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MONITORING OF ROTATING
AUXILIARY PLANT MACHINERY**

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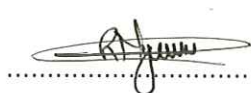
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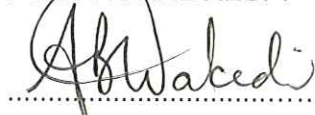
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Introduction

All operating machines vibrate and since an increase in machine's vibration almost always accompanies deterioration in running conditions, it is possible to acquire information about a machine's condition by monitoring its vibration levels and use this information for preventive and predictive maintenance.

Vibration condition monitoring as an aid to maintenance and maintenance planning has become well established in Eskom and is closely linked with the principles of Reliability Basis Optimisation (RBO). The application of the RBO methodology will assist in determining the extent to which Condition Monitoring can effectively be applied. The benefits of a machinery vibration monitoring programme include:

- a) Early indication of equipment malfunctioning or potential failure;
- b) Indication of incorrect maintenance practices;
- c) Reduced maintenance costs;
- d) Improved machinery reliability/productivity and
- e) Extended machinery life.

Monitoring the vibration characteristics of a machine gives us an understanding of the health condition of the machine and this information can be used to detect problems that might be developing and therefore allowing corrective measures to be put in place to prevent catastrophic failures on these machines. Vibration measurements can be used for a number of purposes including routine operational monitoring, acceptance tests and diagnostic and analytical investigations. This standard is based on all parts of ISO 10816, ISO 13373 and ISO 18436 and defines the guidance for evaluating performance of rotating machinery.

1. Scope

1.1 Purpose

The purpose of this document is to assist Eskom Generation personnel in establishing a vibration condition monitoring program for power plant's rotating auxiliary machinery and to provide minimum requirements to vibration sampling, testing, analysis and possible corrective actions. This is intended to promote consistency of vibration monitoring procedures and practices among the power stations in Eskom. This standard is focused on machinery under handheld vibration monitoring program. The on-line vibration monitoring (Main Turbo-Gen and Turbine Feed Pumps) will be dealt with on a separate document.

1.2 Applicability

This standard is applicable to all fossil fired power stations in Eskom.

2. References

The following documents contain provisions that, through reference in the text, constitute requirements of this document. At the time of publication, the editions indicated were valid. These documents are subject to revision and users are responsible to ensure that the most recent editions of the documents listed below are used.

ISO 10816-1: Mechanical vibration - Evaluation of machine vibration by measurements on

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non-rotating parts - General Guidelines.

ISO 13373-1: Condition monitoring and diagnostics of machine – Vibration condition monitoring - General guidelines.

ISO 13373-2: Condition monitoring and diagnostics of machines - Vibration Condition Monitoring - Processing, analysis and presentation of vibration data.

ISO 17359-1: Condition monitoring and diagnostics of machines - General guidelines.

ISO 18436-2: Condition monitoring and diagnostics of machines - Requirements for training and certification of personnel - Vibration Condition Monitoring and Diagnostics.

EPRI 1009586: Vibration monitoring and analysis - Program development.

TECHNICAL ASSOCIATES: Vibration Analysis Level II and III

3. Definitions and abbreviations

3.1 Definitions

- 3.1.1 Acceleration:** The rate of change of velocity. The acceleration of an object is the rate at which it is gaining or losing speed in a particular direction.
- 3.1.2 Accelerometer:** A transducer with an electrical output directly proportional to the acceleration of the vibrating point in the direction in which the transducer is attached.
- 3.1.3 Amplitude:** The magnitude of a signal or periodic motion e.g. the magnitude of the velocity of a vibrating body. Amplitude can be expressed in a variety of ways, the most common amplitude types being peak, peak-peak, and root-mean-square (rms).
- 3.1.4 Cavitation:** A condition where the inlet pressure of a pump or water turbine is too low and therefore causes a mixed flow of fluid and vapour. Cavitation causes random high frequency vibration.
- 3.1.5 Displacement:** The position of an object relative to a fixed reference point measured in a particular direction. Displacement units commonly used in the field of vibration analysis are micro meter (metric) and mil (imperial).
- 3.1.6 Fast Fourier Transform:** An algorithm for calculating a discrete spectrum from a discrete waveform.
- 3.1.7 Fmax:** The maximum frequency displayed on a vibration spectrum i.e. the frequency range over which amplitudes are displayed.
- 3.1.8 Forcing frequency:** The frequency of an excitation force. Several forcing frequencies may be simultaneously present in a vibrating system.
- 3.1.9 Frequency:** The number of periodic cycles or oscillations completed per unit time. Frequency is the reciprocal of period, and is usually expressed in Hz/CPS/CPM etc.

