CMVA Certification Program
Category 2 – Basic Analysis
Performance Objectives

Basis

These performance objectives define what an individual certified at Category 2 should be able to do on the job. They are based directly on the ISO standard 18436-2:2014(E) and were prepared by members of CMVA's Training and Certification Committee.

Titles are from the ISO standard Annex A Table A.1 and are reprinted by permission. The full text of the standard is available to CMVA members under license on www.cmva.com by clicking on the Members Only tab. The noted percentages of questions on a subject are derived roughly from the ISO standard, which indicates the number of hours during a 38 hour course to spend on each topic.

In general, each category is responsible for most of the same topics, with the depth and breadth of knowledge increasing with the increasing categories.
The major (but not exclusive) focus of each category is as shown in the title. Vocabulary is part of the required knowledge at each category.

Certification Examination

Each exam consists of 100 multiple choice or true/false questions, and exams are different each time they are given. Anyone who has mastered the indicated performance should be able to pass the associated test. Category 2 candidates are also responsible for all the performance objectives listed for Category I and have minimum 18 months vibration related experience.

Exam questions are straightforward. Don't look for hidden meanings. If you think a question is tricky or badly worded or unfair, note that fact on the test; it may be taken into consideration in the marking and the question will certainly be reviewed before the test is given again.

Number of Hours Allowed To Write the Exam (minimum pass mark is 70%)

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

1) Principles of Vibration about 10% 11 questions per exam

Master the same performance objectives as shown in Category I, for more complex signals. Distinguish between vibration as a problem (causes trouble) and vibration as a symptom (indicates the presence of trouble).

Definitions, Usages, Relationships

Identify the characteristics, applications, and limitations of acceleration, velocity, and displacement readings, along with the typical frequency ranges of use.

Choose RMS, peak, and peak to peak readings appropriately, depending on the expected fault(s) to be found and the vibration parameter to be used.

In the context of vibration analysis, define free vibration, forced vibration, time domain, frequency domain, force and response.

Define relative phase between two single frequency waveforms. Define absolute phase as measured using a once per turn phase marker.
Use phase to relate vibration time waveforms at different locations on a machine. Identify uses for phase measurements.
Demonstrate the phase relationship between displacement, velocity and acceleration.

Relate natural frequency, resonance and critical speed to forcing frequency. Distinguish between forcing frequency, natural frequency and resonance.

Calculations and Plots

Recognize time waveforms resulting from several frequency components.

For more complex signals than in Category 1, calculate frequency from period, and period from frequency, and read them from plots.

Convert acceleration amplitude measured in standard dimensional units to acceleration in terms of units of the acceleration due to gravity.

Convert from displacement amplitude to velocity or acceleration amplitude at a given frequency and perform the reverse operations.

2) *Data Acquisition about 10%* - 11 questions per exam

Technical Aspects

Define piezo-electric accelerometer, eddy current probe, proximity probe, seismic displacement transducer, ICP velocity transducer and moving coil velocity transducer, and identify the uses and limitations of each.

Match the sensitivity of the sensor to the measurement definition i.e. mV/in/sec, mV/g,

mV/mil, mV/mm/s, mV/μm. The sensitivity (value and units) of the transducer must match that set in the instrument and in the software.
From specifications, determine the usable frequency range for accelerometers that are hand-held, 2 pole magnet, quick connect, flat rare earth magnet with flat target, adhesive, stud-mounted. Distinguish between low frequency response, general purpose and high frequency response accelerometers. Determine which of these is appropriate for an application taking into account such problems as saturation.
Identify methods, benefits and limitations of different mounting types in different circumstances.

Relate maximum frequency (Fmax) and acquisition time.

Define motion and sign conventions for accelerometers, velocity transducers and eddy- current probes i.e. motion of housing surface positive towards accelerometer or velocity transducer, shaft motion relative to housing positive towards eddy-current non-contact probe.

Collect data from permanently mounted transducers (e.g. panel readings) as required. Define

external triggering.
Explain triggering methods: multiple pulses /revolution, single pulse per revolution, signal input level, manual, time based, free-run.

Explain the use of a phase reference signal. .
Explain the difference between a trigger and a once per turn phase marker. Use a once per turn reference device to measure phase.
Explain what is involved in once-per-turn phase reference signals using: a magnetic pickup, and optical probe, a laser and an eddy-current probe.

Testing

Collect new baselines when machine is significantly changed – e.g. new bearings.

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.

