CMVA Category 3. Diagnostics and Program Management.

Performance Objectives

Category 3 candidates are also responsible for all the performance objectives in Category 1 and Category 2.
The Performance Objectives are based on ISO 18436-2:2014(E), and are designed to amplify that document. Exam questions and objectives have all been provided by volunteers among CMVA members, over a two year period. All exams have the same percentage of questions per major topic as is shown in the heading of that topic.

This document is available on www.cmva.com to members of CMVA. Check often for the most current version. Please comment to director@cmva.com if you think there should be changes, consistent with ISO 18436-2.

Exams are closely related to these objectives. If you master them, (and don't panic when you write an exam) you should have no trouble achieving the pass mark of 70%.

Number of Hours Allowed to Write the Exam

Category	**1**	**2**	**3**	**4**
# of questions	60	100	100	60
# of hours allowed	2	3	4	5

Contenu

1 Principles of Vibration 5%

1.1 Vibratory Motion

Define periodic motion, amplitude, frequency, time period.
Define the relationship between angular measurement in radians and in degrees.
Define the relationship between angular velocity measured in radians per second, rotational speed measured in revolutions per minute and rotational frequency measured in Hz.

Define the amplitude conventions: peak, peak to peak and root-means-square (rms).
Define the sine and cosine trigonometry functions and how they relate to a simple time domain vibration wave-form.

Explain periodicity in a complex (many component) wave-form.

Convert from an rms to peak amplitude value and vice versa for a pure, single component wave- form.

Explain why you cannot convert simply an rms amplitude to a peak amplitude for a complex wave-form.

Define spring stiffness.
Define viscous (velocity) damping.
Explain the behaviour of a spring-mass-damper system in free vibration.

1.2 Amplitude Measurement Conventions (pk, p-p, rms) re overall levels

Choose the appropriate amplitude convention (peak, rms) of the time waveform based on the parameter (displacement, velocity, acceleration) being used, transducer, and the practice in your plant.

Explain the pros and cons of peak versus rms with respect to overall levels, based on the characteristics of the machine being monitored and its common modes of failure.

Distinguish between true peak and the value (a.k.a. pseudo-peak) derived from an rms reading by multiplying by the square root of 2.

Define crest factor.
Explain the utility of the crest factor.

1.3 Parameters (displacement, velocity, acceleration)

For a simple sinusoidal vibration wave-form, derive velocity and acceleration from displacement and vice-versa. Distinguish between instantaneous values and peak values.

Select the appropriate parameters for measuring vibration on different types of equipment and their different modes of failure. Use the same list of equipment as shown in Section 7 of this document.

Distinguish seismic vibration from shaft vibration relative to housing and define where each type of measurement would be appropriate.

1.4 Units, unit conversions

Master the units and unit conversions mentioned in Ref 3.

Interpret linear and log scales including decibels (dB). Choose the appropriate scale for the application.

1.5 Time and frequency domains

Relate time domain and frequency domain plots.
Define the Fourier concept of component superposition in qualitative terms. Define Fourier analysis in qualitative (non-mathematical) terms.

1.6 Vectors

Distinguish between scalar and vector quantities.
Demonstrate rotating vectors in the context of vibration and unbalance. Relate a rotating vector to a time-domain wave-form.
Add and subtract vectors.

1.7 Modulation

Explain modulation of a waveform. Distinguish between amplitude modulation (AM) and frequency modulation (FM). Relate to spectra. Identify time waveform patterns due to modulation and explain the phenomena.

1.8 Phase

Define in-phase and anti-phase vibrational behavior for a rigid machine.
Define relative phase at a single frequency for measurements at different locations. Determine the phase relationship between two sinusoidal time signals.

Define absolute phase relative to a once per turn reference pulse.

Explain the North American convention for measuring absolute phase against the direction of rotation and how this differs from the more widely used convention in the direction of rotation.

Explain phase lag and show examples.

1.9 Natural Modes and Frequencies, Resonance, Critical Speeds

Define natural modes and natural frequencies

Recognize that machines and structures have more than one natural frequency, and identify them.
Explain qualitatively translational and rotational modes of vibration for a simple rigid machine case on four vertical flexible supports.
Demonstrate qualitatively natural modes and frequencies for a shaft on two flexible

bearings. Explain how natural modes and natural frequencies affect vibration response.

Explain resonance. Show in detail how to avoid resonance by changing force, changing frequency or changing response.

Explain "critical speeds" in relation to rotor-bearing-support system natural frequencies.
Show what properties of machines affect critical speed.
Explain the significance of critical speeds with respect to unbalance response.
Discuss the location of unbalance forces relative to the mode shape, and discuss their importance.

1.10 Force, response, damping, stiffness.

Demonstrate the form of the frequency response function (FRF) for a spring-mass damper, single degree of freedom (DOF) system, subjected to a constant magnitude force of varying frequency. Demonstrate the effect of varying the damping in the single DOF system subjected to a constant magnitude force of varying frequency.

Demonstrate the form of the FRF for a spring-mass damper, single degree of freedom (DOF) system, subjected to a rotating unbalance force of varying frequency.

Demonstrate phase lag with respect to a rotating unbalance FRF.

2 Data Acquisition 5%

2.1 Selection of Instrumentation

Select appropriate instrumentation, including electronic hardware, sensors e.g. charge versus voltage accelerometers, shear or compression type accelerometers, ceramic high temperature accelerometers, IEPE (Integral Electronics Piezoelectric) accelerometers or velocity transducers, (also known commercially under the registered trade marks: ICP, DeltaTron, Isotron, CCLD and ACOTRON), corrosion resistant transducers and non-contact probes, for a condition monitoring program, permanent monitoring or specific problem investigation.