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- 3.1.10 Gear mesh frequency:** The rate at which gear teeth contact. This is equal to the number of teeth on the gear multiplied by the rotation speed of the gear.
- 3.1.11 Measurement Parameters:** The details about a measurement that must be specified before the measurement is taken e.g. before a spectrum is taken, the Fmax, number of spectral lines to be used, averaging type, windowing type etc need to be specified.
- 3.1.12 Modal Analysis:** The process of developing a mathematical model for the vibration of a system so that the mode shapes of the system can be determined for different excitation forces.
- 3.1.13 Mode Shape:** The collection of vibration amplitudes at all points of a system, or the 'shape' of a system, when it is subjected to a particular excitation force.
- 3.1.14 Narrowband:** The measurement of the vibration amplitude at individual frequency values or for small frequency bands.
- 3.1.15 Natural frequency:** The frequency at which a system will vibrate when it is vibrating freely by itself without the influence of an excitation force.
- 3.1.16 Phase:** The time relation of a signal or a vibrating object to another signal or vibrating object of the same frequency.
- 3.1.17 Resolution:** The finest frequency or time 'step' possible on the horizontal axis of a discrete spectrum or waveform.
- 3.1.18 Rigid:** Infinitely stiff and does not deform. There are no truly rigid objects in the real world. In practice, a rotor is considered rigid if it does not bend significantly at its rotating speed.
- 3.1.19 Rolling Element Bearing:** A bearing with rolling elements to enable smooth shaft rotation.
- 3.1.20 Signal:** An electrical voltage or current that is proportional to the magnitude of a physical quantity. A signal may be analogue or digital and continuous or discrete.
- 3.1.21 Signature:** The vibration spectrum of a system from which much can be inferred regarding the vibration behaviour of the system.
- 3.1.22 Spectral Lines:** Vertical lines that make up a discrete spectrum.
- 3.1.23 Spectrum:** Amplitude versus frequency chart of a measured vibration.
- 3.1.24 Transducer:** A device that translates the magnitude of one quantity into another quantity e.g. an accelerometer is a transducer that translates acceleration into voltage.
- 3.1.25 Vibration:** A reciprocating or back-and-forth movement involving a continual interchange of kinetic energy and potential energy.
- 3.1.26 Waveform:** A signal level versus time chart of a measured vibration.

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3.2 Abbreviations

- 3.2.1** RBO: Reliability Basis Optimisation
- 3.2.2** CM: Condition Monitoring
- 3.2.3** ISO: International Organisation For Standardisation
- 3.2.4** Fmax: Maximum Frequency
- 3.2.5** RPM: Revolutions Per Minute
- 3.2.6** DE: Drive End
- 3.2.7** NDE: Non Drive End
- 3.2.8** CMMS: Computerised Maintenance Management System
- 3.2.9** PdM: Predictive Maintenance
- 3.2.10** GMF: Gear Mesh Frequency
- 3.2.11** HFE: High Frequency Envelope

4. Requirements

Critical machines like boiler feed pumps and draught plant fans would be beneficial to be on permanent monitoring systems, however as a minimum requirement for the new built, these machines shall be put on permanent monitoring systems.

4.1 Responsibilities

4.1.1 Power Station Managers

The Power Station Manager is responsible for ensuring that the requirements of this document are met.

4.1.2 Power Station Engineering Managers

The Power Station Engineering Manager shall ensure the overall direction and functioning of this document. He/she is responsible to establish a program owner to ensure that the tasks are executed and the program remains effective.

4.2 Monitoring Program

4.2.1 Equipment Selection

The process of selecting what plant equipment is to be included in the vibration monitoring program is typically part of the Reliability Basis Optimisation (RBO). It is required that each station develops a formal procedure on the basis of this standard to ensure that changing monitoring frequencies, adding or removing plant equipment from the vibration monitoring program follows a formal procedure as outlined in the Core Principles of RBO Manual GGM1526. Once the plant equipment has been selected, it is recommended that a vibration monitoring flowchart be developed such as one shown in figure A.1 of Annexure A.

4.2.2 Measurement parameters

Setting measurement parameters define the area of interest within a frequency range and once the overall frequency range is defined, these parameters are developed to identify the specific fault frequencies. The frequency range will depend on the type of machine to be

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monitored but the parameters that determine how much or how fast data is collected are the parameters $F_{\max}$, Spectral lines and # Averages. For machines with speed >600 RPM, 4 averages per point for all frequency ranges is recommended and slower machines with speed <600 RPM require more averages. The frequency range of measurement shall cover frequencies from 0,2 times the lowest rotational frequency to 3,5 times the highest excitation frequency of interest.

The parameters used for measuring vibration spectra are divided into four classes namely, parameters that determine:

- a) How data is collected
- b) How much or how fast data is collected
- c) How data is processed
- d) How data is displayed

The following are three general types of measurements that may be employed for machine vibration condition monitoring:

- a) Vibration measurements taken on the non-rotating parts of the machine such as bearing housing machine casing or machine base.
- b) Relative motion between the rotor and the stationary bearings or housing.
- c) Absolute vibration motion of the rotating elements.