Develop and execute test procedures based on plan as approved by supervisor.
If required, collect and save extra data, to include higher resolution or zoom spectra; extended or reduced frequency range data; time domain data with higher sample rate; time domain data with shorter or longer sample time as indicated in pre-defined procedures.

Read trends, spectra, spectrum trends, and time waveforms.

Data Formats

Check the labels and scales on horizontal and vertical axes during analysis to ensure they are appropriate for the data you are reviewing.

Distinguish between linear and log scales.

Data Quality

Calibrate your instrument with its sensors periodically, as recommended in its manual, and whenever you have reason to suspect the quality of data it is generating (such as if the accelerometer was dropped). Maintain appropriate records of calibration. Adjust instrument if sensor calibration has changed.
Recognize more subtle examples of bad data, as noted in Category 1. Identify sources of ski slope error.
Given machine description, speed range, and associated trends and/or spectra, candidate will indicate one of

1. good data with proper frequency range and technique
2. poor data due to hand motion
3. poor data due to wrong type of reading – e.g. displacement on a high speed gearbox
4. poor data due to wrong frequency range (e.g. too narrow to get vane-passing or gear mesh frequency, too wide to differentiate peaks around runspeed)
5. poor data, taken on wrong machine (e.g. 1800 rpm machine with a clear peak at a frequency of 1200 cpm, and no peak at 1800 – or the description includes the machine name and the plot has some other name)

3) *Signal Processing about 10%* - 10 questions per exam

Define sampling, (analog and digital), sampling rates, Nyquist criterion.

Relate data collection time to number of lines to frequency range to number of time samples.

Define time windows (uniform, Hanning, and flat-top) and identify which one suits best in various circumstances.

Define and identify use and application of filters (low pass, high pass, band pass, and tracking).

Define anti-aliasing and explain why it is necessary. Define and calculate lowest resolvable

frequency LRF.
Define what is meant in vibration analysis by the term band-width.

Define effective resolution. Relate resolution to data collection time, quality of data, window factor, computer space required.

Resolve two components of vibration whose frequencies are close together.

Define averaging, (ensemble (linear), synchronous time, exponential. Relate to data collection time and type of signals (random vs periodic). Know the benefits and drawbacks of averaging in the context of data collection.

Define peak-hold. Define overlapping.

Define dynamic range (of instrument/sensor system). Identify the benefits of greater dynamic range and the limitations of less dynamic range.

Choose a log or decibel scale to improve a spectrum display when there is a wide variation in amplitude.

4) *Condition Monitoring about 10%* - 10 questions per exam

Distinguish between predictive and preventive (time-based) maintenance.

Maintain the database with careful reference to its accuracy and completeness. Ensure that data is reasonable; repeat data collection if unsure. Remove garbage data, both in the machine list and in the results. Prefer no data to bad data.

Keep records of machines which don't get monitored, unreachable test points, safety issues, vibration readings and process variables which should be recorded, (or which are a waste of time), frequency of data collection relative to plan, improperly located test points, etc. and report as required.
Recommend changes to the database for increased safety, for convenience, to add new equipment, to remove discarded equipment, to update details when a machine has been replaced with a somewhat different one, etc.

Plan extra data collection where necessary to ensure all machines are monitored (e.g. spared, not running at time of data collection.)

Exceptions

Review trends of overall readings and flag exceptions.

Identify when an overall reading exceeds alert or alarm categories, or exceeds the baseline. Personnel using specific equipment are encouraged to understand the alarm methods used in their software.

Evaluate exceptions based partly on the priority of the equipment concerned. Recognize when a machine's data collection priority has to change.

Analyze trends relative to changes in process variables to determine whether a change indicates a machinery problem.

Identify the most likely faulty element(s) in equipment by:

- evaluating spectrum components against baselines and historical readings
- relating change in spectrum components to specific machinery faults

Follow up on the action taken as a result of recommendations and record the results, relative to the readings, so the information can be included in the decision making process for future incidents.

5) ***Fault Analysis –about 10%*** - 11 questions per exam

Define spectrum analysis, harmonics, subharmonics, sidebands. Recognize that sidebands of gear mesh frequency are relative to runspeeds of different shafts. Recognize that additional harmonics or higher amplitude harmonics suggest more damage.

Use trends of overall readings, and spectra including baselines and history, as appropriate, to assess equipment and identify the most likely faulty element(s).

Recognize that a rising or falling trend may be just as significant or even more significant than exceeding an alarm level.

