AN31E

Application Note
VibroMetra System
Balancing System VM-BAL

Balancing Theory

Aim of balancing

An unbalance exists when the principle mass axis of a rotating body, the so-called ‘axis of inertia’, does not coincide with the rotational axis. This can cause centrifugal forces and vibration. The aim of balancing is to reduce these unwanted vibrations in order to:

- Improve product quality
- Extend machine life
- Reduce noise emission

How an unbalance evolves

When a machine part is set in rotation, all mass particles will generate a centrifugal force. If the sum of these force vectors becomes zero, no dynamic force will load the bearings. The rotor is completely balanced. If the sum of force vectors is not zero a centrifugal force remains which will transmit vibration into the bearings (Figure 1 and Figure 2).

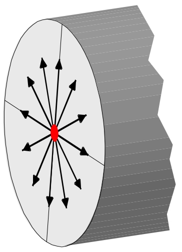


Figure 1:
All centrifugal force vectors compensate each other. The rotor is balanced.

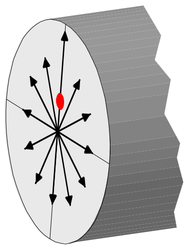


Figure 2:
The centrifugal force vectors do not compensate each other. A centrifugal force is produced causing an unbalance.

Expression of unbalance

The reason for an unbalance is a rotating mass outside the rotational axis. Unbalance is expressed as the product of this mass times distance from the rotational axis, such as gram-millimeters (gmm) or kilogram-meters (kgm). Unbalance is a vector quantity. Therefore the vector direction or angle is needed for definition. The graphic representation is a polargraphic diagram with an unbalance pointer.

Types of unbalance

The following types of unbalance are distinguished:

- **Static Unbalance** is present in a rotor when the mass axis does not coincide with the rotational axis and when the mass axis is parallel to the rotational axis. This is also known as **single-plane unbalance**. The following figure illustrates that the magnitude and direction of the force generated by this unbalance is equal at both bearing journals.

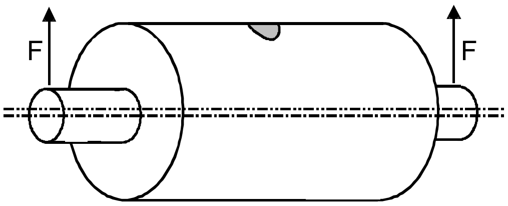


Figure 3: Static unbalance

- **Couple Unbalance** is present when the mass axis does not coincide with the rotational axis and intersects the rotational axis at the center of gravity of the rotor. The force vectors created by this type of unbalance are equal in magnitude at both bearing journals, but 180° opposite in direction.

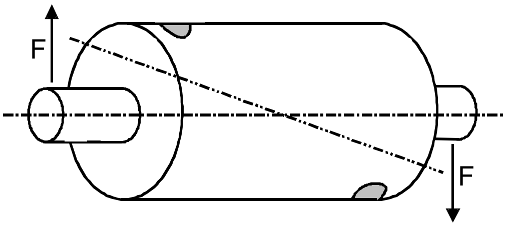


Figure 4: Couple unbalance

- **Dynamic Unbalance** is the condition where the mass axis does not coincide with the rotational axis, is not parallel to it, and does not intersect it at the center of gravity. This condition is also known as **two-plane unbalance**. Dynamic unbalance is a combination of static and couple unbalances.

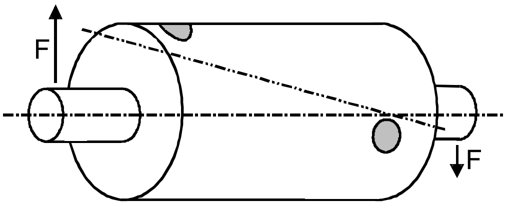


Figure 5: Dynamic unbalance

Disk-shaped rotors usually can be treated with static balancing. Most rotor types, however, should be balanced dynamically.