Select instrumentation that meets the required safety standards e.g. intrinsically safe if necessary.

Choose a permanently installed or a portable, periodic (route based) system, based on plant goals, effectiveness, and available resources.
If necessary, choose different instrumentation based on whether the goal is prediction or trouble- shooting.

2.2 Dynamic Range (DR), Signal to Noise Ratio (SNR)

Define Dynamic Range and Signal to Noise Ratio in analog (dB) and digital (bit) terms.

Distinguish between Dynamic Range (the ratio of the highest possible amplitude undistorted signal to the lowest) and Signal to Noise Ratio (the amplitude of the actual signal. to the lowest undistorted signal). Explain the consequences of inadequate dynamic range and how to compensate for it.

Identify what affects the dynamic range and how those effects show up.

Calculate available dynamic range based on the number of bits in the instrument. Recognize a time waveform or spectrum taken with insufficient dynamic range.

Explain the causes of good versus bad SNR.
Identify and recognize the effect of excessive noise in the signal. Identify techniques to improve the SNR
Discuss allowable or necessary SNR
Discuss the effect of integration and double integration on SNR.

2.3 Vibration Transducers

2.3.1 Accelerometers

Describe accelerometers.
Define shear mode versus compression mode, and know which is best for a given application. Define charge mode versus voltage mode transducer operation and applications.
Describe what is meant by "Integral Electronics Piezoelectric" (IEPE) in regard to certain accelerometers and velocity transducers
Discuss sensitivity and maximum frequency response of different accelerometers and the pro and cons of selecting one type versus another.

2.3.2 Velocity Transducers

Describe what extra circuitry is installed into an ICP® velocity transducer compared with an ICP® accelerometer.
Describe a moving coil type velocity transducer and its advantages and disadvantages

compared with an ICP® velocity transducer.
Describe an eddy-current non-contact vibration transducer.

Define the convention for positive direction of motion with respect to transducer

orientation. Define and explain the use of a once per turn speed and phase marker.
Describe several methods of producing a once-per turn speed / phase marker including soft- wired, temporary installations and permanent installations.

Recognize and explain the significance of

- usable frequency range
- temperature limitations
- quartz or ceramic piezoelectric element
- eddy current probes
- scale factor
- calibration
- bias voltage (accelerometers and velocity transducers)
- sensor natural frequencies (accelerometers and velocity transducers)
- transducer overload.

Specify appropriate transducer based on frequency range and above factors.

2.4 Mounting methods and mounted natural frequency for seismic transducers

Describe the various mounting methods for seismic transducers (accelerometers and velocity transducers) and the usable frequency range for each. Explain the other pros and cons of each mounting method.
Identify and explain how to avoid potential problems with mounting – e.g. stress on the accelerometer from mounting on an uneven surface
Describe grounding issues for permanent sensors and explain how to deal with them.

2.5 Non-Contact Probes

Describe the set up and function of an eddy-current non-contact probe. Explain the significance and use of the mean gap voltage.
Describe the effect of mounting resonance on the signal from an eddy-current probe. Describe how to check probe gap with a voltmeter.
Describe how to field calibrate an eddy current probe to a particular shaft material.
Describe the type of application where the use of a non-contact probe would be more effective than an accelerometer and why.

2.6 Low-Pass Filtering (Fmax).

Explain the purpose of setting a maximum frequency (Fmax), so that only components of vibration below that frequency are recorded or included in overall level calculations Describe issues relating to the choice of Fmax for different applications.
Discuss the pros and cons of using the same or different Fmax throughout a condition monitoring program.

2.7 High-Pass Filtering (Fmin) or cut-off frequency.

Explain the purpose of setting a minimum frequency so that only components of vibration above that frequency can be recorded.

2.8 Acquisition Time.

Calculate data acquisition time for a sampling point, based on Fmax, the number of lines of resolution, the number of samples to be averaged and the overlap.

2.9 Effective Resolution

Define effective resolution and distinguish between this and an analyzer's lowest resolvable frequency.

Explain with examples how to set up parameters such that you get the appropriate resolution for the reading.

Choose the appropriate Fmax, number of lines and window function to achieve the effective resolution required.
Calculate the lowest resolvable frequency.

2.10 Sample Triggering

Choose the triggering method (hammer, amplitude, speed, once per revolution pulse, many times per rev, manual, time, free-run,) based on measurement objective.
Explain the physical characteristics of transistor-transistor logic (TTL) trigger. Explain the physical characteristics of analog triggering.
Explain the pros and cons of TTL triggering versus analog triggering.

2.11 Test planning

Plan the frequency of periodic data acquisition for trending purposes, based on program goals, criticality, available resources, and failure cycle.
Plan a test to identify one or more of the faults mentioned in section 5, including determine objectives, identify measurement points and measurement types, define analyses to be used,

and design report.

2.12 Data formats

Choose the appropriate data format based on the required analysis e.g.

- frequency spectrum versus Hz or orders,
- inclusion of additional spectrum for the same point with a different Fmax,
- inclusion of time wave-forms and / or orbits,
- spectrum amplitudes in peak, peak to peak or rms,
- filtered or un-filtered data plots,
- electrical spectra amplitudes in dB to analyze electric motor rotor bars.
- log scale versus linear scale
- decibel amplitude scales and octave band frequency scales.

2.13 Recognition of poor data

Recognize typical characteristics of bad data e.g. ski-slope spectra, clipped wave-forms, saturated signals.
Be aware of causes of bad data such as cable problems, poor connections, inadequate shielding and incorrect type of cable, faulty adaptors, and temperature effects.
Undertake investigations of data collection to ensure good data in complex circumstances such as low speed machines or variable speed machines.

