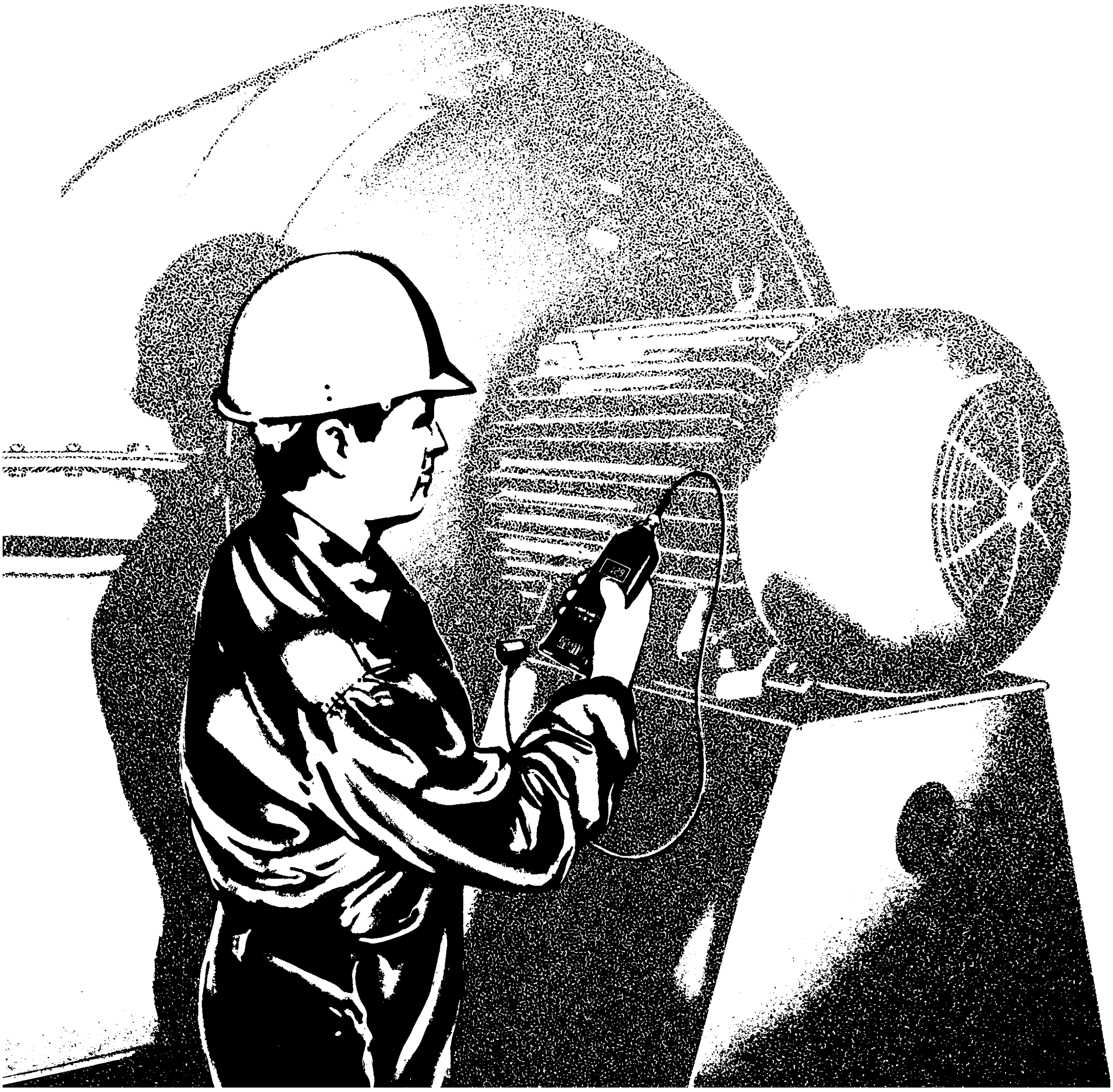
Instruction Manual

Vibrameter VIB-11



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Vibration Monitoring

Instruction Manual for Vibrameter VIB-11

Contents

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Condition Based Maintenance

Condition Based Maintenance is by now a widely accepted concept in industry. The idea is simple and not exactly new: keep plant machinery in good working condition by locating and repairing minor faults before they grow large enough to cause expensive breakdowns and production stops.

The problem is to assess machine condition and detect a slow deterioration long before a piece of plant grinds to a shuddering halt. In the past, a skilled operator could do this largely without the help of instruments, by listening, touching, smelling. Modern machinery is often unattended, soundproofed, out of easy reach. It rotates faster and is less massively constructed, which means that even a minor deterioration of its working condition can have very serious consequences. Therefore personal skill and subjective judgement have to be supported by monitoring systems and instrument readings.

Vibration Monitoring

Vibration monitoring is a very useful method for an overall assessment of machine condition. Changes in the vibration level always imply changes in the operating condition. Excessive vibration has basically three causes: something is loose, misaligned or out of balance. These three causes cover virtually all possible mechanical faults.

Moreover, the assessment of machine vibration has been much simplified by international standards which define the acceptable vibration level for a given type of machine and recommend monitoring methods suitable for industrial purposes.

A Maintenance Tool

Effective Condition Based Maintenance requires economical and simple monitoring methods which can be applied by maintenance personnel without special training. Their primary task is to locate trouble spots early and direct the efforts of the maintenance crews to the right place at the right time. Fault analysis and repairs are a secondary step which may require expert knowledge and a different type of instrumentation.

SPM vibration monitoring equipment is designed as a maintenance aid. In accordance with the international standards, it measures vibration severity over a large frequency range. It allows a practical classification of machine condition in relative terms: good, acceptable, just tolerable or bad. Regular measurements will also show the development trend of the vibration level and thus the urgency of the maintenance problem: stable condition, slow deterioration or fast deterioration.

Measurements can be carried out in various ways; either periodical readings with portable equipment (Vibrameter VIB-10), or continuous monitoring of preset limit values (SPM Vibration Monitor VIB-20). This manual gives an introduction to vibration monitoring and describes condition assessment and basic fault analysis with SPM Vibrameter VIB-10.

Measuring Units

ISO Recommendations use metric units (mm/s RMS) for measuring vibration severity. In this manual, all metric units have been converted to inches /1 in = 2.54 mm / 1 mm = 0.03937 in). A metric version (VIB-10) is available, together with an instruction manual (71518 B) and follow-up forms (VIC-11) with metric tables.

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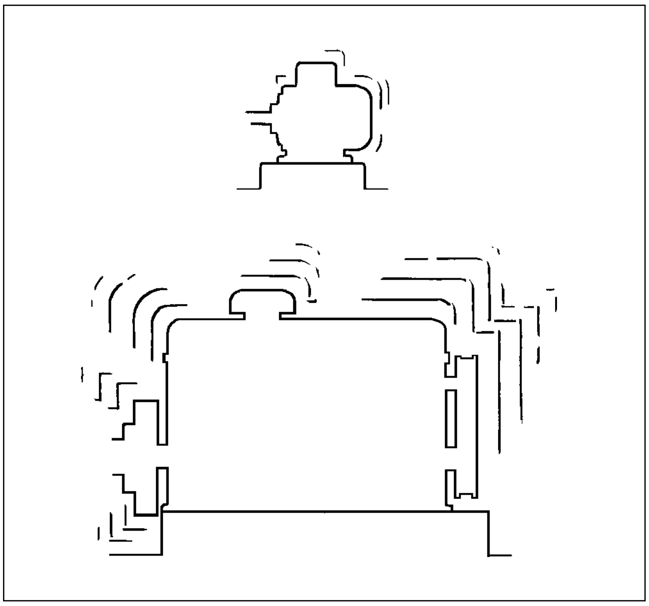
Vibration

In every moving machine, part of the force that makes it work acts on the machine itself. Since no structure or machine is perfectly rigid, any force acting on it will cause slight movements.