VM-BAL allows both static and dynamic balancing.

Measuring technique

VM-BAL uses a relative measurement technique:

1. VM-BAL records the rotor vibration under operating conditions. This is the initial balancing run.
2. In the next step, an additional unbalance with known mass and position is attached to the rotor. The calibration run follows. For dynamic unbalancing, two calibration runs are required.
3. VM-BAL compares the vibration signal with and without additional unbalance and thereby calculates the initial unbalance.

The measurement is based on a linear and phase coherent vibration system. This means:

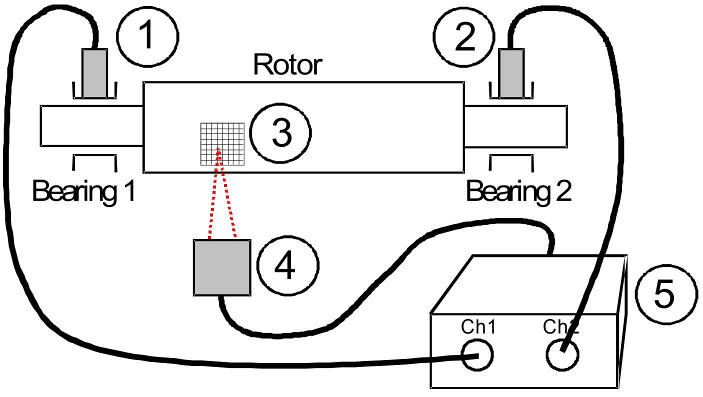
4. A magnitude change of the unbalance changes the vibration magnitude in the same way.
5. A phase shift of the unbalance results in the same phase shift in the vibration signal.

In practice, this ideal condition will never be achieved, however. Bearings attenuate the vibration signal and may cause phase shift errors.

For this reason, please do not expect that balancing will always be successful on the first try. In many cases, it will be necessary to repeat the balancing procedure to obtain a satisfactory result step by step.

Measuring arrangement

Unbalance cannot be measured directly. The measured quantity is the resulting vibration. VM-BAL uses piezoelectric accelerometers with ICP® compatible output which may be connected to the M302 hardware. Preferable bearing cases or other locations close to the bearings are used for sensor mounting. For static balancing, one accelerometer is sufficient, for dynamic balancing, two.



1: Accelerometer at bearing 1
2: Accelerometer at bearing 2
3: Reflecting label
4: Photoelectric reflex switch
5: M302

Figure 6: Balancing instrumentation

In addition to the vibration signal a position information is needed. For this purpose a photoelectric reflex switch and a reflective sticker at the rotor are used. The photoelectric reflex switch can be connected to the M302 hardware. A tripod or magnetic stand may be helpful to mount and adjust the sensor.

Compensating an unbalance

The aim of unbalance compensation is to align the mass axis of the rotor with its rotational axis in order to avoid vibrations. This can be achieved in three ways:

- Removing material at the unbalance position by machining
- Adding mass opposite the unbalance position
- Changing the position of adjustable balancing masses

Practical machining techniques are drilling or milling. VM-BAL calculates the machining depth based on given tool and rotor data.

Adding a mass can be done in different ways. Typical attachment techniques are by screws, adhesive or welding. The attachment must be strong enough to withstand rotation under normal operating conditions.

Adjustable balancing masses can be, for instance, screws or rings. With screws, the radial position of the mass can be changed while the angle stays unchanged. With rings, the angle can be adjusted while the radius is unaltered. VM-BAL calculates the adjustment parameters for both types.

When is an unbalance compensated?

The criteria when an unbalance can be regarded as compensated, only you can define. Sometimes a maximum permissible tolerance for the unbalance is given. The suppression of vibrations may also be the criterion. Many manufacturers state for their equipment vibration velocity values to ISO 10816-1 which can be measured, for example, by the VM-Meter instrument.

