AN31E

Application Note
VibroMetra System
Balancing System VM-BAL

Basics of Balancing

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).

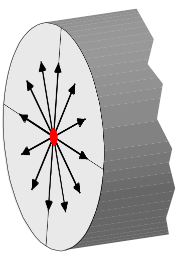

Figure 1:
All centrifugal force vectors compensate each other. The rotor is balanced.

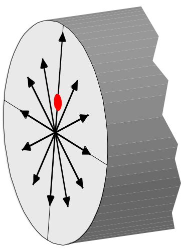

Figure 2:
The centrifugal force vectors do not compensate each other. A centrifugal force is produced causing an unbalance.

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 polar-graphic 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 <u>mass axis is parallel to the rotational</u> 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.

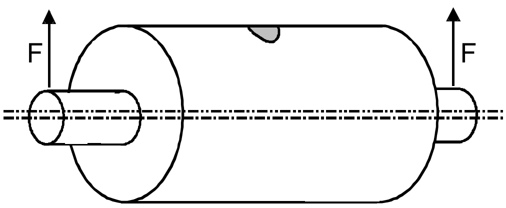

Figure 3: Static unbalance

- **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.

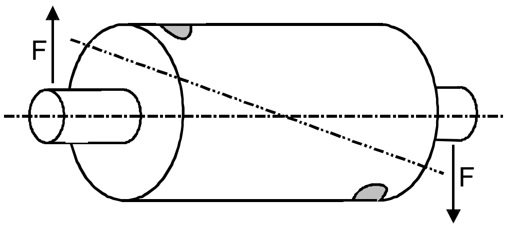

Figure 4: Couple unbalance

- **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.

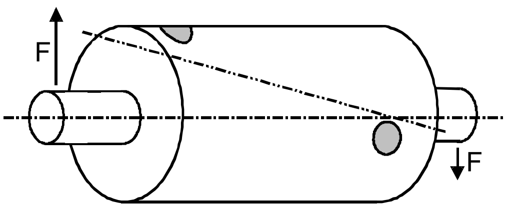

Figure 5: Dynamic unbalance

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.

Unbalance as Vibration

When we measure the vibration of a machine with an accelerometer we will notice a dominant vibration with the frequency of rotation speed in time domain and a spectral line of high amplitude at this frequency due to unbalance.

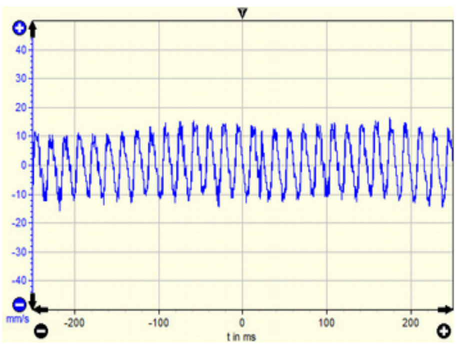

Figure 6: Unbalance in time domain

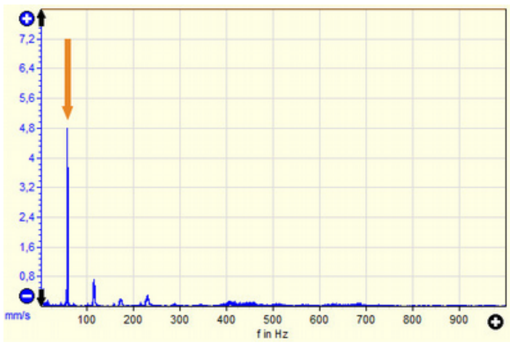

Figure 7: Unbalance in frequency domain

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Measuring technique

VM-BAL uses a relative measurement technique:

1. In an optional **Pilot Survey** (only VM-BAL++) can be verified that balancing will be carried out in a rotary speed range which is free of resonances. This is done by ramping up rotary speed. If the rotor is not speed controlled it is also possible to coast down from nominal speed. VM-BAL++ informs about potential problems for rotors at fixed speed and gives recommendations for rotors with variable speed.
2. In the **Initial Run** the system measures unbalance vibration of the unchanged rotor under field condition.
3. In the next step an artificial unbalance is created by attaching a known mass at a known angle position at the rotor. The result is measured in a **Test Run**.
4. For two-plane balancing attaching the test mass and performing a test run needs to be done for the second plane as well.
5. VM-BAL compares the vibration signal with and without additional unbalance and thereby calculates amplitude and angle of the initial unbalance.
6. Now VM-BAL can calculate the necessary corrections to compensate the unbalance. These can be different kinds of attaching or removing mass.
7. The result of the balancing measures is verified in a further test run.

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

- A magnitude change of the unbalance changes the vibration magnitude in the same way.
- 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. Bearings may attenuate the vibration signal and cause phase shift errors. Both effects will cause a non-linear relationship between vibration and unbalance

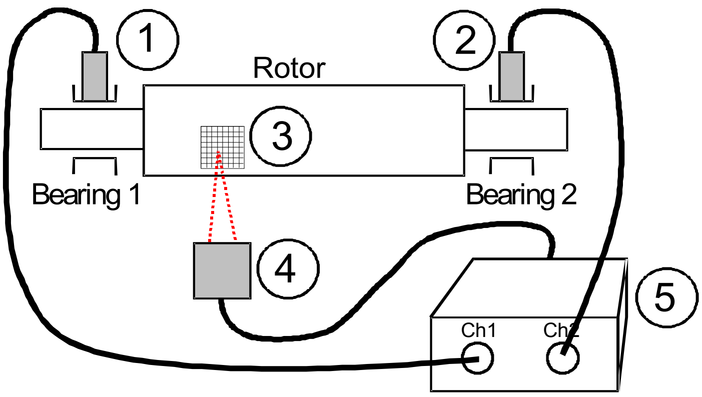
For this reason, please do not expect that balancing will always be successful on the first try. In many cases, it will be necessary to repeat the balancing procedure to obtain a satisfactory result step by step.

Measuring arrangement

Unbalance cannot be measured directly. The measured quantity is the resulting vibration. VM-BAL uses piezoelectric accelerometers with IEPE compatible output which may be connected to the USB sensor interface M302. Preferable bearing cases or other locations close to the bearings are used for sensor mounting. Don't use flexible parts for attaching the sensors.

For static balancing one accelerometer is sufficient, for dynamic balancing, two.

In addition to the vibration amplitude the balancing algorithm needs the angle position of the rotor. It is measured by a photoelectric reflex switch which is also connected to the M302. A magnetic stand simplifies the placement of the reflex switch. A piece of adhesive reflex foil needs to be attached at the rotor.



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

Figure 8: Balancing instrumentation

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 by centrifugal force. This can be achieved in two ways:

- Removing material at the unbalance position by machining
- Adding mass opposite the unbalance position

Practical machining techniques are drilling or milling. Version 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 remains unchanged. With rings, the angle can be adjusted while the radius is unchanged. Version VM-BAL++ calculates the adjustment parameters for both types.

It is also possible to specify certain angle positions for balancing which can be useful when balancing propellers or fans, for example.

VM-BAL++ also calculates balancing measures based on a set of pre-fabricated mass pieces.

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 RMS vibration velocity values between 10 and 1000 Hz to ISO 20816 which can be measured, for example, by the VM-Meter instrument.

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

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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 label) 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.

A Typical Balancing Process With VM-BAL+

In the following example a longish rotor is balanced in two planes. The mass changes are done at a rotor radius of 300 mm. The accepted unbalance is 150 gmm. Correction takes place by counterweights which are to be attached at the opposite side of the unbalance. Corrections can be done at the entire circumference of the rotor.