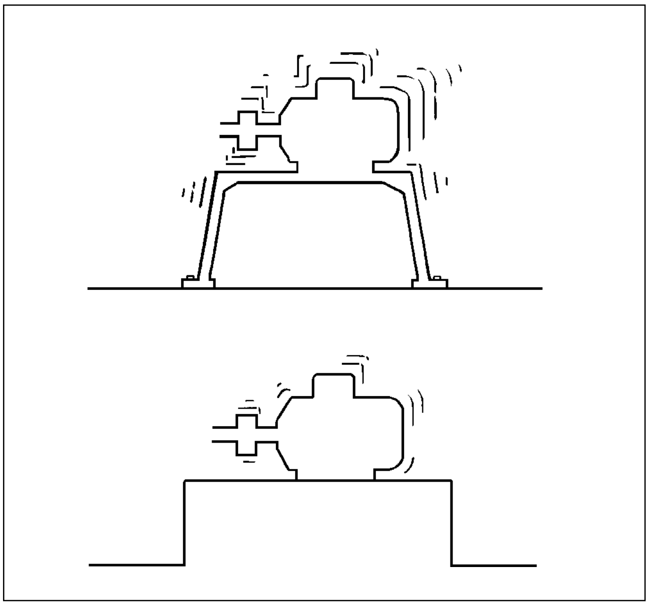
The forces causing movement are usually cyclic, that is they operate regularly first in one direction and then in another. They can act in two main directions, like the up and down forces associated with piston engines, or they can rotate with the shaft, like out of balance forces on a fan. They move the machine back and forth from its rest position: the machine vibrates.



Up to a degree, vibration is tolerated because it simply cannot be avoided. Machines are designed to withstand a "normal" amount of vibration for a long period of time. To assess the condition of any particular piece of plant, one has to determine its "normal" vibration level, then measure the actual amount and type of vibration and compare the two values.

To decide what is normal one has to consider

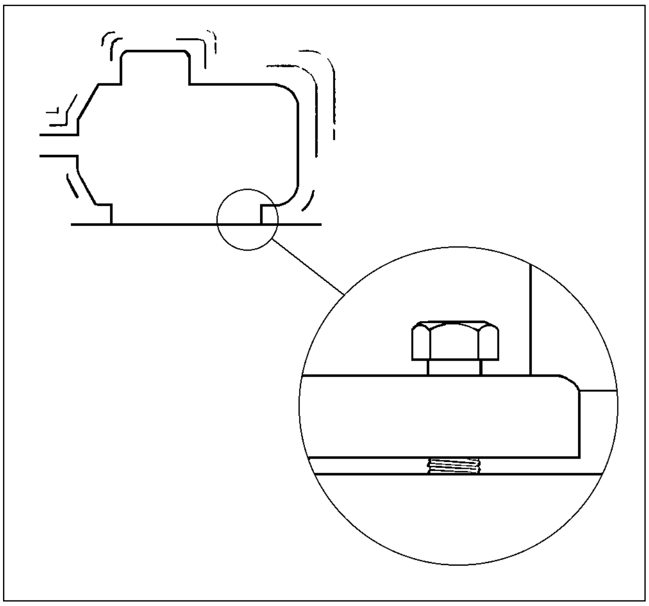
- **the function of the machine and the forces involved**
- **the rigidity of the machine structure**



A large diesel engine vibrates more than a small electric motor - the forces involved are very different.

More force is needed to vibrate a machine on a stiff concrete foundation than it takes to shake the same machine on a flexible metal frame. The machine structures are different and so are their normal vibration levels.

Due to changes in the operating conditions and the mechanical state of machines, vibration levels are subject to gradual or sudden changes. Loose fixing bolts or excessive bearing play will make the structure less rigid - vibration will increase. A growing soot layer on the impeller blades of an exhaust fan adds to the out of balance forces. Vibration will increase above the normal level and show that the machine is getting worse. Usually the deterioration accelerates: heavier vibration will further weaken the structure which in turn will raise the vibration level.



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Measurement

If a fan is out of balance, it will shake at its speed of rotation, i.e. move backwards and forwards once per revolution. The number of vibrations per time unit is the **vibration frequency**, measured in Hz (Hertz = cycles per second).

The rotational speed of any piece of plant is known as its **fundamental frequency**. For a fan with a speed of 1 500 r.p.m. the fundamental frequency is 25 Hz (1 500 r.p.m. ÷ 60).

In practice, machine vibration usually consists of many different frequency components. For a general assessment of machine condition one uses **wide frequency band measurements**, that is all vibrations within a large frequency range are measured simultaneously.

Cyclic movement can be measured and described in three different ways, as

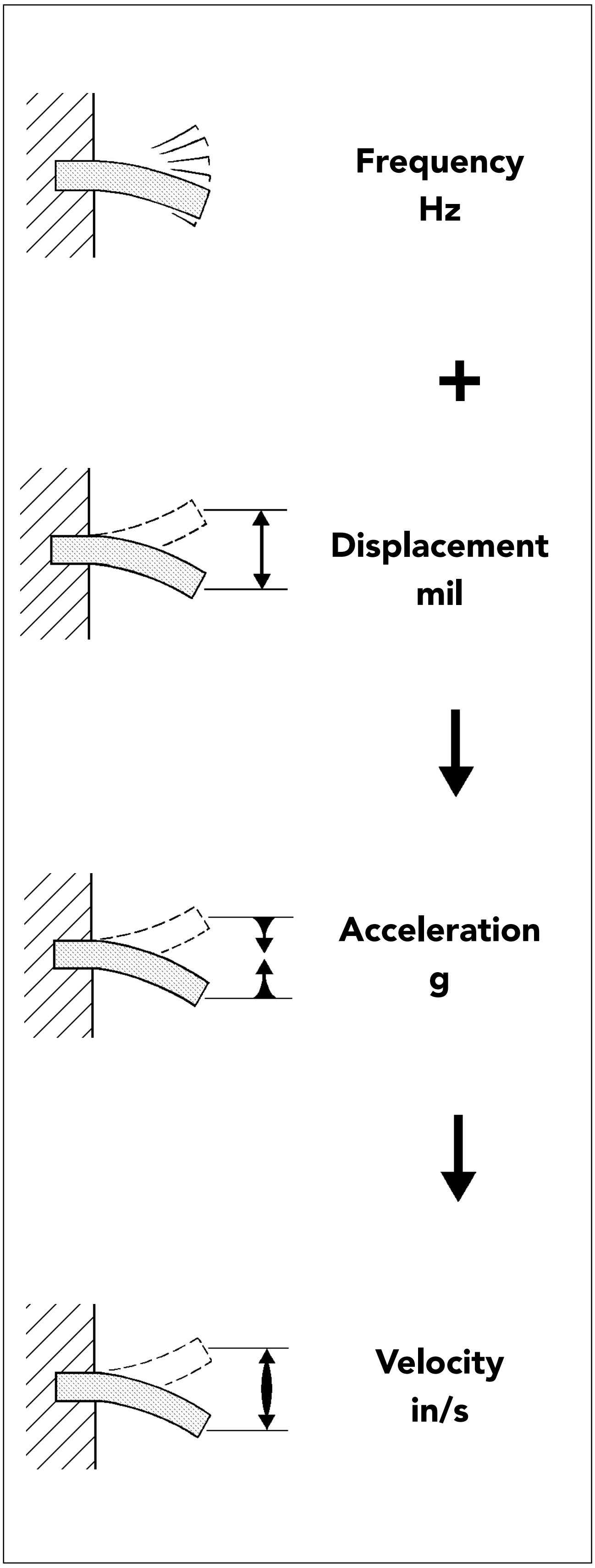
- **displacement**
- **acceleration**
- **velocity**

Displacement means the actual distance the object moves, measured either from its rest position in one direction (peak) or as the total movement in both directions (peak to peak). Displacement is usually measured in mils.