Vibration on the non-rotating parts shall be measured in velocity (r.m.s) and may be combined with acceleration (g's) and for high speed machines with anti-friction bearings a combination of velocity (r.m.s) and acceleration (0-peak). Usually when the machine speed is up to 600rpm, displacement is measured, between 600rpm & 20 000rpm velocity is measured and above 20 000rpm acceleration is measured. The velocity is measured more often than displacement and acceleration because velocity is directly proportional to the stress and resulting wear on a mechanical system. The sensitivity of the transducers shall be taken in consideration when specifying measurement parameters. Where machines operate at speed below 600 RPM, a low frequency transducer with sensitivity of 500mV/g shall be used as a minimum, between 600 RPM and 20 000 RPM a transducer with 100mV/g sensitivity shall be used and on high speed machines over 20 000 RPM a transducer with 10mV/g shall be used.

4.2.3 Measuring positions

The transducer shall be placed as close as possible to the bearing with solid metal between the bearing and the sensor. Bearing caps made of thin metal and fan housing of a motor are examples of poor conductors of vibration energy and therefore should be avoided.

Typical measurement positions are radial (vertical and horizontal) and axial directions where possible. Measurement positions shall be identified and clearly marked so that the data can be collected in exactly the same manner each time a measurement is taken to ensure that the data is repeatable and can be trended over time. A transducer shall be mounted firmly to the measurement position so that it does not rock or move independently of the machine. A loosely mounted transducer produces signals distorted by its own independent movements and therefore gives the wrong reading, therefore magnet mounted transducers shall be used as a minimum method of transducer attachment/mounting.

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The measurement position shall be clean and truly magnetic when using a magnet mounted transducer. It is preferred that quick-mount bases and fittings be used over the magnets due to their high frequency range and consistency in measuring positions. Hand-held (stinger/probe tip) transducer probes are not recommended for use due to their low usable frequency range. These probes may only be accurate to frequencies up to 30 000 CPM and many significant fault frequencies can be missed if these probes are used. Tri-axial sensors may be carefully used to enable quicker data collection but this is not mandatory. Machines that are not easily accessible and may pose safety threat to vibration personnel shall have permanent transducers installed and routed to the junction box for access of data collection.

4.2.4 Data storage and Database management

Vibration analysers / data collectors come with software for data management. The accepted method for collecting and analysing vibration data is to start by setting up the database that entails machine information, measurement points, measurement orientations, machinery fault parameters and measurements parameters. A vibration database essentially contains all of the information pertaining to how vibration signatures should be sampled during routine data collection.

Machines on the database shall be clearly labelled in accordance with the plant labelling to avoid misidentifications. The data collected from the machine shall be transferred to a database for analysis and archive. The database shall be created on the server where controlled access can be granted. The database server will be maintained by the Information Management personnel similar to all the process servers. Where the condition monitoring service is outsourced, the contractor shall store the data and reports on the above mentioned server.

Any changes or optimisation made to the database shall be formally recorded. A clear guidance to those responsible for writing or making changes to the database shall be established and included in the procedure. From a database, it can be seen which readings need to be taken on which machines, at which points on the machines, in which orientations and using which measurement parameters. Appropriate alert and alarm limits shall be defined in the database to detect faults associated with known frequencies. The following parameters should be set in the database:

a) Overall alarm levels

It is important that the analyst take into consideration the type of machine and it's mounting when beginning to specify overall alarm levels. Once the baselines are known, these alarm levels shall be individually reviewed and adjusted based on the need. The overall alarm levels are merely set to give the general overview of the overall condition of each of the machine based on the highest overall levels. Tables B.1 to B.4 shown in annexure B are generally used for classification of vibration severity zones for machines referenced from ISO 10816-3.

b) Spectral alarm bands

It is vital to properly specify the spectral alarm bands as they are one of the most critical tools for detecting potentially serious problems in machinery. Problems such as deteriorating bearings, gears, electrical problems, etc. may not affect the overall vibration levels for some time even though there would be a definite increase in amplitude of the defect frequency.

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c) Narrowband alarm envelopes

The benefits of using narrowband spectral alarms include early warning of impending failures, prevention of false alarms on machines that do not actually have problems, more effective and timely diagnosis of problems in machinery and improved analyst's diagnostic confidence. There are two types (absolute threshold and total power) of narrowband alarms and the analysts must know which type to use. The absolute threshold works effectively in situations where there is limited vibration amplitude whereas the total power is often used for detecting problems appearing at low amplitude such as late failure stage of rolling element bearings, cavitations, etc. The process of setting up these alarms is included in the vibration training manuals.

4.2.5 Data collection

Personnel responsible for collecting data shall be as consistent as possible when collecting data to ensure repeatability. The machine shall be in its normal operating condition such as running speed and load where possible when vibration data is collected. If these conditions are not met, the vibration signature may not match with the previously recorded ones and trending vibration levels over time becomes impossible.