Preparations

- Install the accelerometers close to the bearings.
- Connect both accelerometers and the photoelectric reflex switch to the M302.
- Make the software connection in VibroMetra between the accelerometers and the corresponding measuring channels (VibroMetra main window, “Sensors”, “Measuring channels”)
- Assign suitable names to the measuring channels, e.g. ‘Plane A’, ‘Drive side’, ‘Bearing side’ etc.
- Attach a piece of reflective tape to the rotor surface. Usually a size of 1 to 2 cm² is sufficient.
- Adjust the photoelectric reflex switch so that the yellow LED flashes when the reflective tape passes the sensor spot.
- Open VM-BAL.

☞ **Press the F1 key in any place of the program to obtain help.**

Settings for the first run (initial unbalance)

- In the “Settings” tab select “Two-plane balancing” and enter the balancing radius for both planes.:

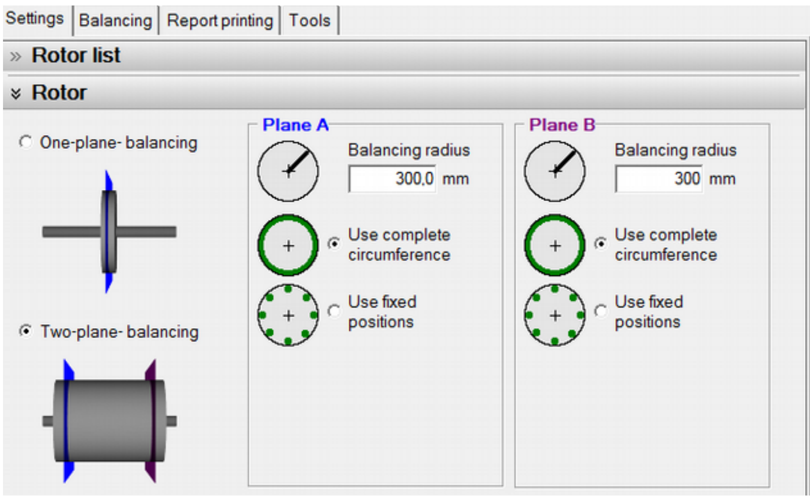

Figure 9: Rotor settings

Note that the balancing radius is not always the radius of the rotor itself.

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Enter for both planes the balancing aim (acceptable unbalance):

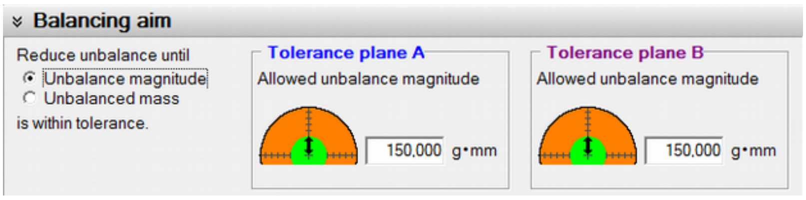

Figure 10: Balancing aim

The measuring channels will be selected automatically. If you don't use more than one M302 no changes are necessary.

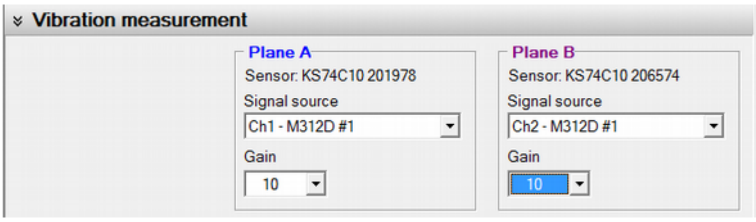

Figure 11: Measuring channels

☞ 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 auto-ranging 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. Gains are selected under Settings / Vibration measurement.

- For good results a constant rotation speed is crucial during the balancing process. In the Menu “Settings / Measurement of rot. speed” you can enter the parameters of rotation speed monitoring.
- Here you can enter the maximum allowable deviation of rotation speed in percent.
- You may also set a minimum rotation speed for monitoring. The value should not be higher than the nominal speed of your rotor less the expected tolerance. The lower the minimum speed value the longer the balancing procedure will take.
- “Cycles for measurement run” determines how many revolutions are measured for speed monitoring”. A higher value provides better accuracy but increases also the duration of measurement.