2.14 Test procedures

Develop and execute test procedures for both condition monitoring and diagnostics.

3 Signal Processing 7%

3.1 Static and Dynamic Data.

Define static data. Define dynamic data.
Explain why it is more difficult to acquire a large number of dynamic data samples compared with the same number of static data samples e.g. saving a wave-form for every sampled point. Explain the uses, advantages and disadvantages of time domain data versus frequency domain data.

3.2 Analog Sampling, Digital Sampling

Describe an analog signal and how it is acquired and stored. Describe a digitized signal and how it is acquired and stored.

List the advantages and disadvantages of saving the analog signal for later use. Discuss the limitations of saving only the digitized signal.
Explain how the advent of very high sampling rates and large memory storage capability reduces the major disadvantages of digital sampling.
Explain the biggest advantages of digital sampling.

Define 8 bit, 16 bit, 32 bits etc. in the context of vibration amplitude and explain the benefits of the higher numbers.

3.3 Fast Fourier Transform (FFT) Computation

Explain in non-mathematical terms the function of the Fourier Transform and the Fast Fourier Transform (FFT).
Explain the significance with respect to vibration instrumentation of having the FFT on a micro- chip.

3.4 Time windows (uniform, Hanning, flat-top)

Explain why a window function is necessary for FFT calculations.
Relate amplitude accuracy and frequency accuracy based on choice of window types.
Compare FFT's derived from the same time domain signal using different windows.
Discuss the implications of the different choices (trade-offs and constraints)
Define exponential window and identify its uses.

3.5 Anti-Aliasing

What is the effect of anti-aliasing?
Define the Nyquist Criterion and calculate a simple example.

3.6 Bandwidth

Define bandwidth, including constant bandwidth, constant % bandwidth.
Note: not to be confused with resolution, or with the band-width referred to in the communications industry.

3.7 Filters

Define low pass, high pass, band-pass, and tracking filters
Discuss the purpose of high-pass, low-pass, band-pass and tracking filters.
Discuss digital versus analog filters, in particular the flexibility of digital filtering. Discuss enveloping filters and how to select the appropriate one.

3.8 Averaging

(rms ensemble, arithmetic ensemble, synchronous time, exponential)
Discuss the purposes of averaging e.g. improving the statistical value of the amplitude at a specific frequency, reducing the effect of noise by averaging out the random signal (not improving the SNR).
Discuss the optimum number of samples in an

average. Discuss retaining or discarding the individual samples.
Discuss number of samples for steady-state data, for transient data and for bump tests.
Discuss the uses and potential problems of using synchronous time averaging, such as improved SNR, but loss of non-synchronous and non-harmonic data.

Identify the applications of peak hold (which is normally included on instruments under averaging but which is not in fact averaging) and overlapping.

3.9 Dynamic range (see also Data Acquisition)

Calculate dynamic range based on # of bits. Define auto-ranging relative to dynamic range.

3.10 Spectral maps

Define spectral maps: waterfall (third axis time), cascade (third axis speed), Campbell diagram) and identify uses (e.g. for start-up and coast-down.)

4 Condition Monitoring 8%

The detailed techniques used in a condition monitoring program will depend to a significant degree on the particular package of hardware and software that is available. Therefore this section covers in general terms those skills required.

4.1 Computer Data-base

Set up a computer and maintain a data-base giving due consideration to:

- A schedule for purging and archiving old data taking into account legal requirements re due diligence.
- Backups – what method to use, network usage and care of recording media where appropriate.
- Off-site backups
- Removing machines that are no longer operational from the data-base.
- Up-dating a machine set-up in response to new faults found.
- Recording history when faults occur and
- Communication with interested parties for action.

4.2 Define the scope of a program

Decide which machines should be regularly monitored on a route-based system, which machines should be continuously monitored and which machines should not be routinely monitored using vibration measurements, based on criticality, available resources and predictability.
Document what faults can be detected and what are unlikely to be detected using a route-based approach.
Explain how a permanent on-line monitoring system would operate, what machines it

would be used on and what should be the plant philosophy with respect to alarms, danger indications and automatic trips.
Ensure that all stake-holders know the scope and the limitations.

4.3 Route Set-up.

Given a specific machinery description complete with speed range:
List the appropriate readings to take periodically, complete with type of reading (acceleration, velocity, and displacement), frequency range, location(s) and direction(s) of readings.
Suggest a desirable length of time between periodic readings – balancing the ability to detect problems with the resources required to run the program.
List the types of problems that can be identified on this machine, without shutting it down, indicating which reading(s) will identify each problem.

4.4 Alarm set-up

Includes absolute, relative change, overall, narrowband and spectral envelope.
Set up alert levels appropriately, including some combination of absolute, statistical, and ratios of baseline, giving due consideration to expected faults, standards, history on this machine and on similar machines in the plant, and the effect of variable speed versus fixed speed on alarm settings. Set first alert level, second alert level (if appropriate), alarm or danger level.

Set up relative change alert and alarm/danger settings in dB terms where appropriate. Set relative change alerts with two or more relative change increments and including an alarm or danger level change as appropriate.

4.5 Baseline assessments, trending.

Ensure new baselines are taken under standard operating procedure and tag new baselines in the database.
Record in the data-base if new faults have been introduced by the repair or replacement.
Review the data for repeated faults to identify the root cause and transmit this information to others for action.
Choose the appropriate trend variables (overall levels, spectral band levels), and select process variables to be trended that may correlate with vibration.

