THE PREDICTIVE MAINTENANCE PROGRAM ON ROTATING EQUIPMENT AT THE BRUCE HEAVY WATER PLANT

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1.0 ABSTRACT

The Predictive Maintenance Program (PMP) on rotating equipment at the Bruce Heavy Water Plant (BHWP) has been greatly enhanced by the purchase of the Vitec DC+ Data Collector, along with its associated software and a computer. This equipment, which was purchased by the Maintenance Unit in 1986, allows rotating equipment to be monitored and analysed more effectively, and with less resources, than was previously possible.

The reason for this increased effectiveness is the equipment's ability to more easily take readings in the field, and to generate trend data and vibration frequency spectrums quickly and accurately. This data quickly identifies problem areas which may require close monitoring, more detailed analysis and/or immediate repairs. The end result is that timely repairs are made in a planned, orderly manner before an unsafe condition or serious damage occurs.

The following Vitec DC+ PMP Flowchart is provided as a summary of the Predictive Maintenance Program on rotating equipment at BHWP, (Figure 1).

2.0 THE PREDICTIVE MAINTENANCE PROGRAM

The primary purpose of the predictive maintenance program on rotating equipment is the early detection of any deterioration of rotating equipment, so that corrective action can be taken before any major equipment failure takes place. The overall impact of the program will be the lowering of equipment maintenance costs and a reduction in unscheduled downtime. The program is divided into two main functions, a Vibration Monitoring Program and a Vibration Analysis Program.

The Vibration Monitoring Program (VMP) gathers information by taking readings on rotating equipment in the field. This is usually performed on a weekly basis. Also, as part of this program, visual defects are noted and recorded for correction.

The Vibration Analysis Program (VAP) takes this information from the field and produces a mass of data from which experienced personnel can diagnose exactly what is wrong with the equipment. Corrective action is then initiated by preparing work orders (DR's) and forwarding these to the appropriate work group for action.