A part that is moving from rest, speeding up, slowing down and stopping twice per cycle is obviously accelerating and decelerating continuously. Acceleration is measured in g (1 g = 32.17 ft/sec^2).

The third measuring parameter is the speed at which the object moves, the vibration velocity. Velocity is expressed in in/sec.

Both acceleration and speed are constantly changing. One can measure a peak value of either, but a mean value often gives a better indication of the forces involved in the movement. Most instruments measure the **RMS value** (root mean square value) of the movement and use a scaling factor to indicate the peak levels if they are given at all.



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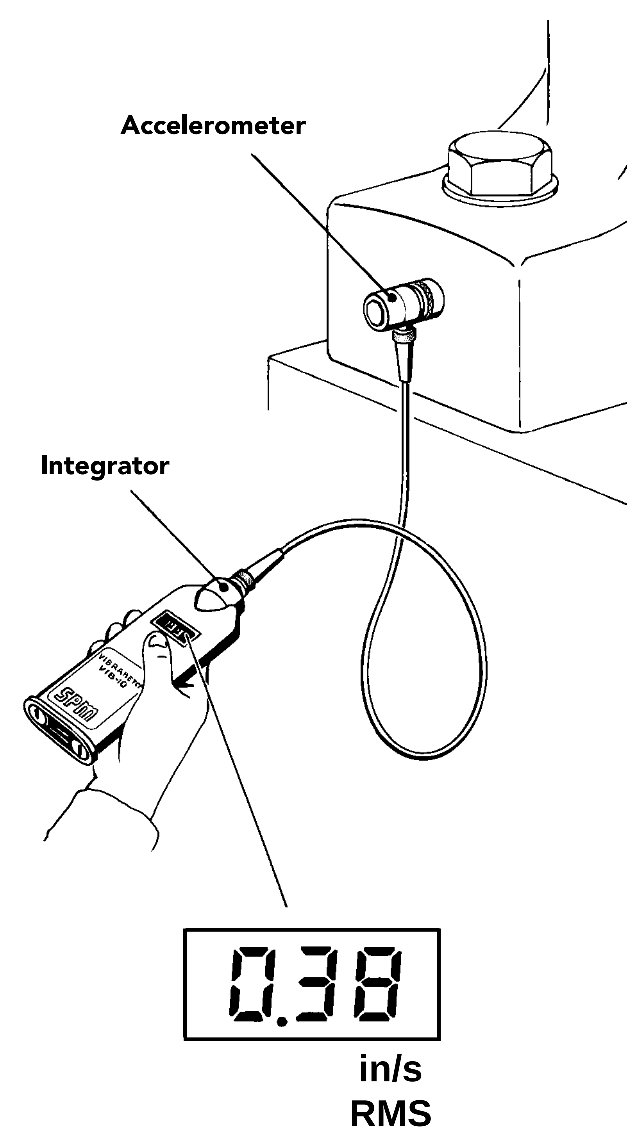
Measure Acceleration - Display Velocity

All three vibration parameters - displacement, acceleration, velocity - are mathematically related. One can, for example, place an accelerometer on a vibrating surface and convert its signal, via integrating circuitry in the measuring instrument, into a reading of vibration velocity or displacement.

The choice of displayed parameter (the instrument reading) and measured parameter (the transducer type used) depends on the problem to be solved and on the cost, the complexity and the reliability of the measuring equipment.



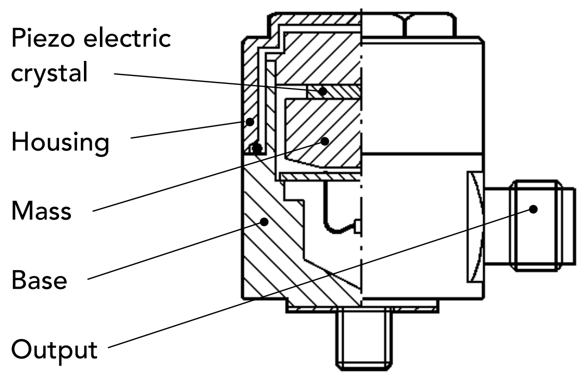
Experience has shown, that the RMS level of vibration velocity, measured over a frequency range of 10 to 1000 Hz, is most useful for general assessment of machine condition. The technical term used is **vibration severity**, defined as above and displayed in **in/s RMS** on the instrument. Vibration severity is directly related to the energy level of machine vibration, and thus a good indicator of the destructive forces acting on the machine.

There are transducers which measure velocity directly, i.e. seismic probes with either moving coils or moving magnets. These transducers are normally bulky, easily damaged and expensive to manufacture. They are therefore gradually being replaced by accelerometers.

An accelerometer is basically a piezo electric crystal (a crystal that develops an electric charge when it is compressed or stretched) with a small reference mass attached. As the transducer is moved back and forth, the reference mass compresses and stretches the crystal and the transducer gives an output directly related to acceleration.

Piezo electric accelerometers are small, very robust and relatively cheap to produce. They can work over a very large frequency range. They can be mounted on machines, held by hand against a vibrating surface or be temporarily attached by wax or magnets. That is why most practical measuring systems now use an accelerometer as the transducer and an integrator within the instrument to give a display in terms of velocity.

Piezo electric accelerometer



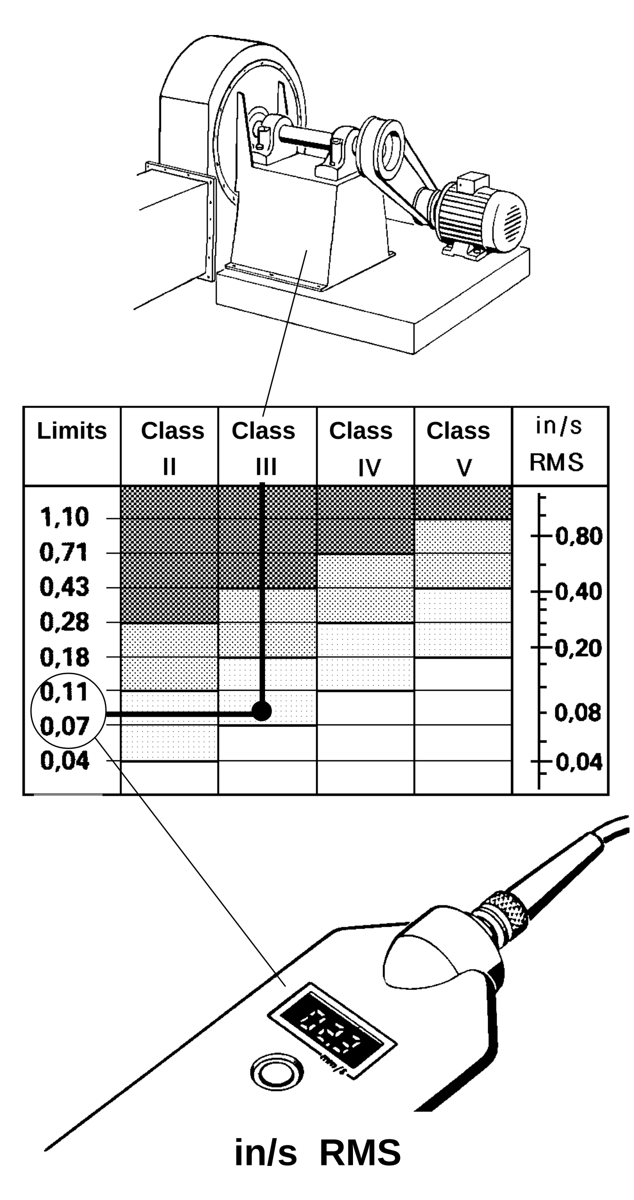
Machine Classes

To assess machine condition, the vibration severity measured on a specific piece of plant has to be compared with a representative norm value.