4.6 Alternative technologies

Includes oil analysis, infrared thermography, motor current analysis and acoustic emission. Define the above alternative diagnostic tools and identify their benefits and limitations for condition monitoring.
Define how the above alternative technologies are used in specific situations, in particular how they would be used to reinforce the decision making process where appropriate.

5 Fault Analysis 20%

Section 5 and Section 9 overlap somewhat, but the focus of Section 5 is primarily analysis and the focus of Section 9 is primarily additional testing and diagnostics.

5.1 Single Channel Wave-form and Spectrum

From a vibration time wave-form, identify: the peak amplitude, dominant frequency, beats, amplitude and frequency modulation (FM and AM), and truncation.

From a time wave-form taken with a once per turn marker, identify a dominant vibration component that is:

- an exact sub-harmonic of rotation speed,
- an exact multiple (harmonic) of rotation speed,
- subsynchronous but not sub-harmonic.

Relate a frequency spectrum to its corresponding time-waveform plot.

Identify the benefits and limitations of time domain and frequency domain analysis and why they should be used in a complementary fashion.

From a vibration spectrum, identify: harmonics of rotation speed, subsynchronous vibration, harmonics and sub-harmonics of rotation speed frequency, bearing fault frequencies and harmonics, vane-passing frequencies and harmonics.

Explain the difference between analog and digital overall levels and the pros and cons of

each. Explain why a digital overall level from a spectrum cannot be a true peak level.

Explain why a digital overall rms level can (under optimum circumstances) be the same as an analog rms level.

Explain the effects of low-pass filtering on a wave-form and the true peak

level. Explain the effects of low-pass filtering on a spectrum.

Explain the effects of high-pass (cut-off) filtering on a wave-

form. Explain the effects of high-pass (cut-off) filtering on a

spectrum.

Explain why you might use both high-pass and low-pass filtering in your route set-up or trouble- shooting data acquisition.

5.2 Enveloping

Define acceleration demodulation for detection of bearing faults. Know filtered ranges and methodology for the technique you are using. Identify what faults can be found with this method.

5.3 Orbit analysis i.e. X-Y Displays or Lissajous figures

5.3.1 Display

Show how two simultaneous orthogonal signals represent the physical movement of a shaft or a bearing housing in a two-dimensional space.

5.3.2 Simultaneous Sampling

Explain why the signals have to be sampled simultaneously (not multiplexed or sampled sequentially).

5.3.3 For unfiltered shaft orbits with no once per turn phase marker:

Deduce possible machine problems from various shaft orbit shapes. Explain the possible significance of:

- truncated or “chopped-off” shape,
- extremely flat orbit,
- a figure eight shaped orbit,
- a large very circular orbit close to the size of the bearing diametral clearance,
- a large wide elliptical or round orbit when you know from an FFT that the major component is rotation speed frequency
- an orbit with an inside loop or multiple inside loops,
- an orbit with multiple outside loops,
- an extremely small orbit.

5.3.4 For shaft or seismic orbits if you have filtering and a once-turn phase marker:

Deduce the major modal contribution to an operating deflection shape using orbits at several locations, filtered at rotation speed frequency and the once per turn phase-marker.

Determine if there is a subsynchrous or sub-harmonic component of vibration using the phase marker appearance.

Determine (together with time wave-forms) using the once per turn phase markers if the vibration is supersynchronous or harmonic.

Determine the direction of precession given a once per turn phase marker that gives a bright- blank or equivalent indication of which bit of the pulse came first.

Orient the 2 transducers correctly in all of above for various probe installation configurations. Use a velocity orbit shape to determine if the structural dynamic stiffness

is very directional.

Use the shape of a seismic orbit with a once per turn phase marker to evaluate the state of unbalance.

Graphically compensate a "1X" filtered orbit for run-out.

Demonstrate how an elliptical orbit can be decomposed into two circular orbits, one representing the forward precession components and the other the reverse precession components.

5.4 Rotational Frequency Operating Deflection Shape.

See Section 9.

5.5 Fault Identification from Steady-State Analysis

Identify the specific fault or possible fault(s) using any combination of the available steady-state analytical techniques:

- single or two channel time wave-forms with or without a once per turn phase marker,
- single or two channel frequency spectra,
- shaft or seismic orbits, with or without a one per turn phase marker.

Identify possible misalignment and distinguish between angular and parallel misalignment.

Identify possible mechanical looseness and distinguish between looseness, rubs and misalignment.

Identify possible unbalance. Distinguish between the characteristics of unbalance and other faults. Carry out other analyses or procedures to help this determination.

Identify faults in rolling element bearings using time wave-forms and/or frequency spectra together with a knowledge of the characteristic fault frequencies, where appropriate. Take into account the appropriateness of the type of bearing in the specific application e.g. is a roller bearing appropriate or should it be a deep-groove ball bearing (see also equipment knowledge)

Identify gear problems in gear-boxes using time wave-forms and/or frequency spectra as appropriate. Determine the gear mesh frequency(ies) and other characteristic fault frequencies of a gear train.

Identify sleeve or tilting pad journal bearing problems:

- excessive clearance,

- unloaded bearing,
- pre-loads,
- pad problems.

Identify possible instabilities:

- oil whirl,
- oil whip,
- steam/gas whip.

Identify possible flow induced vibration, due to

- flow turbulence,
- stall and surge,
- cavitation,
- aerodynamic instability,
- low or excessive flow,
- recirculation,
- insufficient back pressure,
- water hammer,
- Strouhal effect (vortex shedding).

Know the effect on vibration of operating a pump off the design point on the performance curve.