4.2.6 Data analysis and reporting

a) Data analysis

The first step of analysing vibration data begins during vibration data collection. Most data collectors have the option to allow the user to display previous and current overall vibration values and current alarm conditions as data is being collected. The collected data gets uploaded to a computer and with the appropriate alarms defined in the database, running exception report will determine machines with points in alarms.

Machines points that are not in alarm on the exception report are assumed to be in a good condition and no further analysis is necessary. The vibration analyst shall perform detailed analysis on the data in alarm and determine the root cause of the problem and its severity. Figure 4.1 is an example of exception reports that can be generated by most of the vibration software.

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MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE-SEV	DAYS TO ALARM
U1A S/O Vacuum Pump					
1A Vacuum -					
		{ 11-Nov-08 }			
		{RPM = 1430.}			
		(LOAD = 100.0)			
---->	M1P --- OVERALL VALUE	.169 G-s	.059 .098	D - 48	0
->	PK-PK WAVEFORM	1.645 G-s	1.500 3.000	C - 4	266
---->	1xTS	.087 G-s	.020 .059	D - 46	0
-->	M1V --- CREST FACTOR	3.776	3.000 4.000	C - 31	9
	M-Brg6206 FTF	0. mm/Sec	7.620 12.70	Lo	???
	M-Brg6206 BPFO	0. mm/Sec	.300 .500	Lo	???
	M-Brg6206 BPFI	0. mm/Sec	.300 .500	Lo	???
->	M2H --- CREST FACTOR	3.023	3.000 4.000	C - 1	???
	2 X TS	0. mm/Sec	12.70 25.40	Lo	???
	M-Brg6206 BPFI	0. mm/Sec	.300 .500	Lo	???
-->	M2P --- OVERALL VALUE	.092 G-s	.059 .098	C - 34	93
->	1xTS	.020 G-s	.020 .059	C - 1	???
->	M2V --- CREST FACTOR	3.093	3.000 4.000	C - 4	133
	M-Brg6206 FTF	0. mm/Sec	7.620 12.70	Lo	???
	M-Brg6206 BPFO	0. mm/Sec	.300 .500	Lo	???
->	M2A --- CREST FACTOR	3.327	3.000 4.000	C - 13	???
	M-Brg6206 FTF	0. mm/Sec	7.620 12.70	Lo	???
	M-Brg6206 BSF	0. G-s	.300 .500	Lo	???
	M-Brg6206 BPFI	0. mm/Sec	.300 .500	Lo	???

Figure 4.1: Example Exception Report

i) Overall Vibration Signal

The overall vibration signal is a combination of a host of components at different frequencies. These frequencies are primarily a representative of the activities happening in the machine elements in relation with the machine operating speed. The approach of analysing overall vibration signals is simple but tends to be insensitive to large changes in the amplitude of particular frequencies due to a small contribution to the overall signal. The overall vibration readings are only an indication of machine condition and therefore do not diagnose the machine fault. If the measurement points as set in the database are in alarm, this means that there is a potential problem and further analysis is mandatory. The alarm limits and database parameters if used efficiently provide sufficient information to the analyst to evaluate the severity of the problem before detailed signatures analysis. Figure 4.2 shows a standard severity chart to be used for evaluation of severity of machine problem.