The international standards group industrial machinery into six different vibration classes , depending on

- machine size and function
- stiffness of foundation

For each class, the standards give vibration severity levels in four bands, ranging from very good condition through average and poor to bad. Provided that the correct class is chosen, the instrument reading can be directly related to machine condition.



Most industrial plants belong to vibration classes II, III and IV.

Class I refers to independent parts of machines, for example electric motors up to 15 kW.

Classes V and VI are used for heavy reciprocating prime movers and machines which are intended to vibrate - for example vibrating screens (see Appendix page 15 for precise definitions).

Motor power and types (electric, turbine, diesel), machine size and foundation stiffness (concrete base, metal frame, etc.) will give a first indication of machine class. For example, most smaller process pumps on a chemical plant would be Class II. A 100 kW ventilation fan on a concrete base would be Class III. However, the same fan fastened to the less rigid metal deck of a ship could be considered as Class IV.

II Medium size machines without special foundations

III Large machines on rigid foundations

IV Large machines on soft foundations

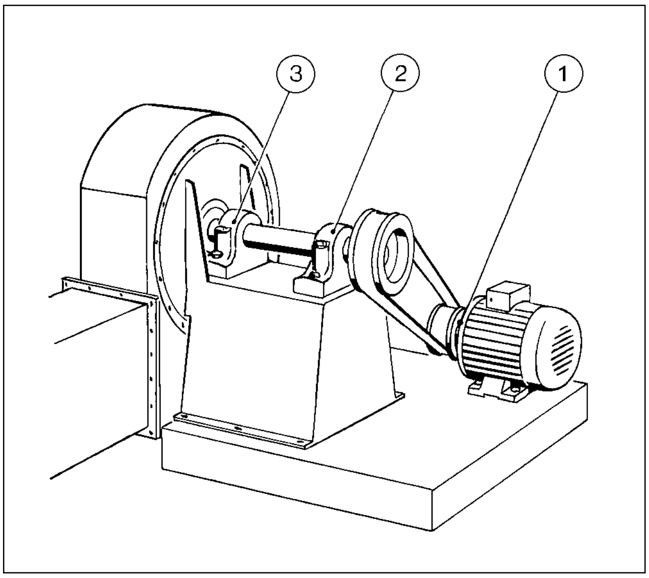
Classification of machinery is largely a matter of experience because the definitions provided by the standards are deliberately loose. Manufacturers should be able to specify acceptable vibration levels for their equipment, and their information can be used as a reference.

Similarly, if it is reasonably sure that a machine is in good condition, the actual vibration reading can be used as a starting point for the assessment of future changes.

Measuring Points

Vibration at the measuring point should be representative of the overall vibration pattern of the machine. The forces involved are usually transmitted through the bearings and their housings to the machine foundation. Consequently measuring points should be located on or near the bearing housings.

Machine guards, cover panels and other parts which are considerably less stiff than the main structure are not suitable as measuring points.

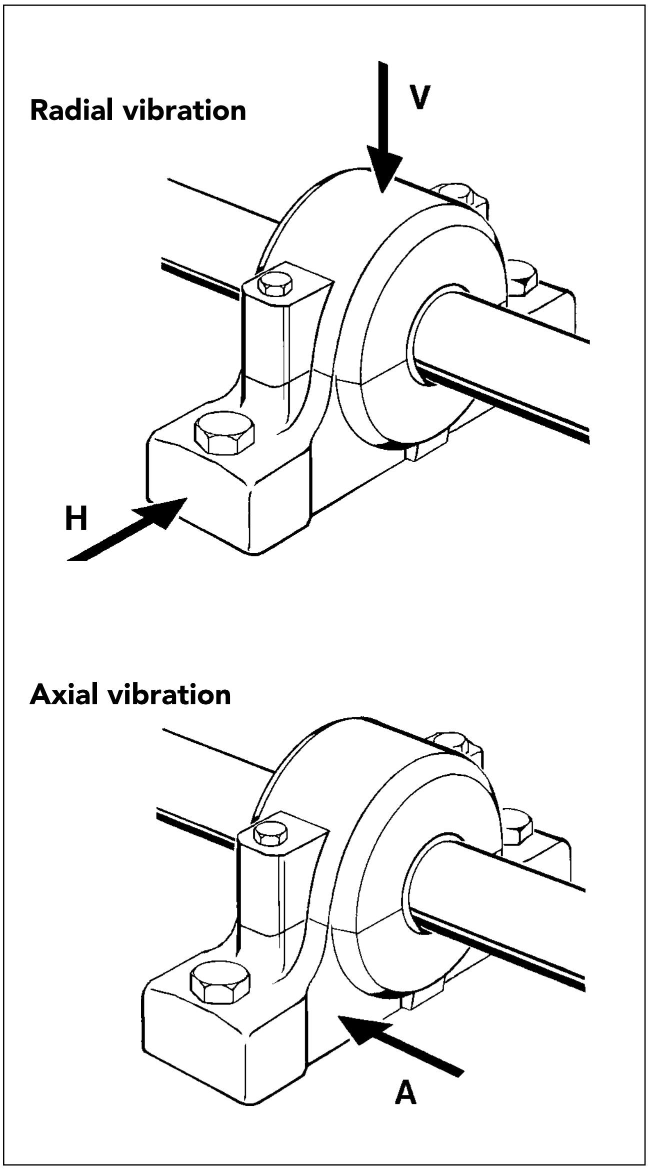


Generally speaking, the more measuring points chosen, the easier it is to locate a specific mechanical problem. Consider a fan, belt driven from an electric motor. Measurements taken on the fan bearing (3) will primarily give information on fan balance. If out of balance is the only problem to guard against, measuring on that bearing will be sufficient. To be able to make an adequate assessment of the mechanical state of the whole machine, one should also measure on the drive end bearing (2) and the motor (1).

The direction of measurement is very important. Out of balance forces rotate with the shaft and cause radial vibration acting in all directions within the plane of rotation.

Axial vibration, along the line of the shaft, is normally caused by faulty alignment, i.e. badly assembled couplings or bent shafts.

Normal practice is to take vibration readings in three directions at each measuring point: vertical (V), horizontal (H) and axial (A). Of the two radial measurements, a reading in the vertical direction tends to give information about structural weakness, whereas the horizontal reading is most representative of balance conditions.



The measuring point, meaning the exact spot on the machine where the transducer is placed, should be clearly marked and used each time a reading is taken. Relatively small changes in the measuring point can cause misleading changes in the measured value and trend analysis difficult.

Recording of Readings

The SPM follow-up form provides space for readings in all three directions at up to four different points, which should adequately cover most industrial machines. Experience will soon show which of the points and directions provide the most useful information for diagnosing a specific problem on any particular piece of plant.

In the case of a furnace extract fan (example opposite), three measuring points should be sufficient. With this type of machine, the usual problem is out of balance caused by soot on the impeller blades. That makes the vibrations measured in the horizontal direction at point 3 most significant. General directives for maintenance (6) should be based on the readings at that point.

A graph (11) is the best way to show clearly all significant changes of the vibration level. To keep the form simple, draw only the graph for the most significant direction (7), normally that giving the highest readings.

In the example, the extra space (17) was used for a second graph for the important point 3, in order to show the axial vibration trend as well.

There are no general rules about how often vibration should be measured. The intervals between readings - a day, a week, perhaps a whole month - depend wholly on the individual machine, its work, its importance for the plant and on the rate of change in its vibration level. Obviously an exhaust fan with a soot problem will need more frequent surveillance than a fresh air fan, but only practical experience can help to determine the optimal number of checks per month.

If the form is to be used for machines class I, V or VI, fill in the relevant vibration levels under (16). Note that the condition bands (12-15) only apply if the machine is classed correctly.