Identify electric motor defects

- Excessive bearing housing clearance,
- Excessive shaft to bearing clearance,
- Rotor and stator not parallels (wrong line bore),
- Rotor not axially centred in magnetic iron
- Bearing fits to tight (thermal expansion problems),
- Loose stator lamination,
- Shorted stator/rotor lamination
- Shorted winding turn to turn,,
- Ground fault,
- Rotor thermal bow,
- Broken rotor bars,
- Loose rotor bars,
- Current line unbalance,
- Resistant or loose connection joint,
- Starter star-delta fault,
- Shorted rotor poles (Synch motor),
- Uneven air gap (Synch motor with pedestals),
- Diodes or/and SCR broken in D.C. & Synch motor,
- Motor stator overheating,

- Motor bearing overheating,
- Motor lubrication problems

5.6 Transient (start-up, shut down) analysis

5.6.1 FRF

Describe the frequency response function (FRF or Bode plot) due to residual unbalance for a stiff shaft machine on flexible supports, as the machine speed passes through a speed range including the machine's first critical speed.

5.6.2 Interpret Bode plots and Polar (Nyquist) plots:

Identify the critical speed(s). Determine shaft run-out.
Determine qualitatively the balance quality.
Use a Bode plot to determine if there is a resonance problem.
Explain how to derive the Amplification Factor from a Bode plot

5.6.3 Shaft centerline analysis

Measure gap voltage at operating speed and on a shut-down to determine mean position of rotor within a sleeve or tilting pad bearing.
Explain what faults can be found with this method.

6 Corrective Action 15%

6.1 Managing Corrective Action

This section addresses how to get a repair done after the problems referred to in Section 5 have been analysed and evaluated. There is a very wide selection of machinery in many different industries. It is not practical for an analyst in one industry to be familiar with machinery that is only found in some other industrial sector. However, many machine components are common to different types of machines and the methodology for getting corrective action taken is to a large extent also common.

6.1.1 Additional Measurements.

If, after the measurements and analysis referred to in Section 5 have been carried out, the severity of a problem or the exact nature of the problem is not yet clear

- recommend what other vibration measurements need to be taken, if any, to further diagnose an identified problem
- recommend what non-vibration methods of analysis need to be employed, if any, to further diagnose a problem e.g. ferrography, thermography, current analysis, oil analysis
- recommend an increased monitoring frequency and/or more detailed measurements

6.1.2 Actions.

Recommend the required corrective action that you have identified:

- indicate the urgency of the action,
- give all the necessary information, including identifying descriptions and part numbers for replacement parts.

Define follow-up procedure, including how to determine whether the repair was successful. Assign responsibility for:

- procuring parts,
- installation or other corrective action,
- overseeing the action and ensuring it is carried out properly,
- follow-up evaluation including vibration measurements.

6.1.3 Document the process – see also Section 11.

Verify that work orders were implemented, and verify results. If the problem was not resolved, implement further measures. Document the history and transmit to interested parties.
Review history to determine if problems are repeated with a frequency that suggests a systemic or design problem.
Initiate follow-up if design or systemic, operational problems may be root causes.

6.1.4 Program evaluation – see also Section 11.

Document the effectiveness of the PDM program: Was the diagnosis correct?
Was the recommended action appropriate?
How effective was the repair in reducing vibration levels?

Did the repair have any effect on performance or machine availability? Is there a history of repeat repairs of the same nature?
Was the corrective action effective in preventing a potentially dangerous and/or costly failure?

6.2 Mechanical Problems of an Installation or Set-Up Nature.

Where your analysis has determined that there is a mechanical problem, such as misalignment, looseness or soft foot, initiate, via your Plant Management System the appropriate repair with all the necessary information.

Indicate the severity of the problem, the nature if possible e.g. parallel, angular or combination and the urgency of correction in the case of misalignment.
Indicate who should be responsible for doing the correction (even if self), who should oversee the corrective action and carry out a follow-up check on the vibration.
In the case of looseness and soft foot problems for example, identify the location and nature of the problem as precisely as possible, the severity and the urgency.
In the case of structural problems, recommend if engineering studies need to be carried out.

6.3 Component Failure Problems.

6.3.1 Defective rotating components.

When the analysis carried out in your PDM program or other investigation indicates defective components, such as,

- rolling element bearings,
- worn or broken gears,
- damaged seals,

set into motion via your Plant Management System, the process of getting the part(s) replaced.

6.3.2 Sleeve bearings or tilting pad bearings

Identify the nature of the problem e.g. excessive clearance requiring re-Babbitting of the bearing or problems with the operation of one or more pads in a tilting pad bearing.
In the case of a worn bearing, indicate the severity of the problem and the urgency of a re- Babbitt.
If a bearing is too lightly loaded, verify the alignment, the correctness of the design (specific loading) and bearing length to diameter L/D ratio.
Ensure that replacement bearing parts are installed correctly.

6.3.3 Tilting pad thrust bearings

Verify the mid point and cold float of the thrust bearing,
If your data indicates that the thrust position of the rotor is into an alarm condition, schedule corrective measures with regard to the possible damage caused by a thrust failure, the amount of Babbitt still on the thrust pads and safety considerations.

6.4 Motors

6.4.1 Motor electrical problems

Recommend other tests, such as current and flux analysis to confirm a conclusion of an electrical rather than a mechanical fault, if necessary.
Consult plant engineer for motor specifications
Initiate repair of an electrical fault through the Plant Management System making sure that the appropriate people are informed of the nature and severity of the problem.
Carry out follow-up vibration measurements after electrical repairs are carried out and document the before and after results.

6.4.2 Motor mechanical problems

For mechanical problems that are specific to motors such as out-of-round rotors, transmit as detailed a description of the possible mechanical problem as possible via the Plant Management System to those responsible for carrying out repairs or replacement.
Consult a certified EASA electric motor repair shop for mechanical specification that apply to this motor.