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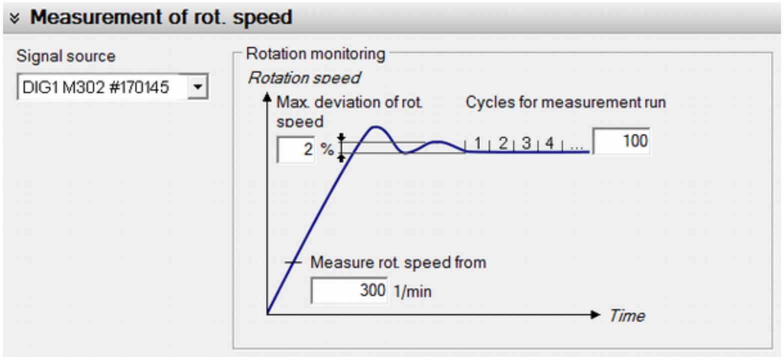

Figure 12: Rotation speed measurement

- Under “Presets for mass changes” the used test masses for measuring the initial unbalance are entered. If the entered parameters do not deliver satisfying results you can still change them later during the balancing process.

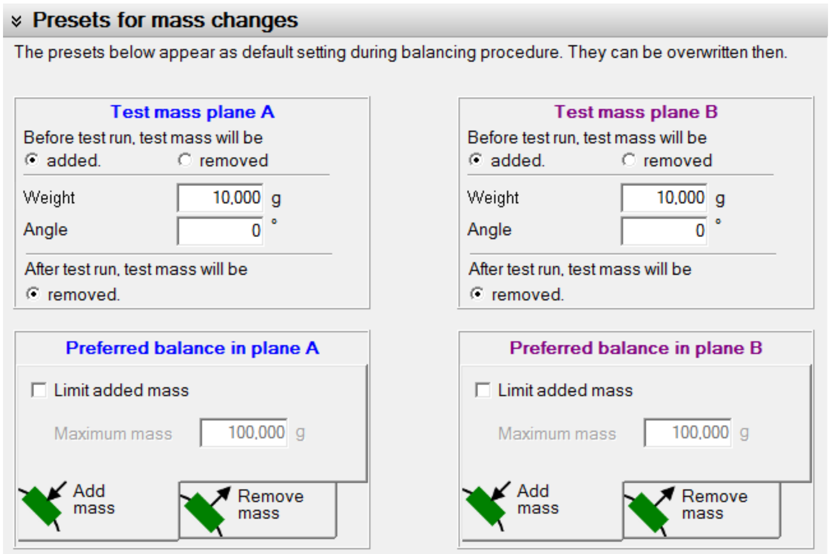

Figure 13: Presets for test masses

Start balancing After finishing the setup confirm your entries by clicking 

Now we are ready for balancing. The following steps are done in the “Balancing” tab.

The balancing process consists of several steps called “runs”. In the initial run the system determines the unbalanced condition. The second test run measures the unbalance after adding a known mass at a certain angle of the rotor. Based on this run the balancing measures are calculated. Finally a verification run is performed. For two planes two separate runs are needed in each step.

The balancing runs can be repeated until the measured unbalance is within the desired limits.

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Initial run

- Start the rotation.
- Select in the measurement tree “Test runs” / “Initial run” / “Vibration measurement” and click “Start measurement”.
- The system will display the polar coordinates of the unbalance (amplitude and angle) for both planes.