Preparation

1 **Record chart number**
2 **Machine designation, number and location**
3 **Machine class**
4 **Machine sketch with numbered measuring points**
5 **Vibration class and levels (cross out figures which do not apply)**
6 **Directives for maintenance**
7 **Number of measuring point and direction plotted on chart**
8 **H = horizontal, V = vertical, A = axial**

Measurements

9 **Date of measurement**
10 **Measured value in three directions**
11 **Plotted value of main direction**

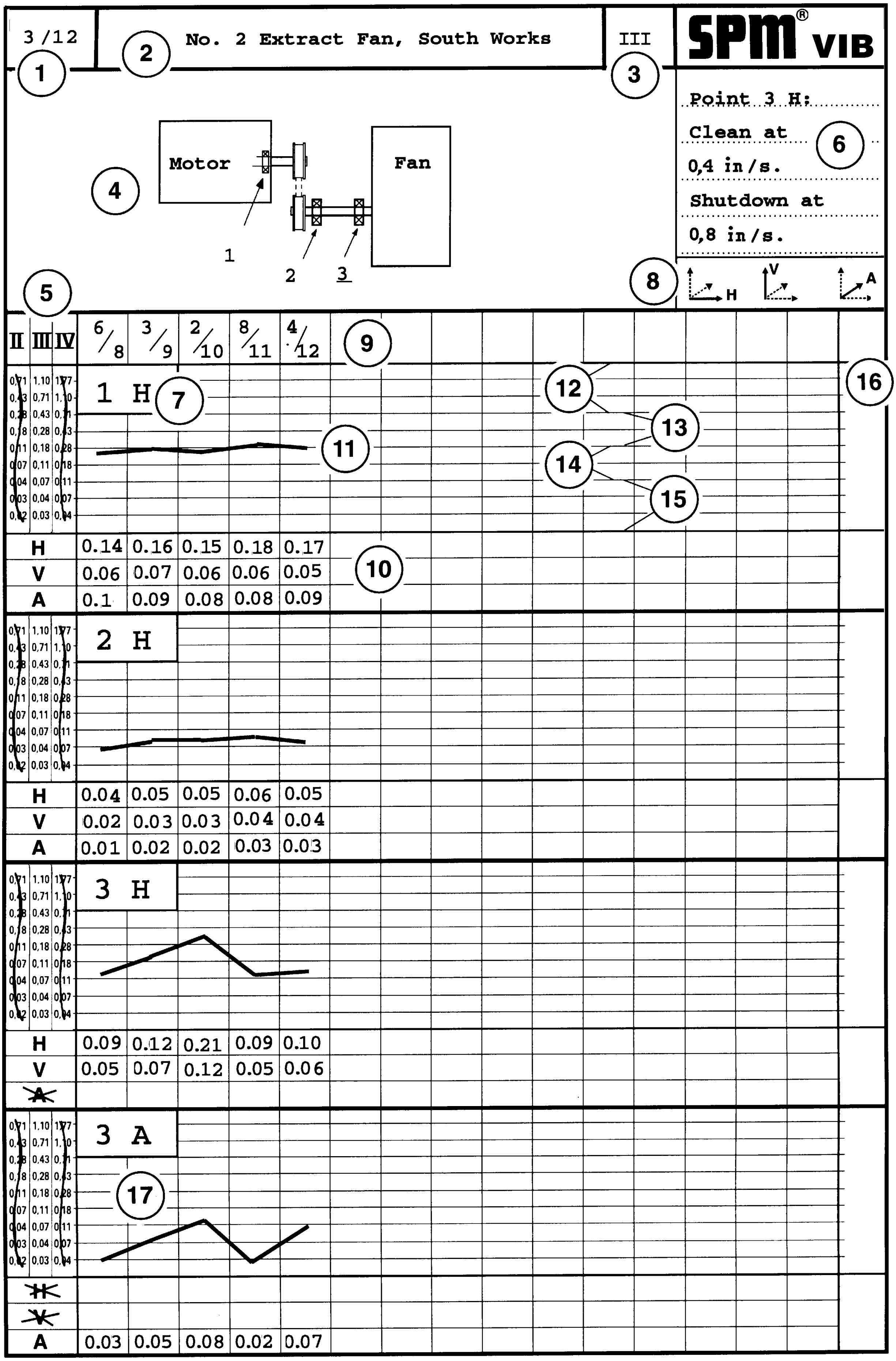
Machine Condition

12	**dark red**	**–**	**bad condition**
13	**pale red**	**–**	**just tolerable**
14	**pale green**	**–**	**acceptable**
15	**dark green**	**–**	**good condition**

Chart Modification

16 **Other machine classes and their respective vibration levels:**

I	V	VI	
0.43	2,80	4.33	**bad**
0.28	1.77	2.80	
0.18	1.10	1.77	**tolerable**
0.11	0.71	1.10	
0.07	0.43	0.71	**acceptable**
0.04	0.28	0.43	
0.03	0.18	0.28	**good**
0.02	0.11	0.18	
0.01	0.07	0.11	



3 /12 — No. 2 Extract Fan, South Works — III — SPM VIB

Motor — Fan — 1 — 2 — 3

Point 3 H:
Clean at
0,4 in/s.
Shutdown at
0,8 in/s.

H — V — A

II	III	IV
0.71	1.10	1.77
0.43	0.71	1.10
0.28	0.43	0.71
0.18	0.28	0.43
0.11	0.18	0.28
0.07	0.11	0.18
0.04	0.07	0.11
0.03	0.04	0.07
0.02	0.03	0.04

1 H

	6/8	3/9	2/10	8/11	4/12
H	0.14	0.16	0.15	0.18	0.17
V	0.06	0.07	0.06	0.06	0.05
A	0.1	0.09	0.08	0.08	0.09

2 H

	6/8	3/9	2/10	8/11	4/12
H	0.04	0.05	0.05	0.06	0.05
V	0.02	0.03	0.03	0.04	0.04
A	0.01	0.02	0.02	0.03	0.03

3 H

	6/8	3/9	2/10	8/11	4/12
H	0.09	0.12	0.21	0.09	0.10
V	0.05	0.07	0.12	0.05	0.06
~~A~~					

3 A

	6/8	3/9	2/10	8/11	4/12
~~H~~					
~~V~~					
A	0.03	0.05	0.08	0.02	0.07

(Callouts 1–17 mark the form fields.)

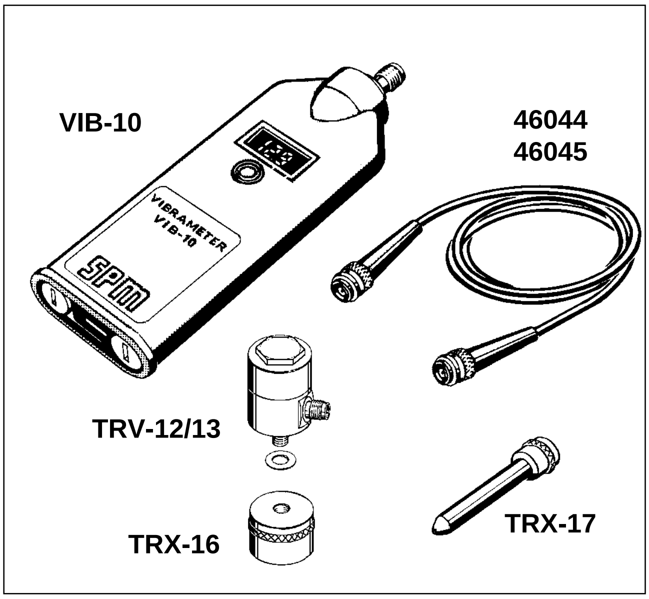
VIC-12

Measuring Equipment

The SPM equipment for manual vibration monitoring consists of:

- Vibrameter VIB-11
- Measuring cable 46044 (46045)
- Vibration transducer TRV-13 (TRV-12)
- TRX-16, Magnetic base for TRV-12
- TRX-17, Probe for TRV-12.