6.5 Flow-induced vibration problems

For flow induced vibration problems such as cavitation, turbulence, vane passing harmonics, and recirculation:
Maintain a data-base of operating data (e.g. flow-head curves for pumps and fans) or ensure you have access to such data in the plant.
Determine if operating conditions are contributing to the problem, e.g. is a pump being operated off its design point or is there insufficient NPSH before recommending corrective action.
Coordinate with operating personnel for any changes in operating conditions that you may wish to try in order to alleviate the problem.
Document any operating changes and their effects on the vibration levels and spectra.

6.6 Resonance problems.

Where appropriate, pursue a solution to resonance problems based on trade knowledge, practical experience, and applicable test data (See Section 9). For example:

- add or reduce structural stiffness,
- add or reduce mass,
- change the force or rotation speed
- avoid certain speed ranges in a variable speed machine,
- use an inertia base and vibration isolators
- use a dynamic vibration absorber
- reduce pressure pulsations
- apply a higher balance quality

Where necessary, work with others to engineer a solution to the resonance problem, using more advanced analyses such as

- detailed FRF calculations,
- mathematical modelling of a solution, or
- experimental modal analysis.

Where de-tuning is not possible to resolve a resonance problem, recommend procedures for reducing the forcing function.

6.7 Field trim-balancing

The I.S.O. Cat 3 requirement is to carry out a single plane balancing procedure using a single channel instrument. The following expands a little on this for practical considerations.
Carry out a single field trim balance using a single channel instrument, a once per turn phase marker and seismic vibration measurement using a graphical vector method if necessary and if the machine configuration allows this e.g. a short span rotor between bearings.

Carry out a two plane field trim balance using a single or two channel instrument, a once per turn phase marker and seismic vibration measurements at two planes using balancing software where a single plane method would not be adequate.
For the two plane trim balance, take the measurements in one direction (e.g. horizontally) only, or in two directions if the software is written to allow this i.e. rms averaging.
Document either manually or electronically the as-found run, the trial weight (calibration) run(s), the balance run, the trim balance run(s), if any and the final run.

7 Equipment Knowledge 10%

7.1 Scope and Procedure

Certain machines are only found in specific industries, however, there are many machine components that are common to a wide variety of machines and there are certain machines that are found in many industries. For the machines they work with, vibration analysts need to have a knowledge of problems specific to that type of machine and how vibration analysis would detect those problems.
Realize what factors in the machine and in its performance and environment will affect vibration. Develop a strategy for obtaining relevant equipment information and use it to help evaluate the machine.
Where necessary, consult machine documentation or manufacturer for additional information. Develop a procedure for recording relevant data about the design and performance of the machine, and use it. Modify the procedure with experience, to include records of parameters which have proven to be important. (e.g. type of lubricant, bearing tolerances, thermal growth, belt length and type, etc.) – See Appendix A.

7.2 Machinery Components

7.2.1 Rolling Element Bearings

Know the various types of rolling element bearing, their appropriate applications and how inappropriate application or installation can affect performance and vibration.

7.2.2 Sleeve bearings.

Know the different sleeve bearing profiles and the importance of loading, clearance, shaft position, and oil properties with respect to machine performance and vibration phenomena.

7.2.3 Tilting Pad Bearings.

Know how tilting pad radial bearings function, in particular their properties concerning machine stability. Know how tilting pad thrust bearings function and the significance of monitoring thrust position.

7.2.4 Seals

Know the various types of seals used in rotating machinery including labyrinth seals, floating ring seals, brush seals, mechanical seals in compressors and turbines and bushing type seals in pumps. Know how the seal design can contribute to or prevent machinery problems.

7.2.5 Couplings

Know the various basic types of coupling design e.g. gear couplings, diaphragm couplings, spline couplings, elastometric couplings, solid couplings and quill couplings.
Know the limitations of the term “flexible” in regard to flexible couplings.
Know what kind of dynamic vibration problems can occur with gear couplings.
Know the importance of correct installation procedures for flexible diaphragm couplings.

7.2.6 Belts

Know the types of belt drives and the relevance of correct belt tension to vibration limitation. Know the typical modes of belt vibration and their causes.

7.3 Electric motors, generators and drives

7.3.1 Induction Motors

See also Atlantic Chapter motor standard on www.cmva.com Members Only/Technical. Understand the information on the motor nameplate.
Know the basic theory of operation of induction motors, the relation of synchronous speed to number of poles, the meaning of slip frequency and how it relates to running speed and synchronous speed. Know the significance of rotor bar-passing frequency and how to set up an analyser to measure vibration at that frequency.

7.3.2 Synchronous Motors

Know the basic theory of operation of synchronous motors and vibration problems that tend to be specific to these machines

7.3.3 DC Motors

Know the basic theory of operation of D.C. motors and vibration problems that tend to be specific to these machines

7.3.4 Variable Frequency Drives (VFD’s).

Know the basic theory of operation of VFD’s and vibration problems that tend to be specific to these drives.
Know the possible collateral damage when using VFD’s with an electric motor

7.4 Fans

Know the basic operating characteristics of centrifugal fans and axial fans and the appropriate application of each. Recognize the common problems of fan applications mounted with rolling element bearings (e.g. minimum load, lubrication, fits and internal

clearance requirements).
Understand the effect of the fan arrangement or type on its vibration behaviour and possible generated faults.
Know the typical type of vibration problems associated with induced draft fans and forced draft fans (e.g. unbalance particularly on ID fans, structural resonance, and blade passing frequency).