An unbalance will only cause vibration at the rotary frequency. If a mixture of other vibration frequencies should be present, the rotary frequency can be band-pass filtered by the VM-Meter or displayed as a spectral line with VM-FFT.

Some useful hints for balancing

- Accelerometers should be mounted as close as possible to the bearings.
- All balancing runs must be performed at the same rotary speed.
- Do not change the measuring setup (sensors, reflective sticker) during the balancing process.
- If the position of the calibration mass is defined as 0°, all other measurements and correction measures can be referred to this point.
- The angle positions of VM-BAL are always measured against the rotary direction.
- It may be necessary to repeat the unbalancing procedure a few times to obtain good results.
- VM-FFT and VM-METER can be used to check whether machine vibrations result from unbalance or other sources.

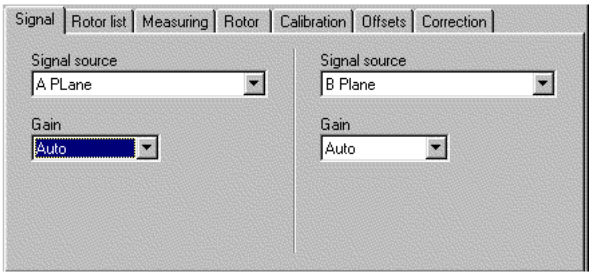
VM-BAL Application Example

In the following example a long rotor is balanced in two planes. The rotor diameter is 350 mm. However, the calibration and correction masses have been attached at a diameter of 300 mm. The tolerable unbalance is 150 gmm. Balancing is carried out by correction masses which are attached opposite the unbalance. Any angle position can be used for correction.

Preparations

- Install the accelerometers and the photoelectric reflex switch and connect them to the M302.
- Make the software connection in VibroMetra between the accelerometers and the corresponding measuring channels.
- Assign suitable names to the measuring channels, e.g. ‘Plane A’, ‘Drive side’, ‘Bearing side’ etc.
- Start VM-BAL.

Settings for the initial run



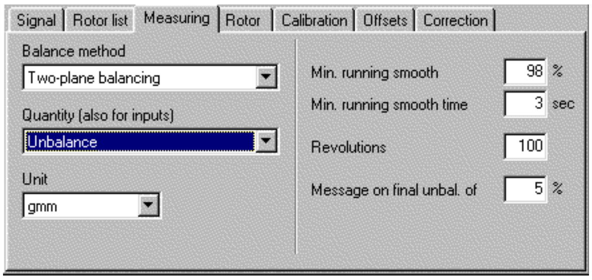
Signal source: A PLane
Gain: Auto

Signal source: B Plane
Gain: Auto

- The correct measuring channels are automatically selected provided that only one M302 is connected to your PC. The gain should be set to *Auto* for the moment.

☞ Usually VM-BAL will operate within one gain range only. In some cases, for example, in the presence of erratic external vibration, VM-BAL may become overloaded and will change its gain range if the autoranging function has been activated. A gain change during the balancing process must be avoided. It will make the balancing results invalid. Therefore, please observe the gain display. If the gain should change during balancing, switch to one of the fixed gains 1 / 10 / 100 / 1000.

- The next step is the rotor list (only Pro version). We do not cover this step in the example.
- Open the measuring setup. Select *Two-plane balancing.*

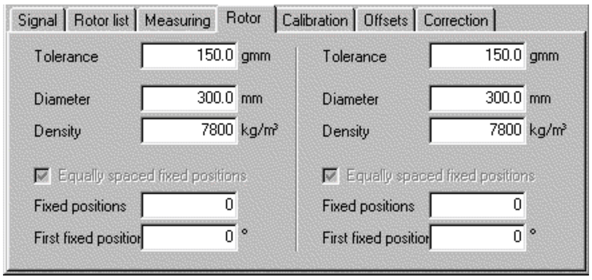


Balance method: Two-plane balancing
Quantity (also for inputs): Unbalance
Unit: gmm

Min. running smooth: 98 %
Min. running smooth time: 3 sec
Revolutions: 100
Message on final unbal. of: 5 %

- Measured quantity is *Unbalance* in *gmm* since the tolerance was stated in this unit.
- Set *Min running smooth* to 98 %.