Follow-up forms can be supplied in pads of 25 each (ordering number VIC-12).



Transducer Mounting

The accuracy of vibration readings depends largely on the connection between transducer and measuring point. Only stiff connections, by magnet, screw or cement, will allow the transducer to accurately follow the movements of the vibrating surface.

Magnetic Mounting

The vibration transducer is normally mounted on the machine with the magnetic base.

Attach the transducer to a **smooth, flat surface**, with the main sensitivity axis pointing in the desired measuring direction. Spot-face the contact surface if necessary. The magnetic base has a diameter of 27.5 mm.

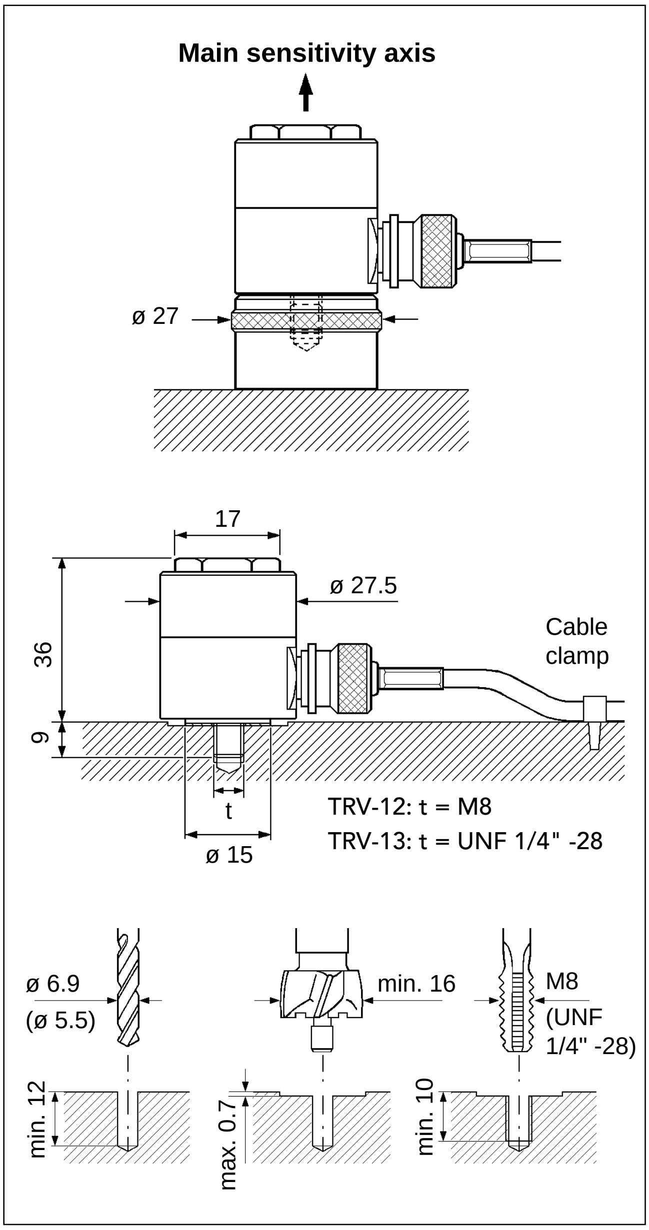
Screw Mounting

Screw mounting is the best alternative where the magnetic base cannot be used. Prepare threaded mounting holes as shown in the figure.

TRV-13 has thread size UNF 1/4"-28 and TRV-12 has M8. The transducers are delivered with three washers for adjusting the connector angle. Each washer turns the transducer 90°.

If the vibration transducer is to be permanently mounted on the machine, secure the low noise coaxial cable with a clamp close to the connector (see figure).

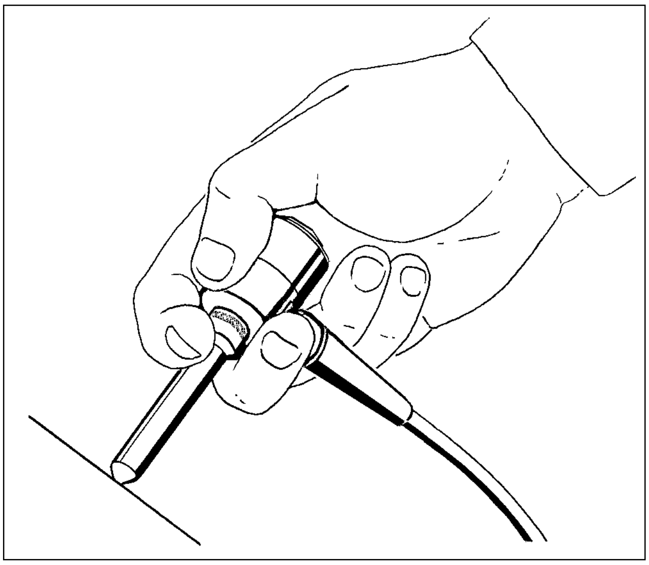
For installations in moist environments, use sealing TNC cable plugs SPM 13008 to prevent cable corrosion.



Hand-held Probe

With the probe TRX-17 attached, the vibration transducer can be used as a hand-held probe. The probe can be fastened directly to the transducer TRV-12.

Hand-held probes are widely used for quick vibration surveys. The advantages are obvious - there is no need to prepare measuring points. Note, however, that the overall stiffness is poor, which can give gross measuring errors. Using a hand-held probe requires practice and repeatable results cannot be guaranteed.



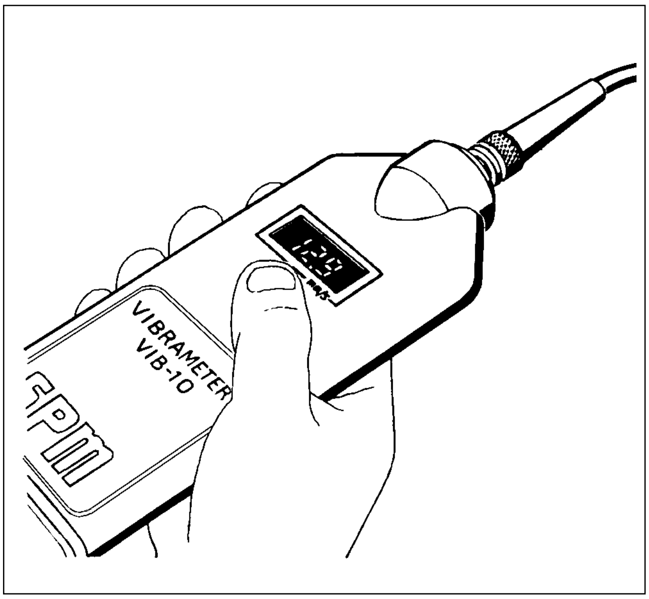
Taking Readings

Connect the transducer to Vibrameter VIB-11 with the measuring cable. Attach the transducer to the measuring point.

Press the button below the display window and hold it down. Wait for the readout to stabilize. Read and record the result.

To switch off the instrument, release the button.

If the display shows "**OFL**", the instrument has an overflow, caused by signals above the masuring range.