THE VITEC DC+ PMP FLOWCHART

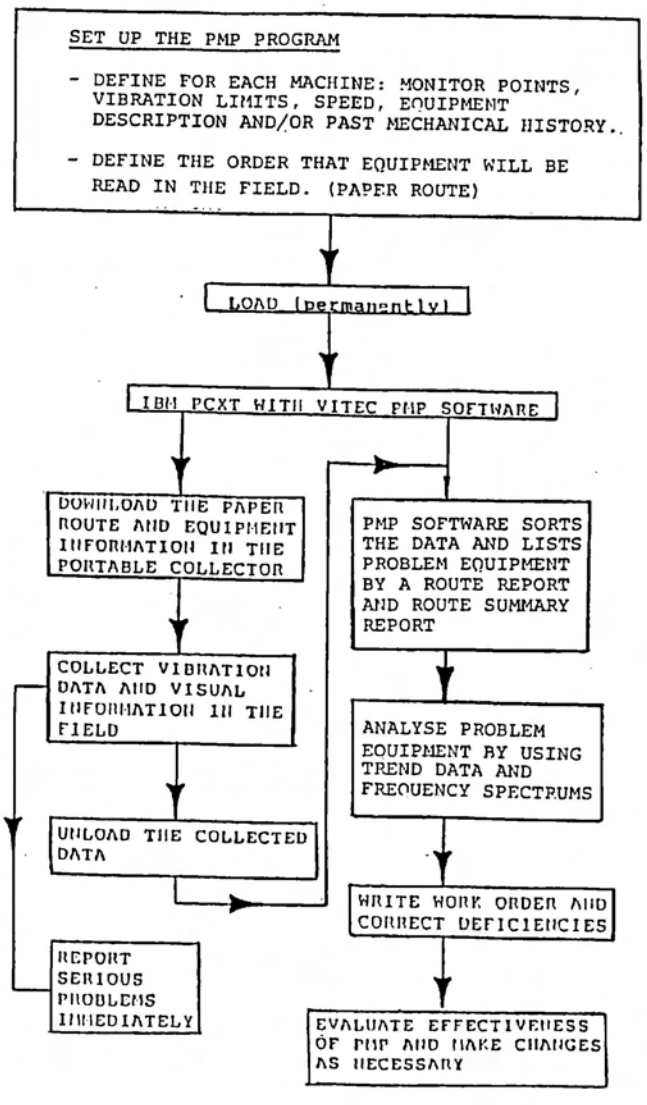


FIGURE 1: PMP FLOWCHART

Both of these programs are the responsibility of a single maintenance crew which normally consists of 2 Mechanical Maintainers. Their responsibilities in terms of vibration monitoring and analysis are as follows:

To take a set of routine readings on all rotating equipment once a week.

To identify rotating equipment that is trending towards or has exceeded preset vibration limits.

To develop base line readings after equipment overhauls.

To take pre-outage surveys to identify work to be performed during the outage.

To respond to requests from plant engineering groups and/or the Maintenance Unit.

3.0 VIBRATION MONITORING PROGRAM

3.1 Equipment

The equipment used at the BHWP for the PMP on rotating equipment is as follows:

3.1.1 A Vitec DC+ portable Data Collector complete with a magnetic accelerometer, case and shoulder strap. The unit weighs 6.5 lbs with physical dimensions of 4" H x 8 1/2" W x 9" D.

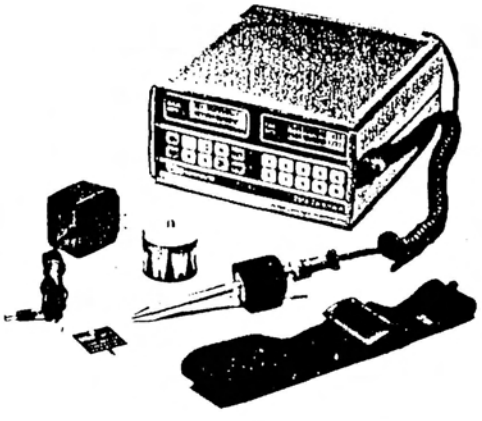


FIGURE 2: VITEC DC+ DATA COLLECTOR

3.1.2 An IBM PC XT host computer complete with graphics card and colour monitor.

3.1.3 A Vitec PMP software package which includes functions for DC+ communications, logging, trending, time domain display and FFT analysis. Software packages are also available for the IBM PC/AT, IBM PC Compatibles and the HP-150.

3.2 Training

3.2.1 The Vitec System comes complete with an operations manual which provides all the necessary information on how to operate the system.

3.2.2 The computer software package is fully user friendly and requires no computer expertise in order to run the program.

3.2.3 A maintenance procedure has been written to indicate how the PMP will be enacted at BHWP.

3.3 Field Data Collection

Data is collected by a vibration crew who follow predetermined routes which have been downloaded from the computer to the portable data collector.

At the BHWP, there are four routes covering the main operational units of the plant. These routes have a combined total of 765 vibration points which are recorded on a weekly basis. The data collector is capable of storing 15 routes, with each route having a maximum of 500 vibration points.

Three vibration readings are taken in one measurement at each monitor point on a piece of equipment. Typically, a verticle centrifical pump requires three (3) measurements compared to a large H_2S blower which requires up to eleven (11) measurements. The three vibration readings taken are as follows:

Overall Vibration (mm/s). This measures velocity in the 2-10 KHz range and is therefore considered a wide band measurement. This measurement detects common machinery problems such as unbalance, misalignment, and looseness. As the velocity of vibration is proportional to the destructive energy being produced, it is the best measurement to take to determine the overall mechanical health of the machine.

Band Pass Vibration (mm/s). This measures velocity in the 0.5-4KHz range and is used to identify problems such as cavitation and lack of lubrication.

Bearing Condition (BU). This measures acceleration in g's and is used to identify problems with rolling element bearings. This measurement is very sensitive to both high frequency (above 500 Hz) and high acceleration values of vibration normally produced by faulty rolling element bearings.