- The rotor should be within the running smooth limit for at least 3 seconds which is the settling time of the autoranging function (*Min. running smooth time* = 3 s).
- To obtain precise results use *Revolutions* = 100.
- If the unbalance remains above 5 % of the initial unbalance after balancing is finished, a message should be displayed (*Message on final unbalance of* = 5 %). In practice, this will only occur when the unbalance is too high for the available correction mass.
- Switch to the rotor setup.



Tolerance 150.0 gmm
Diameter 300.0 mm
Density 7800 kg/m³
☑ Equally spaced fixed positions
Fixed positions 0
First fixed position 0 °

Tolerance 150.0 gmm
Diameter 300.0 mm
Density 7800 kg/m³
☑ Equally spaced fixed positions
Fixed positions 0
First fixed position 0 °

- Enter the required *Tolerance* of 150 gmm.
- The *Diameter* is 300 mm in the example. Make sure to enter here the diameter where the correction masses are to be mounted. This is not always the rotor diameter.
- The *Density* of the rotor material is not needed for this example since no material will be removed for balancing.
- *Fixed positions* have not been defined. Any angle can be used for correction.

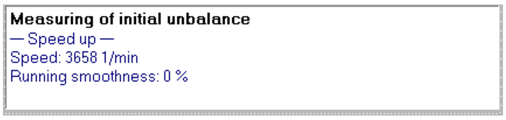
Measuring the initial unbalance

- Switch on VM-BAL.
- The *status* window will inform you about the next steps.

Measuring of initial unbalance
- Remove all calibration masses.
- Start rotation.

- Any *calibration* masses (not the correction masses) from previous balancing runs must be removed.
- Set the rotor in motion.

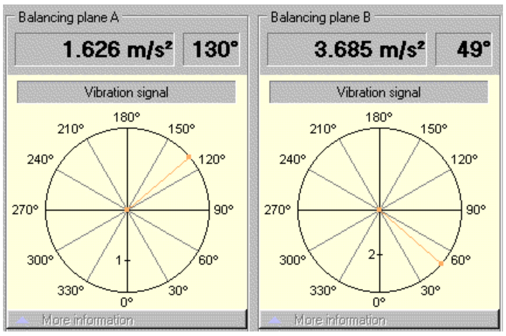
- The photoelectric reflex switch will now detect the rotation. Each time the reflective sticker passes the sensor, an at the sensor case LED will flash.
- VM-BAL automatically detects the start of the measurement. During speed-up, it displays *rotary* speed and stability. Please check if the displayed rotary speed corresponds to the expected rotary speed of the machine. The reason for incorrect values is usually a misalignment of the photoelectric reflex switch and the reflective label.



Measuring of initial unbalance
— Speed up —
Speed: 3658 1/min
Running smoothness: 0 %

- As soon as stable rotary speed is detected, VM-BAL switches to the unbalance measuring mode. It will inform you about the progress.

Measuring of initial unbalance
— Measuring —
Runs: 59
Speed: 3658 1/min
Running smoothness: 99 %



Balancing plane A
$1.626\ m/s^2$ 130°

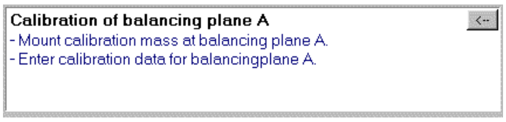
Balancing plane B
$3.685\ m/s^2$ 49°

- With some experience you will soon be able to determine whether an unbalance measurement was successful or not. If the numerical and graphical vibration display quickly reach a certain value with low fluctuation, the unbalance measurement has succeeded. If the graphical pointer abruptly changes its direction, measuring problems may be the reason. The measured unbalance may be too low or the accelerometers may be mounted in an unsuitable location.
- After the rotor has made the stated number of revolutions, VM-BAL will ask you to slow down the rotor.