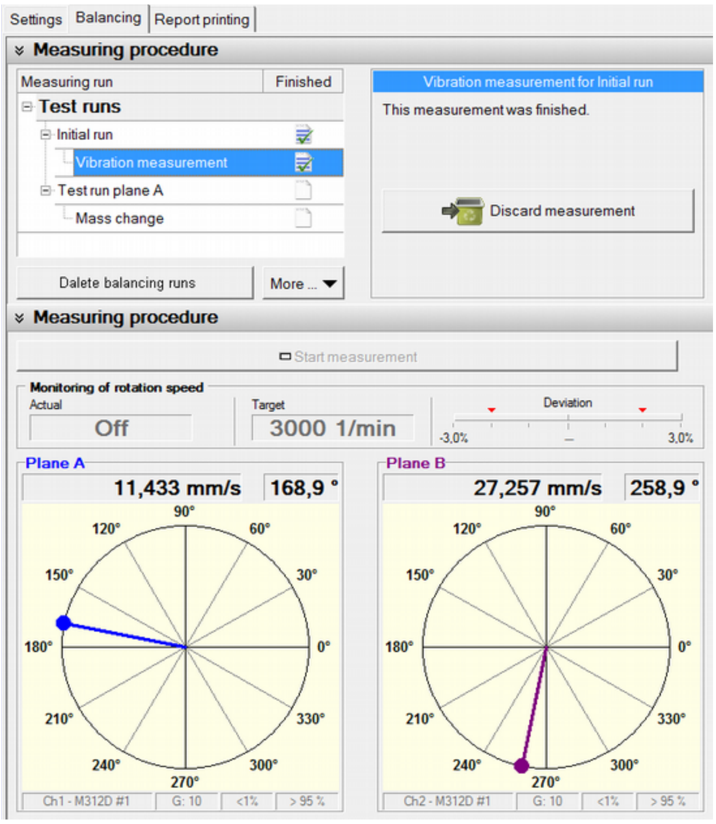

Figure 14: Results of initial run

- VM-BAL automatically detects the start of rotation. It informs you about the current rotation speed and its stability. It is compared to the expected rotation speed. Reasons for deviations can be a poor detection of the reflex switch.
- With some experience you will be able to make predictions about a successful balancing result from the initial run. When the vectors become stable within short time good balancing results can be expected. If the vectors change abruptly there can be problems with noisy or too low vibration signals or with an inadequate position of the test mass.

Notice: Any measuring step or input can be canceled and repeated without loosing previous measurements.

Test mass for plane A

- Stop rotation.
- Click “Test run plane A” / “Mass change”
- You are asked to attach (or remove) a defined piece of mass at a certain angle position.