The portable data collector is equipped with three alarms:

A setpoint alarm which is preset and based on the equipment's operational history and the manufacturer's recommended running levels.

An alarm when the current vibration reading has increased by a factor of two over the previous measurement.

An alarm when the current vibration reading has decreased by a factor of 1/2 compared to the previous measurement.

In the event an alarm is activated, the Data Collector will immediately request the operator to take an AC signal reading for Fast Fourier Transform (FFT) analysis. This FFT analysis provides a display of the vibration levels over the 0 - 0.5 KHz and/or 0 - 4 KHz frequency range and is performed by pushing a button on the data collector and waiting approximately two seconds. The computer will store and present this data in a form which will provide the needed information to highlight the equipment problems.

A means of recording visual deficiencies to backup the vibration reading is provided by entering predetermined trouble codes into the data collector. A list of the trouble codes used at the BHWP is provided in Figure 3.

TROUBLE CODES

PART	MECHANICAL PROBLEMS	LEAKS
0	10 Missing	20
1 Gasket	11 Noisy	21 Leaking Oil
2 Seal	12 Loose	22 Leaking Water
3 Packing	13 Rubbing	23 Leaking Steam
4 Filters	14 Hot	24 Leaking H2S
5 Belts	15 Worn	25 Leaking N2
6 Bearing	16 Bent	26 Leaking Propane
7 Coupling	17 Excess Vibration	27 Leaking Acid
8 Shaft	18 Cracked	28 Leaking Caustic
9 Guard	19 Broken	29 Leaking Process

SERVICING	RECOMMENDATIONS	OUTPUT
30	40	50
31 Low Oil	41	51 Low Flow
32 Excess Oil	42	52 Low Pressure
33 Dirty Oil	43 Recommend Shutdown	53 Low Temperature
34 Dirty Site Glass	44 Repair Immediately	54 High Flow
35 Adjust Set Point	45 Repair Within 7 Days	55 High Pressure
36	46 Repair Within 30 Days	56 High Temperature
37 Repair	47 Repair Within 90 Days	57 Cavitation
38 Replace	48 Repair Next Outage	58 Surging
39 Lubricate	49 Do Complete Analysis	59

WINTERIZATION	ACCESS	MEASUREMENTS
60	70	80
61 No Insulation	71 No Access	81 Routine
62 Poor Insulation	72 Roped Off	82 Special Request
63 Steam Tracing	73 Radiography	83 Before Shutdown
64 Steam Tracing Leaks	74 Scaffolding	84 Baseline
65 Excess Ice		

HOUSEKEEPING	STATUS	NOTE PAD ENTRY
85 Dirty Area	0 Out of Service	99
86 Dirty Machine	98 Out for Maintenance	
87 Oily Pad		

FIGURE 3: TROUBLE CODES

4.0 VIBRATION ANALYSIS PROGRAM

After the data has been collected in the field, the information is uploaded into the host computer for analysis. The computer sorts the data and is capable of providing numerous reports on request.

4.1 Route Reports

The Route Report (Figure 4) provides details on all the vibration readings taken, with codes to identify abnormal readings and trouble codes.

The Route Report also highlights equipment that is trending towards an alarm condition within the next 10 days.

4.2 Route Summary Report

The Route Summary Report lists equipment that is over alarm or trending to an over alarm condition, equipment with trouble codes and equipment removed for maintenance and/or out of service. A typical summary report is provided as Figure 5.