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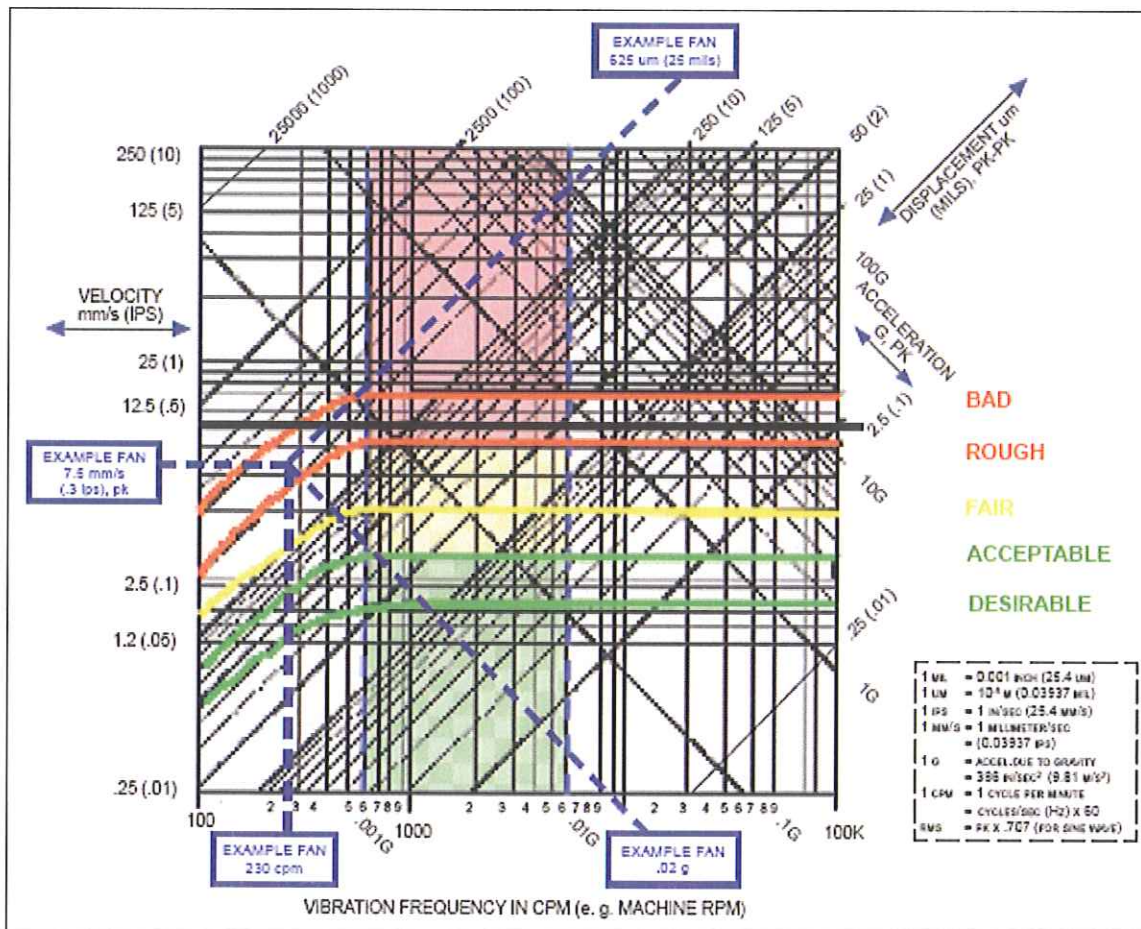
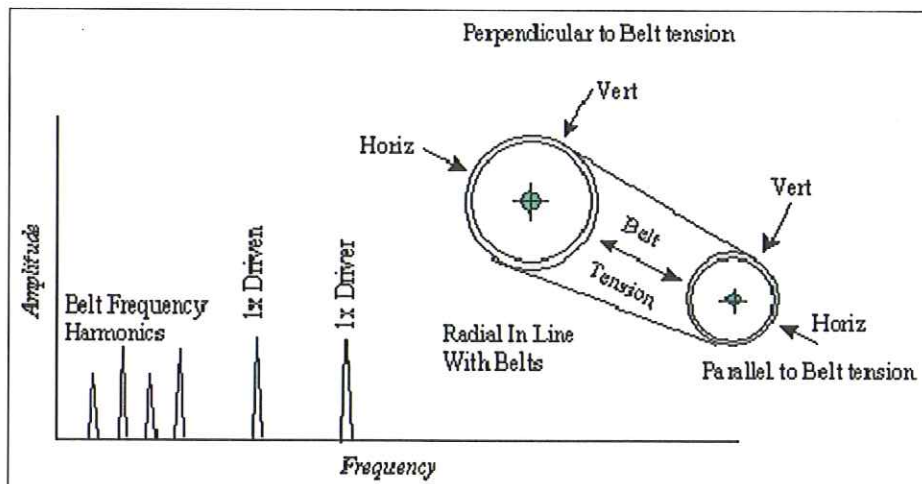


Figure 4.2: Vibration Severity Chart

ii). Vibration Spectrum Analysis

The next step is to perform detailed analysis of the points in alarms to determine the cause of the problem. The most common method of diagnosing the cause of vibration problem is by analysing the spectral plots in comparison with the historical data to predict the duration the machine can still run before catastrophic failure as shown in figure 4.3.



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Figure 4.3: Vibration Spectrum

Additional diagnostic tools such as trends, spectral data, time waveforms, waterfall charts, etc. shall be used to increase the accuracy of the analysis. Operational parameters and maintenance history may also be used to assist in the analysis process. Special tests shall be performed in cases where the confidence level of the analyst is low about the certainty of the problem. There are optional analysis expert programs offered by vibration instruments suppliers that can be used to interrogate the database to enhance the capabilities of the software. When the spectrum fault frequency reaches the alarm levels, the monitoring rate must be increased and the measurement at the individual fault frequencies must be trended using overall levels and waterfall plots. Planned maintenance shall be scheduled once the problem is known and well before the machine condition deteriorates to a trip or shut down alarm levels.

iii). Time Waveforms Analysis

Time waveforms are ideal for the analysis of low-speed shafts, bearings and gears. In general, time waveforms are used to detect problems that are likely to be missed by spectrum analysis. There are other problems that time waveform analysis can help spectrum analysis confirm such as rolling element bearing defects on low to moderate speed machines (50-300 RPM), motor electrical problems, rotor rub, extinguishing between misalignment and looseness problems etc. An example of the time waveform indicating a single broken tooth on a gear is shown in figure 4.4.

