	100	500
8	8	88	8	40	100	30	60	100	500
9	9	120	9	40	100	39	38	100	360
10	10	180	10	50	100	15	30	100	300
11	11	177	11	50	100	15	30	100	300
12	12	240	12	40	100	39	38	100	300
13	13	300	13	50	100	15	30	0	0
14	14	1475	14	300	700	500	1000	0	0
15	15	1600	14	300	700	500	1000	0	0
16	16	1725	14	300	700	500	1000	0	0
17	17	2825	15	300	700	500	1000	0	0
18	18	2950	15	300	700	500	1000	0	0
19	19	3075	15	300	700	500	1000	0	0
20	20	3200	15	300	700	500	1000	0	0
21	21	4325	16	300	700	500	1000	0	0
22	22	4425	16	300	700	500	1000	0	0
23	23	4550	16	300	700	500	1000	0	0
24	-1	0	0	0	0	0	0	0	0
25	24	10	17	20	30	20	35	100	300
26	25	100	18	100	200	25	35	100	300
27	26	200	18	100	200	40	80	100	300
28	27	500	18	100	200	40	80	0	0
29	28	600	18	100	200	40	80	0	0
30	29	1500	19	300	700	150	300	0	0
31	30	5000	20	300	700	500	1000	0	0
32	31	32767	21	500	1000	500	1000	0	0
33	0	0	0	0	0	0	0	0	0
		Freq. (~)	Fault	Warn level (Sensor 1)	Alarm level (Sen. 1)	Warn (Sen.2)	Alarm	Warn (Sensor 3)	Alarm

——— ALL LEVELS ARE MULTIPLIED BY 100 ———

TABLE 2

IDENT TABLE

Table 3

Fault Ident Table

1	ROTOR/MOUNTING RESONANCE	17	SUB HARMONIC
2	UNBALANCE	18	UNKNOWN
3	POSSIBLE MISALIGNMENT	19	FLOW IND. PMP/UNKNOWN/SLOT(MTR)
4	3 X RUNNING	20	FLO NOIS PMP/UNKNOWN/SLOT(MTR)
5	ELECTRICAL NOISE (60)	21	(PMS) RUB
6	4 X RUNNING	22	STRUCTURAL RESONANCE
7	5 X RUNNING	23	1ST CRITICAL
8	PUMP BLADE PASS	24	2ND CRITICAL
9	MOTOR (120)	25	POSSIBLE PUMP INDUCED
10	ELECTRICAL NOISE (180)	26	PUMP BLADE PASS MULTIPLE
11	2 X BLADE PASS	27	POSSIBLE BLADE INDUCED
12	2 X MOTOR	28	MOTOR INDUCED
13	ELECTRICAL NOISE(300)	29	TURBINE INDUCED AXIAL VIB
14	MOTOR SLOT AND S.B	30	RUNNING MULTIPLE
15	2 X MOTOR SLOT AND S.B.	31	TURBINE STRUCTURAL RESONANCE
16	3 X MOTOR SLOT AND S.B	32	ELECTRICAL NOISE(120)