ROUTE REPORT 08-07-1987

MACHINE ID	OVERALL VIBRATION	BANDPASS VIBRATION	BEARING CONDITION	TROUBLE CODES	FFT"S (KHz)
3P106A.A	3.36 mm/s T	0.88 mm/s	1.21 BU		
3P106A.B	1.97 mm/s	0.40 mm/s	0.52 BU		
3P106A.C	1.09 mm/s	0.40 mm/s	0.38 BU A	11	.5,4
3P106B.A	7.43 mm/s	1.19 mm/s	0.86 BU		
3P106B.B	2.77 mm/s	0.38 mm/s	0.62 BU		
3P106B.C	1.28 mm/s	0.38 mm/s	0.39 BU		
3P106C.A	2.52 mm/s	1.03 mm/s H	0.94 BU	22	.5,4

T - forecasted trend alarm within 10 days.
H - current reading is higher than 2X last reading.
L - current reading is less than half of the last reading.
A - current reading is in alarm.
* - stop added manually.

FIGURE 4: ROUTE REPORT

ROUTE SUMMARY REPORT

Machine Monitor Points That Recorded FFT's:

3P106A.C
3P106C.A

Machine Monitor Points in Vibration Warning Status:

3P106A.A

Vibration Signal Levels Exceeding Rate of Change Limits:

3P106C.A

Vibration Signal Levels Exceeding Alarm Limit:

3P106A.C

Vibration Signal Levels Not Read:

3P151B.B

Trouble Codes Recorded:

3P106A.C - Noisy
3P106C.A - Leaking Water

FIGURE 5: ROUTE SUMMARY REPORT

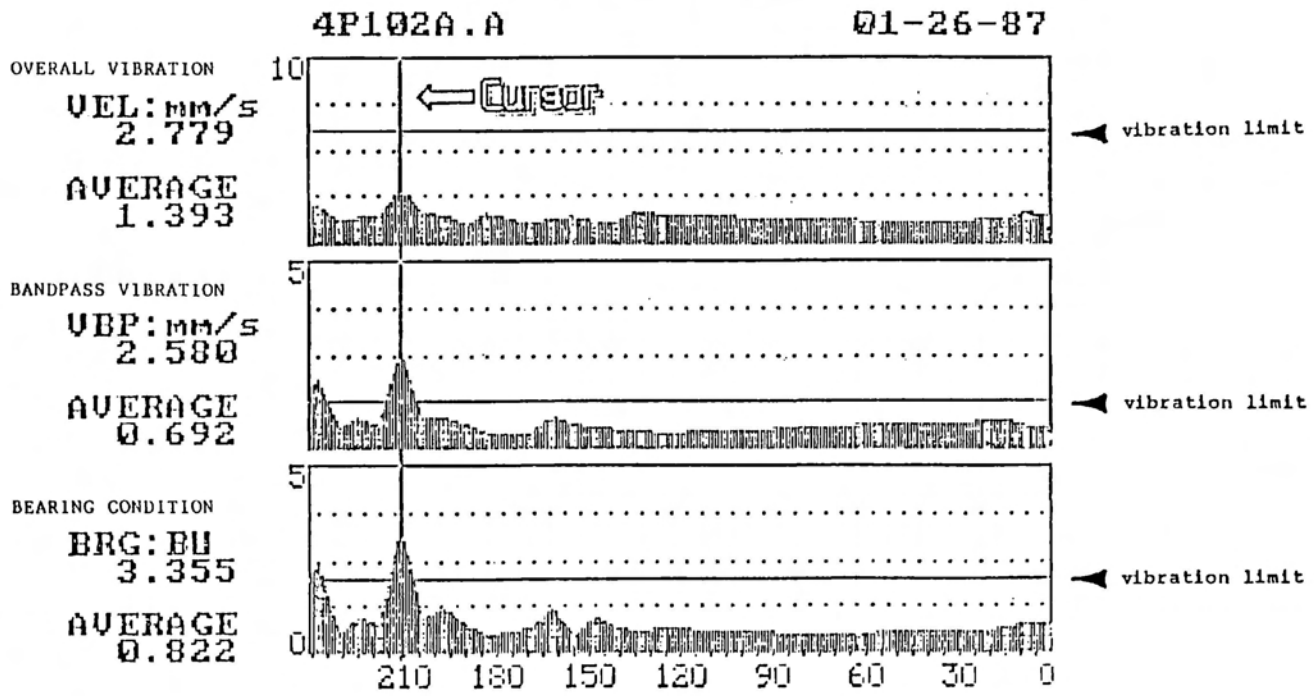
4.3 Trend Graphs

A Trend Graph (Figure 6) can be created for each monitor point which displays the three vibration readings recorded over a period of up to 300 days. The vibration limit is identified on the graph for each vibration reading and a verticle moving cursor allows the operator to read the exact vibration levels on the side scale. This trend graph can be expanded to predict vibration levels up to 30 days in the future.