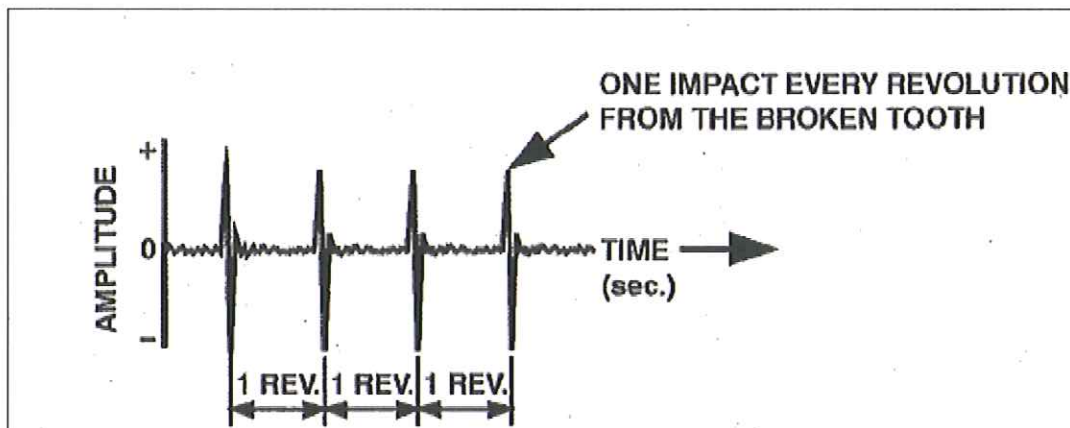


Figure 4.4: Example Time waveform indicating a broke tooth on a gear

iv). High Frequency Enveloping Analysis

HFE spectral analysis or any equivalent method shall be employed in the vibration monitoring program to allow early detection of a variety of problems which might not be picked up by normal vibration analysis alone. This tool should be used as a supporting technology to vibration analysis. The HFE uses high-pass filters to eliminate the lower frequency high amplitude sources from an acceleration time waveform and passing this signal through the low-pass filter to display the results in FFT frequency domain so that the vibration generated by impulses and impacts remains for analysis. This technique can be used to detect problems such as wear/improper loading of rolling element bearings, gear problems, inadequate lubrication, low-speed rolling element bearing wear etc.

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b) Data Reporting

The machine vibration condition reports are a very important step of the vibration program as they indicate the action to be taken by plant personnel on machines diagnosed with faults. All vibration monitoring software has a variety of standard reports that can be generated and can be used effectively by the analysts. A vibration report shall include the condition during which the measurement was collected, problem identified, findings in the analysed data (including severity), recommendations and prioritized maintenance action date.

Each power station shall develop a formal process that defines the reporting requirements in line with this standard. The reporting formats may vary from station to station but the report generated shall cover the above inclusions. The findings in the analysed data shall be supported by relevant plots in the report. An example of a basic vibration report is shown in figure 4.5. The recommendations of these reports must be addressed with the relevant system engineer.

Machine: U1A Primary Air Fan Asset Number:KKS000 Date: 02/11/2007	
Problem:	Unbalance in rotor due to dirty fan blades.
Findings in the Data:	1xRPM vibration on DE fan bearing horizontal = 5.9mm/sec rms. 1xRPM vibration on NDE fan bearing horizontal = 6.2mm/sec rms. After the fan was cleaned 6 months ago, readings have steadily increased every month by 0.9mm/sec. Over the last 10 years, this fan has required a cleaning every 6 to 9 months.
Recommendation:	During scheduled maintenance clean fan blades. The work order should contain a post-maintenance vibration check to verify that the fan vibration levels have returned to normal. If they do not, a field balancing should be performed at that time.
Prioritization:	Corrective maintenance action should be performed during next month's scheduled outage.

Figure 4.5: Sample vibration report

In addition to the vibration report, an overall condition rating report shall be compiled to provide management and system engineers with the current state of plant's machinery condition without having to go into details of the machine problems. An example of overall condition rating report is shown in figure 4.6.

Plant Area	Machines Not In Alarm		Machines In Alarm		
	Good To Excellent Operating Condition	Fair Operating Condition	Trend Problem Only (Priority 3)	Schedule Repair At Convenience (Priority 2)	Maintenance Required ASAP (Priority 1)
Milling Plant	1A PA Fan 1B PA Fan 1D PA Fan	1C PA Fan		1E PA Fan	
Drought Group	1LH ID Fan 1RH ID Fan 1RH FD Fan		1LH FD Fan		

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For various reasons, the following machines were not operating or measured:
1B CW Booster Pump

Figure 4.6: Example Overall Condition Rating Report

The analyst is responsible to ensure that the recommended actions are discussed with the system engineer and that the work order or work request is loaded on the CMMS in accordance with the six step process for routine work management. Section 7.1 of GGM1490-Routine Work Management Manual gives an indication of this process in details. However, the final decision to perform maintenance action will be taken by the system engineer considering other machine condition indicators.

c) Data Review

It is important for the analyst to be present during maintenance action recommended from the vibration report. This will help the analyst to confirm the diagnosed problem and its severity. It is also an opportunity to get images of the damaged components and machine's information. The vibration analyst shall perform post-maintenance tests and update the database with new baselines from the acceptable machine condition. All the activities performed during the recommended maintenance action shall be documented in the database and shall include the problem, action taken to fix the problem, post maintenance test data, reason for failure occurrence and prevention strategy applied. This information is then used for continuous improvement to maintain adequate reliability basis.