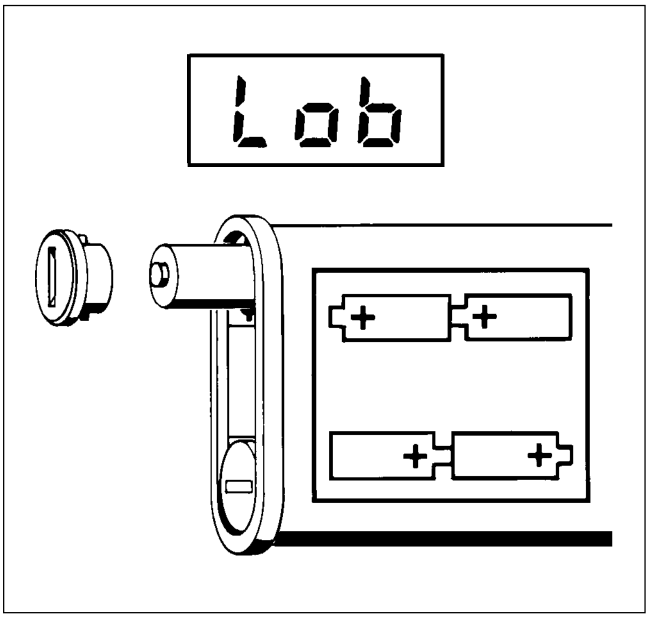


Changing Batteries

The display will show "**Lob**" when the battery voltage is getting low.

Use a coin to give both locks of the battery compartments a quarter turn to the right or left. Insert new batteries as shown on the back of the instrument.

Use only alkaline battery cells, 1.5 V, for example MN 1500 or UCAR E91. Leaking batteries can destroy the instrument. Remove the batteries before storing the vibrameter for long periods.



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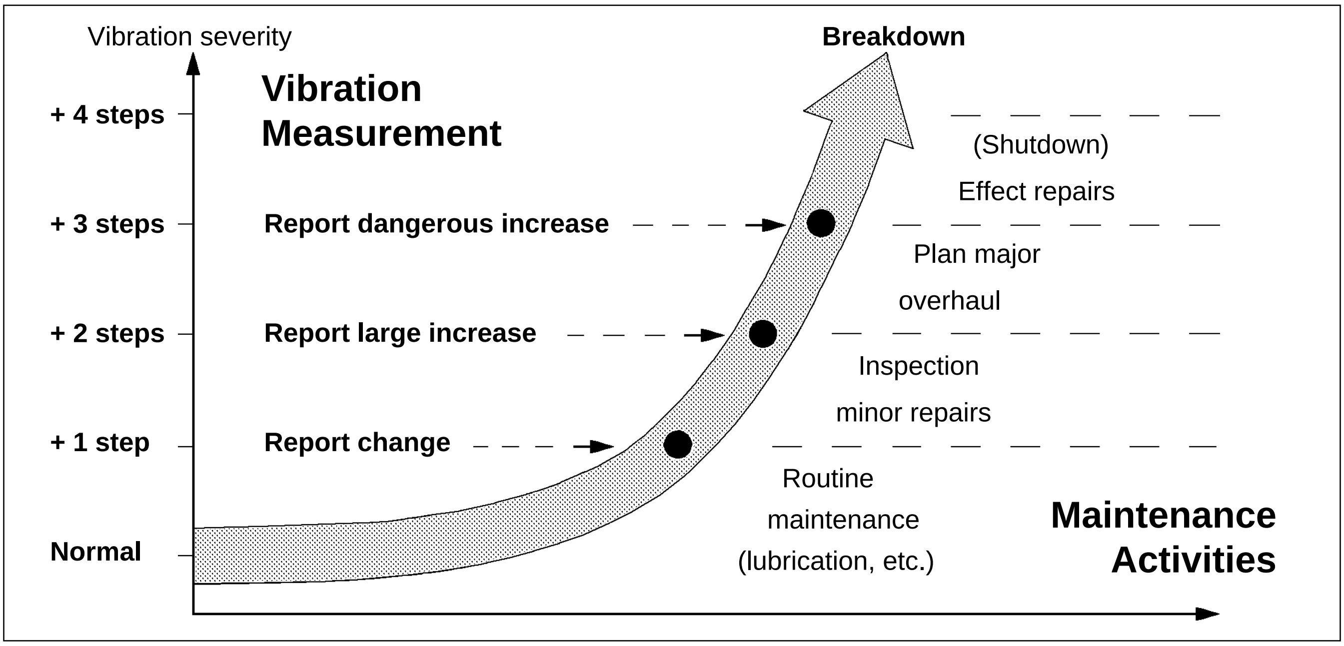
Maintenance Based on Vibration Records



The purpose of regular vibration measurements is to collect data for "condition based maintenance", i.e. maintenance carried out whenever condition measurements indicate a need for action.

To be able to plan ahead and work efficiently, a maintenance department needs regular and easily interpreted information on all **significant** changes in machine condition.

The flow chart opposite provides general rules for the interpretation of vibration data. The diagram above shows an example of how maintenance information can be reduced to a few simple facts, which are passed easily through one department to another.

Establish Norm Values

Usually, when vibration measurements start, the machine is in good condition. If its vibration class is correctly chosen, the initial readings taken after a running-in period should be in the "good" or "acceptable" range. Record these values and use them as a standard of reference for this particular machine.

Provided the vibration level at all measuring points remains stable, the subsequent readings are a matter of routine. Small fluctuations of the values on the follow-up forms are to be expected. They will hardly show up on the graphs and the actual figures are unimportant from a maintenance point of view.

Report Significant Changes

A one step change in the vibration level is generally regarded as significant and should be reported. One step is the space between two lines on the follow-up form. For all machine classes at any level, it represents a 1.6 times increase (decrease) from the previous reading or, if the change is gradual, from the original norm value.

For maintenance, it is a first warning that machine condition is getting worse. At this stage, tightening a few bolts or adjusting a belt may be sufficient to get rid of the excess vibration and prevent further deterioration.

Each condition band consists of two steps. An increase from a starting point in the "good" range to a corresponding point in the next range means that vibration has gone up 2.5 times. A large change like that should be investigated, even though the vibration level is still "acceptable".

Reporting changes in step is the simplest way of indicating the extent and urgency of a maintenance problem. If needed, the supporting figures are on record. Moreover, the method is flexible. As experience increases, individual alarm levels and in-house limits can be easily marked on the recording forms.

Basic Fault Analysis

It should be clearly understood that Vibrameter VIB-11 is not intended to supply data for detailed fault analysis. However, readings from several measuring points in three directions can usually give a good indication of the nature and location of the maintenance problem. Again, the flow chart may serve as a general guide.

Notice where on the machine and in what direction the measured value changes most. A simple report ("motor bearing, up two steps, axial + radial") gives a repair crew a starting point and can save them a lot of trouble.

Fault Analysis Chart

Time Schedule | **Machine Class** | **Measuring Point**

Measure Vibration Severity

Change ?

No change

Record results.

Measure again according to schedule.

Decrease

Recent maintenance, machine off load or stopped.

Measuring fault.

Something broken, loose, or missing.

Treat large unexplained decrease like large increase. Investigate soonest.

Increase

How much ?

< 1 step

Direc- tion ?

Mainly radial

Slow build-up of dirt.

Steady wear, corrosion.

Stretched or slipping belts.

Axial + radial

Slack mounting bolts, loose frame parts, etc.

Coupling wearing or stiffening.

Gear tooth wear.

Plan to maintain when vibration increases 2 steps above new or good level.

> 1 step

Where ?

Part of machine

Radial and axial:

Slack or sheared mounting bolts.

Damaged machine feet, bent or damaged subframes or supports.

Faulty alignment, bent or cracked shaft.

Gear tooth damage.

All over machine

Mainly radial: Failed fan blades, loss of balance weights, shedding of dirt. Oil film hysteresis whirls, excessive bearing play.

Radial and axial: Changes in foundation or support structure causing serious misalignment or looseness. Bent or fractured shafts. Critical speed and other resonances.

Small machines: Possibly transmitted vibration from larger machines.

Vibration up 2 steps from original or good level: Plan to maintain, measure more frequently.