4.4 Trend Summary Report

The Trend Summary Report (Figure 7) provides a summary listing of the minimum, maximum, and average vibration readings on a piece of equipment over the last 300 days plus highlights the vibration limits (alarm setpoints) and last current reading. The report is useful in determining if the alarm setpoints are reasonable and for quickly reviewing long-term history.

FIGURE 6: TREND GRAPH



Trend Summary Report
for Paper Route: F2

Machine ID	Vibration Min	Avg	Max	Limit	Bandpass Min	Avg	Max	Limit	Brg Cond Min	Avg	Max	Limit
1 P251A.A	1.7	2.1	2.7	6.0 mm/s	0.6	0.7	0.8	1.3 mm/s	0.3	0.4	0.5	2.0 BU
Current: 04-24-87				1.8 mm/s				0.7 mm/s				0.4 BU
2 P251B.A	1.6	4.0	6.5	6.0 mm/s	0.4	0.7	1.0	1.3 mm/s	0.2	0.5	0.5	2.0 BU
Current: 04-16-87				2.4 mm/s				0.6 mm/s				0.3 BU
3 P252A.A	1.4	1.8	3.4	6.6 mm/s	0.4	0.4	0.6	1.3 mm/s	0.2	0.4	0.5	2.0 BU
Current: 04-16-87				3.4 mm/s				0.4 mm/s				0.5 BU

FIGURE 7: TREND SUMMARY REPORT

4.5 Frequency Spectrums (FFT)

Frequency Spectrums provide a graphic display of the vibration reading vs frequency. This information forms the basis for identifying most equipment problems. Two spectrums are provided, one in the 0 to 0.5 KHz range and a second in the 0 to 4 KHz range. These are shown in Figures 8 and 9 respectively. Both of these displays can utilize either a verticle or horizontal moving cursor. The moving cursor allows the operator to read the frequency, in both Hz and CPM, amplitude and order of any point in the spectrum by reading the side scale. The order relates the frequency of vibration to the running speed of the equipment. When using a horizontal cursor (Figure 9) in a fixed position, the computer will list, below the printout, both frequency and amplitude for all vibration peaks above the cursor.

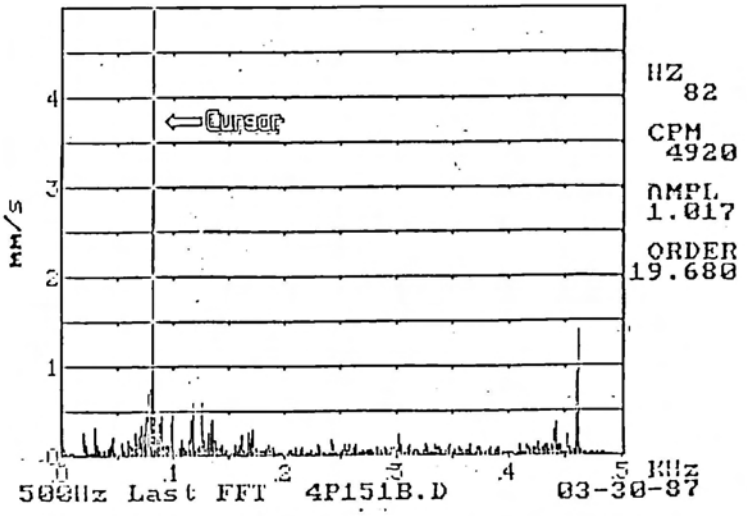
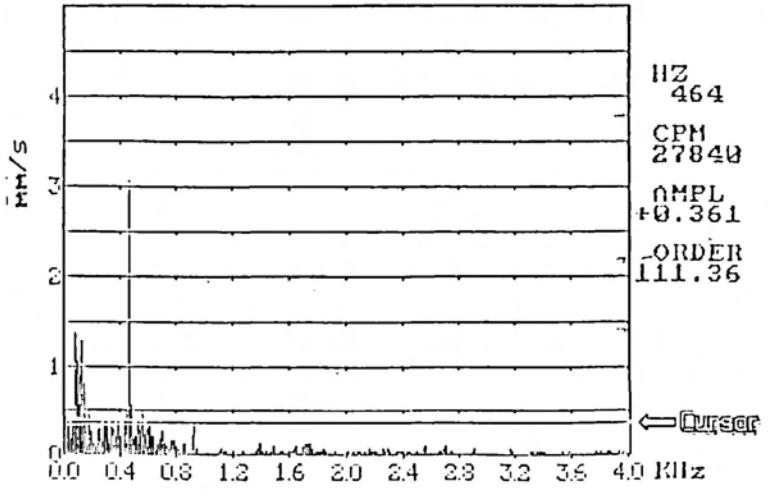