Check for process changes (flow rate, fluid, temperature, pressure, torque, load, etc.) that could influence vibration before suggesting further analysis.

Compare two spectra taken from the same test point on different dates and point out differences that need to be explained.

Given an increase in vibration at a specific frequency, suggest which component is most likely faulty.

Where appropriate, identify the key frequency(s) and/or describe the key phase relationships that would indicate

- mass unbalance
- misalignment
- mechanical looseness
- impellor or blade problems
- journal bearing defects
- rolling element bearing defects
- electric motor defects
- resonance and critical speeds
- gear problems.

Given a set of overall and spectral readings, with history, and a machine description including speed, the student will diagnose likely faults as noted above, indicate the most likely faulty component, and prescribe an appropriate course of action.

Evaluate a reasonably clear spectrum in comparison with an earlier one on the same test point, or in comparison with known alert settings, and from it suggest no problem or one of the faults as noted above.

For the equipment types mentioned in Section 7, identify the most common faults and show how the information obtained in a condition monitoring program can indicate those faults.

Compare peaks in spectrum to bearing fault frequencies. Identify increases. Recommend further analysis (more often or more detailed).
Define high frequency early detection of rolling element bearing faults.

6) ***Corrective Action about 10%*** - 11 questions per exam

- Determine need for alignment.
- Understand offset and angular misalignment concepts.
- Recommend appropriate measurement techniques and corrective actions.
- Recognize the importance and measurement of soft foot checks and correct for soft foot if required.
- Identify the need for balancing
- Identify situations where balancing will not work – e.g. bowed rotor, resonance, radial run-out, torsional problem, dirty blades, loose parts.
- Perform single plane balancing by hand using vector method.
- Demonstrate graphically the principles of a single plane balancing procedure using a single channel instrument, a once per turn phase marker and seismic vibration measurement.
- Understand the concepts of "heavy spot" and "high spot" on a rotor and the addition of balance weights.

Issue a work order or approve one issued by a Category I employee (or follow other clearly defined plant procedures) on identification of any of the following issues:
Safety Issues, e.g.
- poor access to test point
- potential for tripping the unit
- missing or loose guards
- possibility of steam burn, etc.
- leaks of oil, water, steam, H_2S, NH_3, etc.

Process, e.g.
- needed lubrication
- needed replacement of oil or air filters
- dirty fan blades
- improperly adjusted valves

Machine Mounting Problems, e.g.
- loose grout
- cracked or damaged machinery base
- loose bolts, etc.
- broken foundation

Piping Problems, e.g.
- loose or broken clamps
- cracks in piping
- need for adjustment in pipe supports
- pipe strain

Needed Investigations, e.g.

- checking journal bearing clearances
- unusual noises
- hot spots

7) ***Equipment Knowledge about 10%*** - 11 questions per exam

Equipment: same as the list in Category I, plus steam turbines, gas turbines, reciprocating engines and compressors, gearing, couplings, belts, sheaves (pulleys), and journal and rolling element bearings.

In addition to the requirements for Category I, on the entire list of equipment, given run speed of unit, calculate fault or forcing frequencies (as appropriate) in Hertz and CPM for unbalance, misalignment, gear meshing including on intermediate shafts, impellor or vane problems, and electrical faults on synchronous and induction motors. Where relevant, calculate sidebands. Calculate bearing fault frequencies given run speed of unit and fault frequency multipliers provided by manufacturer.

For the whole list of machinery, understand the basic operating principles as well as the effect on the machine and its vibration patterns of variations in operating conditions, such as pressure, temperature, fluid consistency and flow.

Know the elements within each machine that generate vibrations, and the approximate frequency of those vibrations relative to runspeed, including subsynchronous and nonsynchronous vibration and sidebands. Include vibration indicating both “normal” and “abnormal” conditions. Include electrical faults on electric motors, cavitation, too much or too little lubrication, and problems with foundations and grouting. Recognize that variable frequency drives have different electrical frequencies.

Understand that load, combustion and pulsation can affect vibration in reciprocating machinery. Understand that vibration is also related to pressure-volume and pressure- time curves, and that compressor valves are often faulty.

Recognize the effect on vibration of improper lubrication or improper installation of rolling element bearings.

Understand how varying speed affects vibration frequencies.

8) ***Acceptance Testing about 5%*** - 5 questions per exam

Set up instrument and sensors to collect data to meet the written specification provided by client or company policy and industry specifications and standards.
Relate specifications to operating conditions.