4.2.7 Special testing

Some problems have similar frequencies and spectral analysis can only narrow the problem to more than one possible causes. Therefore additional data shall be collected using special techniques to further analyse the problem to its roots. Special testing techniques include:

- a) Phase measurements
- b) Natural frequency determination
- c) Run-up and coast-down tests
- d) Synchronous time averaging
- e) Order-tracking
- f) Motor current analysis
- g) Operating deflection shape (ODS)
- h) Modal analysis
- i) Finite element analysis, etc.
- j) Oil Analysis
- k) Acoustic Ultra-Sonics

4.2.8 Data presentation

This standard proposes standardisation of vibration concept and the type of instrument output across the entire power stations vibration monitoring program with standardised system quality levels, measurements and tolerances. It is therefore essential to specify the measurement method, measurement quantity and measurement points. The compatibility of different monitoring systems shall be such that the same outputs result from standard input data.

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4.3 Training Requirements

Personnel carrying out vibration monitoring and analysis shall have a combination of education, training and experience in accordance with ISO 18436-2. Certification of vibration analysts is divided into four categories in terms of education, training and experience as describe below.

4.3.1 Education and training

Category I or Level I - Person needs to have at least 24 hours of initial formal vibration training regardless of secondary and tertiary education, and a minimum of 6 months (full-time) hands-on experience.

Category II or Level II - A high school graduate needs to have 80 hours formal vibration training plus a minimum of two years full-time experience. A person with 2 or more years of tertiary education in engineering or science needs to have 56 hours formal vibration training plus a minimum of two years full-time experience.

Category III or Level III - A high school graduate needs to have 4 years of full-time experience equivalent to that of Level II. A person having 2 or more years of tertiary education in engineering or science needs to have at least two years full-time experience equivalent to that of Level II. A 4-year degree in engineering or science major needs to have at least one year experience equivalent to that of Level II. Technical Associates recommends a minimum of 80 hours formal vibration training, with at least 72 hours in seminars which cover ASNT Level III vibration analysis topics (independent of educational background).

4.3.2 Experience

Category I or Level I - Person must be proficient with data collection, downloading, and uploading vibration data; have a basic knowledge of vibration fundamentals, instruments & transducers; and may assist in balancing and alignment tasks.

Category II or Level II - Person must be fully proficient with required Level I tasks, plus be capable of performing in-depth vibration signature and phase analysis to detect a variety of machine faults; performing minor vibration reduction; writing clear, concise reports of results and recommendations; and providing guidance to Level I Vibration Analysts.

Category III or Level III - Person must be fully proficient with required Level I & II tasks; plus be capable of administrating or managing a plant wide condition monitoring program; developing acceptance standards, alarm limits, and specifications; performing in-depth time waveform analysis; performing fundamental modal analysis & operating deflection testing on machines & structures; possessing in-depth knowledge of signal processing; and specifying vibration reduction mechanisms (isolation, damping, etc.).

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5. Annexes

5.1 Annexure A

This flow chart links to the outcomes of the RB maintenance strategies and as input to the Works Management process. RB determines the vibration tasks to be performed on the identified machinery and the associated frequencies, these tasks are loaded on CMMS (Works Management process) and then used to develop a vibration program through this flow chart. The information obtained from vibration program is then fed back to the CMMS.