7.5 Centrifugal Pumps

Know the operating characteristics of centrifugal pumps including the use of performance graphs
e.g. flow-head curves and the importance of operating at an appropriate point on the curve.
Know the various hydraulic problems that can occur e.g. recirculation, cavitation, blade passing frequency vibration and the typical causes.

7.6 Gearboxes

Know the components and types of gearing found in the most common single speed increaser and speed decreaser gearboxes. Know the types of failure and wear problems that are typically found in gearboxes and how these can be detected and evaluated using vibration measurement. Know how to calculate the various characteristic frequencies produced by gear box problems. Keep a ready reference of gear-box fault frequency formulae.

7.7 Structures and piping

Recognize that structures and piping behave very differently from rotating equipment, and that vibration guidelines are entirely different.
Know how piping vibration behaves e.g. lateral modes of vibration, shell modes, and acoustical axial modes.

7.8 Reciprocating Compressors and Engines

7.8.1 Cautions

See also "Monitoring Reciprocating Machinery" on www.cmva.com /Members Only/ Technical. Be aware of the specific safety issues when working with reciprocating machines.
Identify the elements of a reciprocating machine that can be monitored using conventional vibration analysis equipment and what cannot, and document that fact.
Know the limitations of what can be done with only vibration analysis.

7.8.2 Behaviour Modes

Recognize that reciprocating compressors and engines behave very differently and have different failure modes than other rotating equipment, some of which are not detectable by conventional vibration analysis.
Know the principles of how forces are generated in a reciprocating machine, the movement of the cylinder, and the associated frequencies.

7.8.3 Techniques

Be aware of other techniques used for monitoring reciprocating machinery, including p-t and p-v curves, pulsation analysis, and torsional analysis
Identify appropriate test points, measurement parameters and frequency ranges to monitor frame vibration, cylinder vibration, bottle and piping vibration. Identify and document what failure modes these measurements can identify.
Know where to take vibration readings, what type of reading to take and with what frequency range.
Know the appropriate allowable vibration at those test points. Evaluate readings relative to a guideline.

7.9 Specialised Machines

The following is a list of specialised machinery. These machines have many of the components referred to above but also have specific aerodynamic or other characteristics that affect vibration and how it is measured.

For the industries they are employed in, vibration specialists should know the operating and mechanical principles of the relevant machines.

- Steam Turbines
- Gas Turbines
- Centrifugal Compressors
- Screw Compressors
- Positive Displacement Compressors
- Rolling mills, paper machines, other process equipment

8 Acceptance Testing 5%

8.1 Scope and Definitions

A formal acceptance test is performed to check if the conditions laid out in specifications documentation are met. It may have economic and legal implications and is typically carried out by a third party.
An informal acceptance test can be an in-house test to decide if a machine is suitable for operation in the judgement of the vibration analyst.
The purpose of this section is that the Cat 3 analyst be able to establish programs for the specification of vibration levels and acceptance criteria for new or rebuilt machinery for either situation.

8.2 Specifications and Standards

Define in detail the vibration levels and parameters which must be met and under what operating conditions of load, speed and other relevant operating condition.
Recognize the implications of acceptance testing on a test bed and differentiate that from vibration levels as designed, as-built, as commissioned, and run under full process conditions. Make use of national, international or industry standards and specifications where applicable and identify those against which the test results are to be evaluated.

8.3 Test Procedure

Define the test procedure to be used, giving due consideration to instrumentation, methodology, national, international and industry standards, the type of machine to be evaluated, the usage defined for the machine, and the goals of the client.

Give due consideration to the operating context of the test.

Describe what characteristics this procedure is intended to test. Identify where there are deficiencies or inappropriate procedures in a referenced standard or specification document.

8.4 Reporting

Define what information should be in the report, including the requirements for a detailed record of the entire test procedure, of the results obtained and of their comparison with the standard established by the test procedure.

Ensure that the report is sufficiently complete and detailed in case it needs to be used in litigation.

Where test results do not meet the specification, suggest additional tests and/or identify possible sources of the problem.

Maintain all records, suitably backed-up. Refer to provincial P.Eng. associations for required documentation of professional practice.

9 Equipment Testing and Diagnostics 8%

9.1 Forced response testing including impact testing

Perform a natural frequency test on a machine structure, using a single channel instrument and a non-instrumented impact device (e.g. rubber hammer) and interpret the results.
Recognize the need for cross channel impact testing (FRF) or shaker excitation testing and determine natural frequency and mobility from typical test data.
Assess the structural response by using a known unbalance force.

9.2 Transient analysis

Understand the main features of Bode plots, polar (Nyquist) plots, waterfall plots, cascade spectra plots, shaft centre-line plots and Campbell diagrams.
Determine critical speed on rotor systems (frequency of maximum unbalanced response) from run-up and coast down tests
Determine natural frequency on structures from run-up and coast down tests

9.3 Operating deflection shapes (ODS) – see also Section 5.

Carry out a basic operating deflection shape analysis using amplitude and phase measurements at rotational frequency and harmonics, using measurements in 3 axes (typically horizontal, vertical and axial but not necessarily so).
Sketch the structure to be analyzed.
Determine where to take readings to develop an ODS, and with a single channel instrument that also has a once per turn phase marker, collect appropriate data. Interpret results and show deflection shapes on the sketch.
Identify situations for which dual channel FRF data collection is required.

10 Reference Standards 5%

Maintain a library of standards relevant to your industry.
Recognize and interpret standards and severity charts relevant to particular industries and particular machine types. See CMVA ISO Chart on www.cmva.com
Choose an appropriate standard for the machine
Where justified, modify the application of the chosen standard based on operating context (exact machine, installation and process being used) and/or local operations experience, and document the reasons.
Refer to the Appendix for sources of standards and other relevant resources.