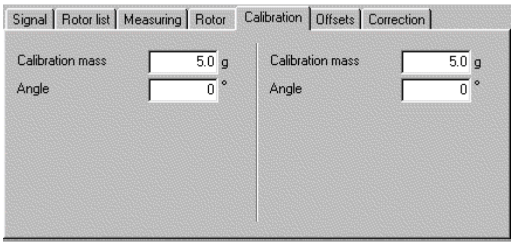
Measuring of initial unbalance
— Slow down —
Required 100 runs were read.
Stop rotation.
Speed: 3636 1/min

Second run: Calibration of plane A

- When VM-BAL has detected that the rotor is standing still the status window will inform you about the next steps.
- Change the calibration settings:



Calibration of balancing plane A
- Mount calibration mass at balancing plane A.
- Enter calibration data for balancingplane A.



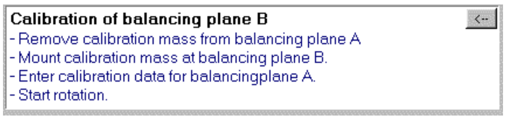
Calibration mass 5.0 g
Angle 0 °

Calibration mass 5.0 g
Angle 0 °

- The selection of a suitable *Counterweight* requires some experience. It should be sufficiently heavy to produce a significant change of vibration. The vibration level should be increased by the factor 2 to 5. When no other data is available refer to the stated *Tolerance* as orientation. In this example it is 150 gmm. The tolerable unbalance therefore corresponds to a mass of 1 gram if it is located at a radius of 150 mm (150 gmm / 150 mm = 1 g). We choose a mass of 5 grams for the first run to be within the expected range.
- The best choice for *Angle* is 0°. In this case all angles will be referred to the angle position of the calibration mass. If you want to choose another zero position, type in an *Angle* between the calibration mass and the desired zero position. Angles are measured against the rotary direction.
- The absolute position of the reflective sticker is not important for calculation. It must not be changed, however, during the entire balancing process.
- When calibration data has been entered and the calibration mass securely attached, start the rotor again. VM-BAL will now detect the start of the calibration run. The following procedure is the same as explained for the initial unbalance.

Third run: Calibration of plane B

- Follow the instruction shown in the status window.

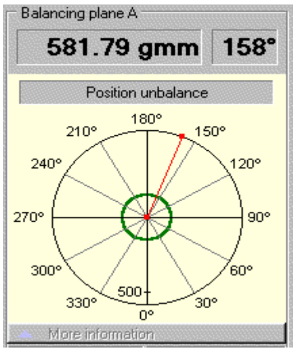


Calibration of balancing plane B
- Remove calibration mass from balancing plane A
- Mount calibration mass at balancing plane B.
- Enter calibration data for balancingplane A.
- Start rotation.

- Remove the calibration mass from plane A and repeat the same steps as in the second run for plane B.

- **Evaluation**

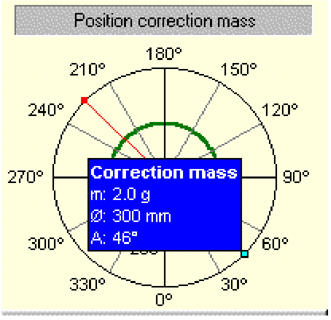
- After finishing the calibration runs, VM-BAL will calculate automatically the actual unbalance and the resulting correction measures which are, in this example, the weight and angle position of a counterweight.



Balancing plane A
581.79 gmm 158°

- The amount and the position of the unbalance are displayed as numbers and polargraphic. The green tolerance circle marks the stated tolerance of 150 gmm. The pointer represents amount and angle of the unbalance.