FIGURE 8: 0 - .5 KHz FFT

FIGURE 9: 0 - 4 KHz FFT



Frequency Amplitudes Above 0.361
80Hz (1.364) 128Hz (1.290) 176Hz (0.446)
414Hz (3.051) 480Hz (0.546) 560Hz (0.471)

All the data is analysed and work orders are prepared to initiate corrective action where necessary. At BHWP, a maintenance procedure has been written which contains for various RPM's the safe vibration operating ranges and corrective action when these ranges have been exceeded. Definitions of the various ranges are as follows:

(a) Below Range A - Safe Operating Range

(b) Range A - Significant Defect, Schedule Early Correction

(c) Range B - Acute Defect, Schedule Early Correction

(d) Range C - Damage level, Immediate Action

Figure 10 shows the Vibration Tolerance Chart.

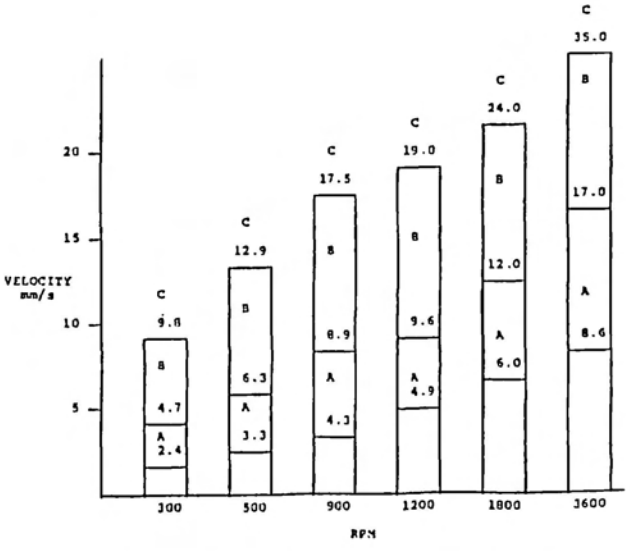


FIGURE 10: VIBRATION TOLERANCE CHART

The setpoint alarm for velocity is generally set to the interface between the safe operating range and the 'A' range. The following actions are taken at the various ranges:

1) Range A, Significant Defect

a) FFT analysis performed.

b) Operations contacted to determine if the condition is due to process change or upset.

c) Frequency of Monitoring increased.

d) Engineering Groups Informed.

e) Based on the FFT analysis, an equipment outage, will be scheduled.

2) Range B, Acute Defect

a) Same as above, only with more urgency.

b) An equipment outage will be scheduled as soon as possible.

3) Range C, Damage Level

a) Immediate shutdown of equipment.