11 Reporting & Documentation 5% – see also Section 6

11.1 Condition Monitoring Reports – Machine Condition

Provide, to the right people at the right time, a list of monitored machines with a statement of their condition, including OK, needs repair but can run, needs further analysis, needs repair, etc. That is, report the decisions that have been made.
Where "needs repair" is the diagnosis, do a "Vibration Diagnostics Report" to justify your decision.
Based on this report, if necessary identify needs for further resources, research, training, etc. to solve remaining problems.
Determine if you need to hire a consultant to help, and if so
ensure that the consultant is professionally and technically qualified to meet the plant's needs Work with the consultants to make sure all the historical and process information is available to them
Follow-up on the recommendations in the consultant's report

11.2 Condition Monitoring Reports – Overall Program

Keep a record of decisions made, the reasons for the decisions, and the correctness of the decision, based on these possibilities:

- predicted fault found
- machine called OK and failed in service
- a fault found after call, but not the predicted fault
- call made, but no fault found.

- call made, but machine not repaired, and either failed in service, or did not fail.

Based on this report, if necessary identify need for further resources, research, training, etc. to improve the program.
Categorize the identified faults, and look for patterns and opportunities for improvement, as per plant policy.
Estimate and record the "economics" for each incident, based on assumptions agreed upon within the plant. Include savings due to prevention of catastrophic failure, reduction of down- time, and the prevention of further faults through root cause analysis and the resultant re- engineering. Track costs associated with failures in service, where possible, for comparison. Report to management regarding program objectives, budgets, cost justification, and personnel development.
With management, identify key performance indicators, and report them to management as required.
Consider defining and reporting an "overall vibration index" as an indicator of machine health across the plant.

11.3 Vibration Diagnostics Reports

11.3.1 Standard

Where maintenance or other action is required, generate a vibration diagnostics report as described under Category 2. Follow a standard engineering format.
Generate a Vibration Diagnostics Report for machines on the program that were called "OK" and failed in service. Determine if the failure could have been predicted or not, and record that information.
Generate a Vibration Diagnostics Report for machines on the program that were called "repair needed" and which were kept in service and did not fail. Determine clearer guidelines for similar calls for the future, and record that information.

11.3.2 Urgent Site Report

If there is an immediate or critical problem, generate, distribute to, and discuss with the stake- holders a site report, which clearly identifies the problem and conveys its urgency. This report should be short and to the point, and might even be hand-written.

11.4 Documentation

Use a consistent system of documentation, accessible to all the stake-holders in the plant, which makes the history of analyses, process changes, results and repairs readily available. A properly executed computerized work order system which requires a work order to be completed and signed off is a good example.
Maintain a backup of all data for a length of time (at least 5 years) determined by management practice requirements.

12 Fault Severity Determination 7% See also Section 6

12.1 Failure Mode and Immediacy

Determine the failure mode and the immediacy of the problem, based on the steady state data acquired as described in previous sections, and considering levels, spectral content, operating deflection shapes and any other relevant vibration or non-vibration test.

12.2 Evaluate the consequences.

Consider functional failure versus physical failure possibly leading to secondary failure and potentially to resultant damage.
Consider consequences of failure in terms of health and safety, environment, production quality and availability, and cost to the customer.
Consider the maintenance implications such as scheduling and availability of parts and labour.

For constant and variable speed machines, evaluate the data relative to criteria in accepted standards documents (see Appendix) as well as to expected faults and acceptable levels based on the history of the specific machine in your plant. Also relate the data to operating context, including load, speed, ambient conditions, temperature and process parameters.

12.3 Recommend

Make recommendations for action (to the right person at the right time, depending on the severity):

- Recommend immediate corrective action if you determine that the problem is severe and that possible failure is imminent.
- Recommend and justify an unscheduled shut-down where required.
- Recommend action that should be performed during the next scheduled shut-down if appropriate.
- If the data is not sufficient to determine the immediacy of the problem, recommend other kinds of evaluation, more frequent route-base monitoring or the addition of instrumentation to closely monitor the machine.

Appendix

References

Ronald L. Eshleman. Machinery Vibration Analysis: Diagnostics, Condition Evaluation, and Correction, Volume I Diagnostic Techniques. Vibration Institute, June, 2002.
Ronald L. Eshleman. Machinery Vibration Analysis: Diagnostics, Condition Evaluation, and Correction, Volume II Analysis and Correction. Vibration Institute, June, 2002.
Vibration Math Formula Sheet. Available on www.cmva.com under Members Only and then under Technical Information. This sheet will be provided to exam candidates.
CMVA "Guidelines for Evaluating Vibration" – chart based on ISO 10816-3. Available on www.cmva.com under Members Only and then under Technical Information. This sheet will be provided to exam candidates.
ISO 10816-3, available on www.cmva.com for CMVA Members only.
ISO 18436-2, available on www.cmva.com for CMVA Members only. Exam candidates must certify by their signature that they meet the requirements for writing the exam.

Standards

Sources for International, National and Industry Standards and Associated Resources.

See the itemized lists in "Reference Standards for Vibration Monitoring and Analysis"
J. Michael Robichaud P.Eng. – obtainable through the

CMVA. International Organisation for Standardization

(I.S.O.). American Petroleum Institute (API)

Canadian Standards Association (CSA)

American National Standards Institute

(ANSI) Hydraulics Institute (HI)

National Electrical Manufacturers Association

(NEMA International Electrotechnical

Commission (IEC)

The Standards Council of Canada www.standardsstore.ca is a source for ISO, IEC, API and other Standards

Techstreet (www.techstreet.com) markets API, HI, ANSI Standards among others.