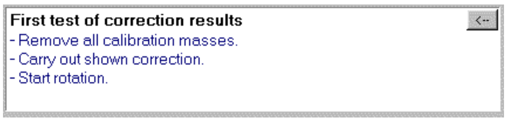
- To view the calculated correction data, open the *Correction* menu. In the polargraphic an additional text window will open with all necessary information based on the selected method. The method is selected by clicking one of the tabs at the lower edge. Choose the method *Counterweight* for this example. The correction text window will show the weight, the diameter and the angle of the mounting location.



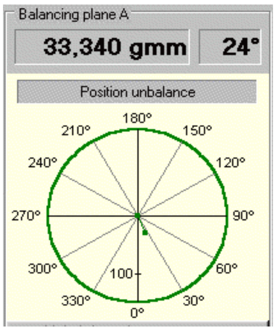
Correction mass
m: 2.0 g
Ø: 300 mm
A: 46°

- For two-plane balancing, correction must be made for both planes since both corrections complement each other. If only one plane was corrected one cannot expect that the unbalance will disappear in this plane and stay unchanged in the other plane. Both planes will be unbalanced insufficiently instead.

☞
- A common error is not removing the calibration mass before starting a new initial run. Therefore, the status window will remind you to do so.


First test of correction results
- Remove all calibration masses.
- Carry out shown correction.
- Start rotation.

Test run
- After the correction has been made a test run will start in order to check the effectiveness of the corrections made. It should yield a significantly lower unbalance below the stated tolerance limit.


Balancing plane A
33,340 gmm 24°

- In practice, due to non-linearity of the balancing system, the unbalance will not become zero after correction. The aim of the correction algorithm is to bring unbalance below the stated tolerance limit. If this is not achieved after the test run, the balancing process must be repeated. For the second balancing cycle a lower calibration mass can be used.

How VM-BAL Calculates the Compensation

After measuring the unbalance, VM-BAL will calculate the compensation measures. You can choose between six methods of compensation. The balancing procedure is as follows:

- VM-BAL checks the acceptability of the selected compensation parameters. The maximum drill depth, for instance, must not exceed the rotor radius. When invalid results are detected a message will be displayed in the field for additional information.
- The next steps depend on whether any point on the rotor surface may be used or only fixed compensation points are allowed. VM-BAL will check if the best calculated correction will actually eliminate the unbalance. If the unbalance is too high for compensation, a message will be displayed in the field for additional information.

Free correction points

- If the entered number of fixed positions is less than four, VM-BAL will calculate an unbalance correction at a free angle position.

Fixed points with equal compensation

- If the entered number of fixed positions is more than three, the compensation will be calculated for fixed correction points. The checkbox *Different correction of fixed positions* is left blank.
- With infinitely fine compensation methods, such as counterweight, drilling, milling and screws, VM-BAL optimizes the balancing measures with the aim of using as few points as possible for correction.
- The methods ring and counterweight list do not allow infinitely fine compensation. VM-BAL will compensate the unbalance as well as possible so that the unbalance remains below the defined limit.

Fixed points with different compensation

- If the entered number of fixed positions is higher than three, the compensation is calculated for fixed correction points. The checkbox *Different correction of fixed positions* is activated.
- When different correction methods are selected for fixed positions, each method is applied in a defined order. VM-BAL starts with methods providing quick balancing success:

Rings	fast but relatively coarse compensation
List of counterweights	↓
Screws	↓
Drilling	↓
Milling	↓
Counterweight	slower but fine compensation

A compensation method is only applied if a fixed position using this method lies outside ± 90° from the unbalance.
Each correction method works as explained above:

- With infinitely fine compensation methods, such as counterweight, drilling, milling and screws, VM-BAL optimizes the balancing measures with the aim of using as few points as possible for correction.
- With other compensation methods VM-BAL minimizes the remaining unbalance.