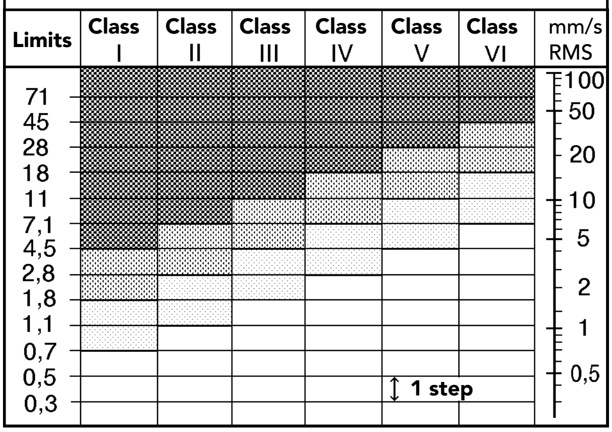
Vibration up 3 steps: Inspect and maintain as soon as possible, measure daily.

Vibration up 4 steps or more: Shut down immediately and investigate.

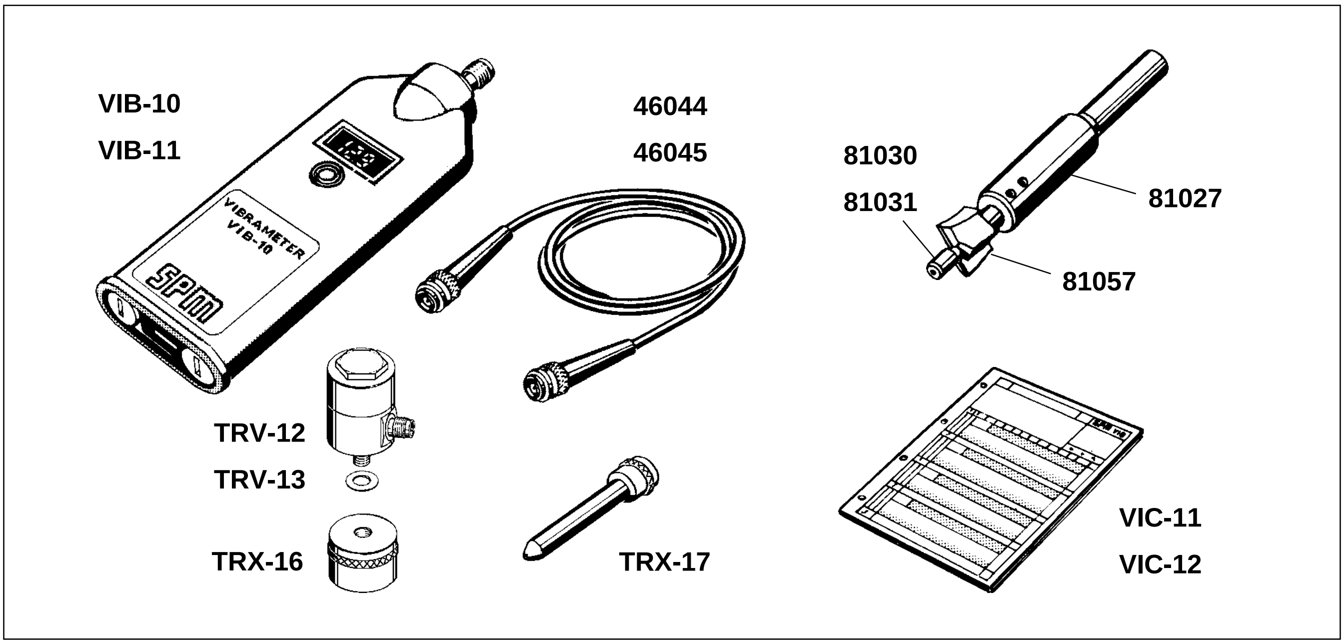
One step on the chart below (any class at any level) represents a 1.6 times increase from previous value.

Each condition band (= 2 steps) represents a 2.5 times increase, i.e. a significant change in vibration severity.

3 steps up is a fourfold increase, an alarming change demanding immediate action.



Technical Specifications



Vibrameter VIB-11

Measuring range	0.5 to 3.93 in/s RMS, 10 to 1000 Hz
Resolution	0.01 in/s
Accuracy	2% ± 0.02 in/s
Power supply	Four 1.5 V alkaline cells (e.g. MN 1500 or UCAR E91)
Temperature range	0° to +55° C (32° to 131° F)
Display	3 digits, red LED
Switch-off	Automatic
Protective cover	Polyurethane
Dimensions	210x75x30 mm (8.3"x2.9"x1.2")
Weight	410 g (14 oz) incl. batteries
Connector type	TNC

Vibration Transducer TRV-12/13

Nominal sensitivity, main axis	12 pC/m/s^2
Transverse sensitivity	max. 10%
Typical base strain sensitivity	0.01 m/s^2/μ
Linear frequency range	10 to 1000 Hz
Max. peak acceleration	600 m/s^2
Temperature range	-30° C to +150° C (-22° F to +302° F)
Typical temperature drift	0.25% / °C
Casing	Stainless, acid proof, steel, AISI 316, sealed
Dimensions	diam. 27.5 mm x 45 mm
Weight	135 grams (5 oz)
Connector type	TNC
Torque limit	10 Nm (7.4 lbf · ft)

Part Numbers

VIB-10	Vibrameter mm/s, incl. battery cells
VIB-11	Vibrameter in/s, incl.battery cells
TRV-12	Vibration transducer, M8
TRV-13	Vibration transducer, UNF 1/4"-28
TRX-16	Magnetic base for transducer TRV-12
TRX-17	Probe for transducer TRV-12
46044	Measuring cable with connectors, 1.5 m
46045	Measuring cable with sealing TNC plug, 1.5 m
VIC-11	Follow-up forms mm/s (VIB-10), pad of 25
VIC-12	Follow-up forms in/s (VIB-11), pad of 25
VIC-13	Follow-up forms, balancing, pad of 25

Tools

81027	Holder for counterbore
81057	Counterbore, diam. 20 mm
81030	Pilot, UNF 1/4" (TRV-13)
81031	Pilot, M8 (TRV-12)

Literature

70977 B
Balancing with VIB-10

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Definition of Machine Classes According to ISO 2372

The following text is a quotation from ISO 2372 (1974, E, page 6, Annex A). This ISO Recommendation has also been published as British Standard (BS 4675, part I). A similar vibration classification of industrial machinery can be found in VDI 2056.

In order to show how the recommended method of classification may be applied, examples of specific classes of machines are given below. It should be emphasized, however, that they are simply examples and it is recognized that other classifications are possible and may be substituted in accordance with the circum-stances concerned. As and when circumstances permit, recommendations for acceptable levels of vibration severity for particular types of machines will be prepared. At present, experience suggests that the following classes are appropriate for most applications.

Class I

Individual parts of engines and machines, integrally connected with the complete machine in its normal operating condition. (Production electrical motors of up to 15 kW are typical examples of machines in this category.)

Class II

Medium-sized machines, (typically electrical motors with 15 to 75 kW output) without special foundations, rigidly mounted engines or machines (up to 300 kW) on special foundations.

Class III

Large prime movers and other large machines with rotating masses on rigid and heavy foundations which are relatively stiff in the direction of vibration measurement.

Class IV

Large prime movers and other large machines with rotating masses on foundations which are relatively soft in the direction of vibration measurement (for example turbogenerator sets, especially those with lightweight substructures).

Class V

Machines and mechanical drive systems with unbalanceable inertia effects (due to reciprocating parts), mounted on foundations which are relatively stiff in the direction of vibration measurement.

Class VI

Machines and mechanical drive systems with unbalanceable inertia effects (due to reciprocating parts), mounted on foundations which are relatively soft in the direction of vibration measurements; machines with rotating slackcoupled masses such as beater shafts in grinding mills; machines, like centrifugal machines, with varying unbalances capable of operating as selfcontained units without connecting components; vibrating screens, dynamic fatigue-testing machines and vibration exciters used in processing plants.

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