Interpret specifications and standards defined by others.

Use proper documentation to clearly note the specifications & standards, conditions, units, measurement parameters and instrumentation used in the testing so the results are meaningful in a subsequent discussion and will be valid if there is a dispute. Recognize that you may have to testify as to the circumstances, procedures, and findings of the test.

Prepare reports indicating whether the equipment being tested met the standard, or if not, what the deficiencies were. Report the results clearly and specifically to management or client, to enable the decision to accept or reject the equipment.

9) ***Equipment Testing & Diagnostics about 5%*** - 5 questions per exam

Define frequency response function (FRF).
Define excitation.
Define harmonic excitation - give examples. Define transient excitation - give examples.

Define single channel bump test, 2 channel impulse hammer frequency response test, unbalance response test, run-up test, coast-down test, harmonic excitation test (shaker). Define over speed test.

Give example(s) of situations where each of the above tests would be appropriate.

Set up instrument for and carry out single channel bump tests to determine the significant natural frequencies of equipment.
Read spectra resulting from a bump test and identify the natural frequencies.
Explain the significance of a natural frequency equal to or close to the run speed or other forcing frequency in a machine.

10) Reference Standards about 5% *- 5 questions per exam*

Distinguish between vibration limits for "overall vibration" and "filtered vibration".

Identify the principles on which ISO 10816-3 is based. (the standard, and a CMVA chart based on it, are available on www.cmva.com.)

Given ISO 10816-3, compare readings to standards and identify warning and danger levels.

Define IEC.

With regard to vibration standards and severity charts, recognize that

- some standards provide guidelines to data collectors, and that comparisons would be invalid if the guidelines were not followed.
- there are many standards and vibration guidelines, including some provided by manufacturers of equipment, and they are averages, developed for many types of equipment and kinds of industry, i.e. they are a starting point.
- alert and alarm levels could be based on machine history, company standards, or industry charts such as ISO 10816 Part 3.

- an increase or decrease in vibration may be as significant as absolute amplitude.
- balancing standards exist and are different than vibration standards.

11) ***Reporting and Documentation about 5%*** - 5 questions per exam

Condition Monitoring Reports

Ensure that Exception Reports have been generated and sent to people designated by supervisor, as per schedule.
Follow plant procedures to ensure that exceptions are dealt with rather than overlooked; including notes on decisions made, work orders generated, follow-ups done, etc.
Make a special effort to bring urgent situations to the attention of the appropriate people.

Periodically, as per plant policy, generate a Condition Monitoring Program Report to summarize the state of the program, and send to people designated by supervisor. Typically, this report would include, for the specified period, at least the following: # of machines monitored, # of machines planned to be monitored, number OK, number of alerts, number of alarms, and a list of machines for which insufficient data has been collected and why (insufficient data collection time, spared machine, machine down at time of data collection, etc.)

Documentation

In the course of your investigations, you may learn details specific to your plant, or to the individual machine (e.g. this pump is particularly sensitive to changes in ambient temperature), that are helpful to the decision-making process. Within a short time of learning such information, share it and record it in a place accessible to all stakeholders.

Vibration Diagnostics Reports

As per plant policy, generate a vibration diagnostics report to explain exceptions and/or justify your conclusions, and send to specified people. Typically, the report might include trends of overall readings, spectra of the problem test points, history, records of process variable changes over time, etc. Provide enough data to support the decision, but not so much as to be overwhelming. If the problem is difficult or its consequences are severe, involve other people such as colleagues, OEM’s or consultants in the process.

12) ***Fault Severity Determination about 5%*** - 5 questions per exam

Define severity and the concept of severity charts.

Determine which parameters are related to severity of the fault (amplitude (displacement, velocity, acceleration)) and which are related to cause of fault (frequency).

Define overall, narrowband, and component levels. Indicate the circumstances in which each would be used to help determine severity.

Interpret severity charts and use them to assess the severity of a fault.

Over time or as compared to standards, use changing amplitudes of spectral components to assess severity of fault, and thus to suggest repair priority.

For exceptions, relate overall readings to historical trends and/or severity charts and categorize them as “no problem, induced by operating condition change, watch carefully, change out at next shutdown, or change out as soon as possible”.
Do the same for anomalous spectral peaks, and indicate the machine component that is most likely faulty.

Prioritize a list of potential maintenance tasks arising as a result of condition monitoring.

Recognize that different amplitudes are acceptable and unacceptable for different machine components.

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