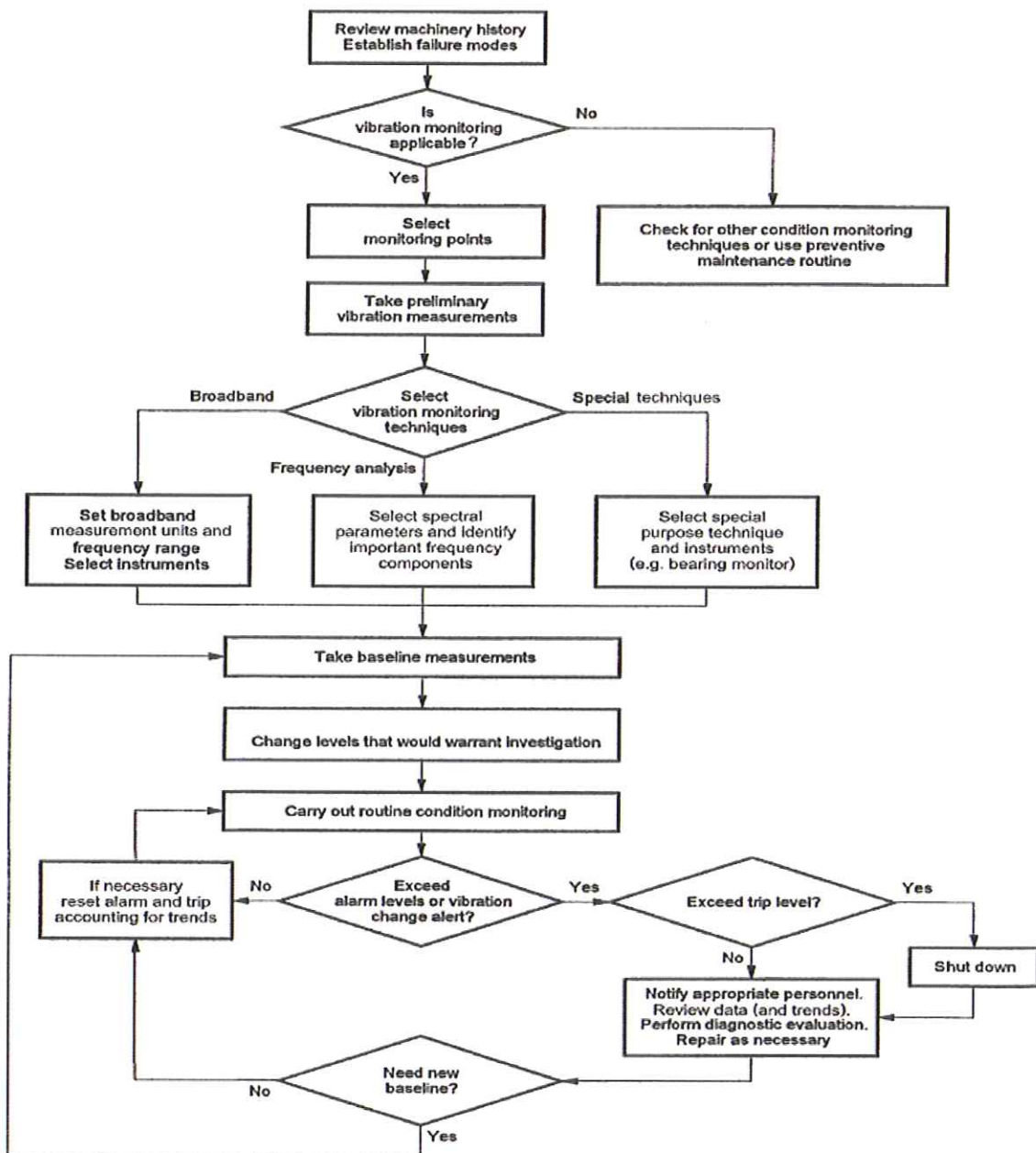


Figure A.1: Vibration Monitoring Flowchart

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5.2 Annexure B

The tables below give typical machine vibration classifications values for the evaluation of vibration severity that machines may be subjected to. These machines may either be installed on a rigid or flexible supports and the velocity values displayed are overall r.m.s vibration amplitudes. Machines in zone boundaries: A/B are considered acceptable for long-term operation, B/C are considered unsatisfactory for long-term continuous operation but may be operated for limited period until the opportunity arises for repairs, C/D are considered unacceptable and call for immediate action.

Support class	Zone boundary	R.m.s. displacement μm	R.m.s. velocity mm/s
Rigid	A/B	29	2,3
	B/C	57	4,5
	C/D	90	7,1
Flexible	A/B	45	3,5
	B/C	90	7,1
	C/D	140	11,0

Table B.1: Typical Zone boundary limits for large machines with rated power above 300 kW and not more than 50 MW; electrical machines with shaft height $H \geq 315$ mm.

Support class	Zone boundary	R.m.s. displacement μm	R.m.s. velocity mm/s
Rigid	A/B	22	1,4
	B/C	45	2,8
	C/D	71	4,5
Flexible	A/B	37	2,3
	B/C	71	4,5
	C/D	113	7,1

Table B.2: Typical Zone boundary limits for Medium-size machines with rated power above 15 kW up to and including 300 kW; electrical machines with shaft height $160 \text{ mm} \leq H < 315$ mm.

Support class	Zone boundary	R.m.s. displacement μm	R.m.s. velocity mm/s
Rigid	A/B	18	2,3
	B/C	36	4,5
	C/D	56	7,1
Flexible	A/B	28	3,5
	B/C	56	7,1
	C/D	90	11,0

Table B.3: Typical Zone boundary limits for Pumps with multivane impeller and with separate driver (centrifugal, mixed flow or axial flow) with rated power above 15 kW.

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Support class	Zone boundary	R.m.s. displacement μm	R.m.s. velocity mm/s
Rigid	A/B	11	1,4
	B/C	22	2,8
	C/D	36	4,5
Flexible	A/B	18	2,3
	B/C	36	4,5
	C/D	56	7,1

Table B.4: Typical Zone boundary limits for Pumps with multi-vane impeller and with integrated driver (centrifugal, mixed flow or axial flow) with rated power above 15 kW.

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