5.0 EVALUATING THE EFFECTIVENESS OF THE PROGRAM

The effectiveness of the Predictive Maintenance Program must be tied back to its ability to meet the main objective of the program, that being its ability to identify problem equipment in an efficient and quick manner and provide a corrective course of action. At BHWP, the following performance indicators have been established:

The number of work orders raised by the system.

The number of catastrophic failures of rotating equipment that were not predicted by the system.

The number of pieces of rotating equipment running at high vibration levels i.e., in the B and C ranges on the BHWP tolerance chart.

These indicators, which may be changed in the future as experience is gained with the system, are an indication of how well the PMP is accomplishing it's objectives, as well as how acceptable it is to our users.

6.0 PERFORMANCE EXPERIENCE TO DATE

The present predictive maintenance program utilizing the Vitec System has been in operation for a period of approximately one year at BHWP. The following is a brief evaluation of our experience to date:

6.1 While the implementation of the program in the field has gone quite smoothly, some initial problems were encountered with the software and communicating the information contained in the volumes of data that the system produces. These problems have been worked out through software changes which improved the format of the reports, making them easier to understand.

6.2 The Vitec DC$^+$ System is able to perform both the Vibration Monitoring Program and the Vibration Analysis Program in about the same time as was previously taken to do the Vibration Monitoring Program. Specific equipment vibration analysis using our existing equipment (Dual - Channel FFT Analyzer complete with graphics recorder) took 4 hrs per piece of equipment. This analysis time

is eliminated using the Vitec System. However, the Vitec System does not completely eliminate the use of the Dual - Channel Analyzer. The Dual - Channel analyzer has a greater degree of accuracy and resolution to better identify non-standard equipment problems.

6.3 The present Vitec System has resulted in an average of four work orders/month being prepared on rotating equipment.

6.4 A total of one catastrophic failure has occurred this year on rotating equipment that the VMP failed to identify. As a result of this failure, which was caused by an overheated bearing, we are considering the use of the recently introduced temperature sensor feature of the Vitec System.

6.5 A review of the vibration limits needs to be carried out from time to time to determine if the limits originally set are appropriate. Key items to look for are equipment running significantly below the alarm set points or else running above the alarm set points with no apparent problems.

7.0 ECONOMIC CONSIDERATIONS

7.1 Costs

7.1.1 The cost in Canadian Dollars of the Vitec Predictive Maintenance program including the portable data collector and software package is $20,000. An additional expense of $8,000 will be required if a host computer is not available. This computer cost includes the purchase of a colour monitor and graphics card.

7.2 Benefits

The cost benefits in using a computerized monitory system can be demonstrated in three areas;

7.2.1 The improved detection capability of the system to identify problems when they first develop and before these problem result in costly repairs and/or equipment replacement.

7.2.2 The reduction in the total time required to monitor rotating equipment and develop meaningful history.

7.2.3 The ease of the collecting and maintaining equipment history.

In the first 6 months of service, the Vitec Program has resulted in a total savings of $50,000. This savings was primarily the result of the early detection of a failed bearing and subsequent timely shutdown and repair of a large centrifugal pump motor.

8.0 SUMMARY

The Predictive Maintenance program on rotating equipment at the BHWP has been greatly enhanced by the incorporation of the Vitec DC + Data Collection System. Its major benefits can be summarized as follows:

8.1 Its ability to collect and store field data in a quick and efficient manner.

8.2 Its ability to do on-line FFT analysis.

8.3 Its ability to provide clear and detailed reports for the collection of meaningful history, equipment trend data and problem analysis.

8.4 Its ability to provide additional data to supplement the vibration readings through trouble codes and process variables.

9.0 REFERENCES

9.1 MACKIMMIE, G.W., "The Vibration Monitoring Program (VMP) Using the Vitec Data Collector (DC + System)", BHWP Maintenance Procedure Manual, 09133-4-9, 1987, May.

9.2 VITEC, "Data Collector Plus (DC^+)", Operator's Manual.