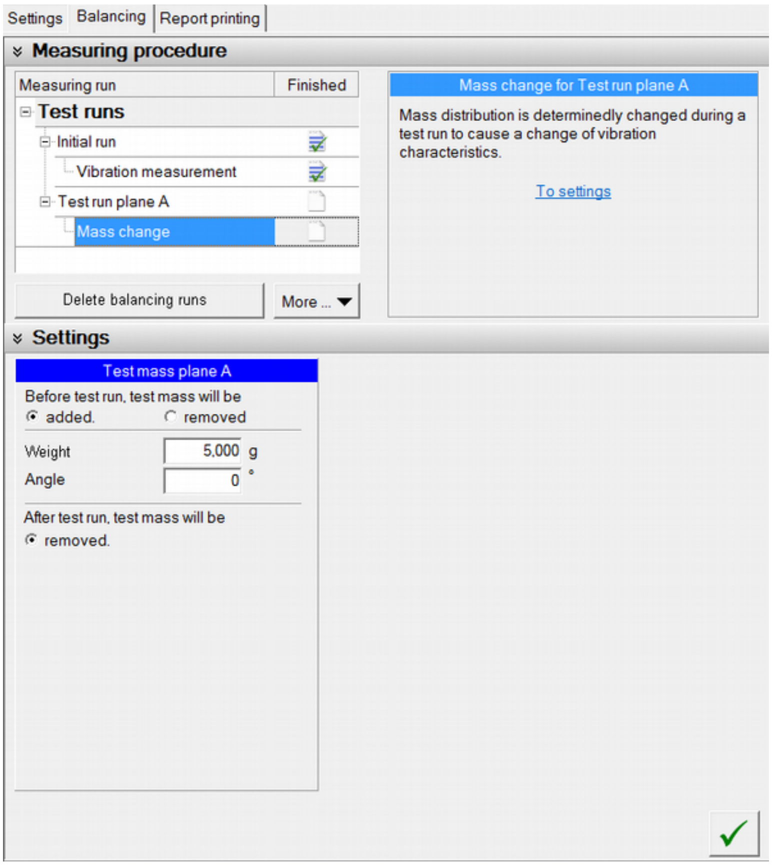

Figure 15: Test mass for plane A

- Choosing the optimum **weight** of the test mass needs some experience. The test weight should be sufficiently high to cause a significant change of unbalance but an order of magnitude. A good value is a doubled unbalance, but also an increase of 3 to 5 times is acceptable. If you don't have practical experience make your decision based on the balancing aim. In our case it is 150 gmm. The tolerated unbalance that may sit on the rotor radius of is therefore

  150 mm is 150 gmm / 150 mm = 1 g

  We use a test mass of 5 grams to be within the recommended limits.
- For the **angle** it is advantageous to enter 0°. Then all calculated angles will be referred to the angle position of the test mass. If other angles are used the difference between 0° and the test mass angle is to be entered. All angles are measured against rotation.
- The angle of the reflective label has no importance.
- Confirm your entries by clicking 
- Start rotation.

Test run with test mass for plane A

Select “Test run plane A” / “Vibration measurement” and click “Start measurement”. VM-BAL shows the polar diagrams of the resulting unbalance with a test mass at plane A for both planes.

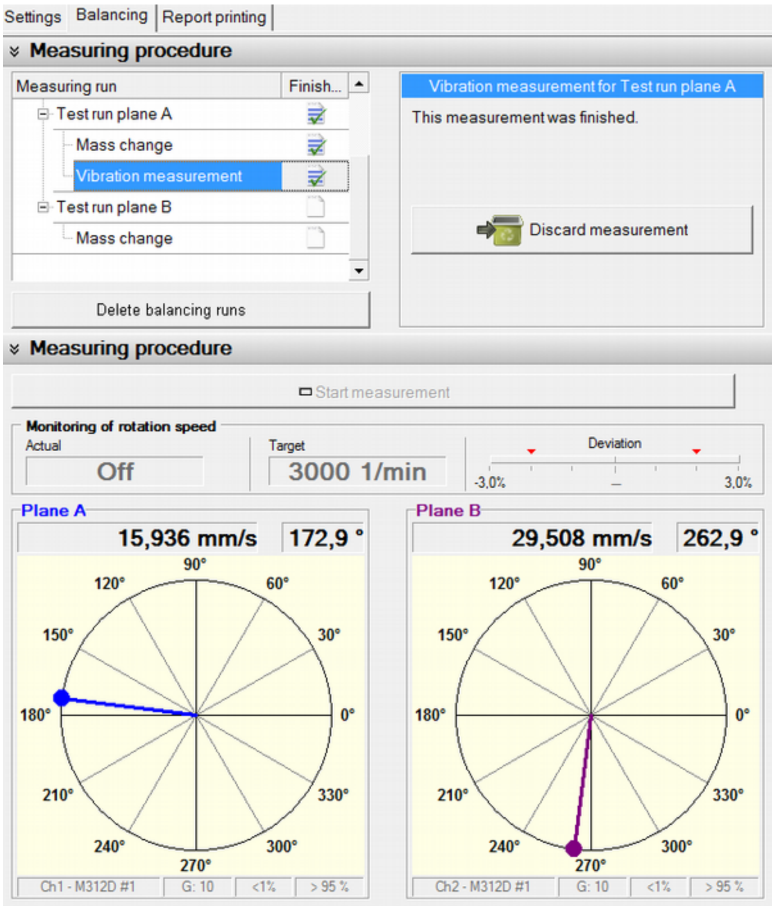

Figure 16: Results of test run for plane A

Test mass for plane B

- Stop rotation.
- Under “Test run plane B” / “Mass change” you are requested to remove the test mass from plane A.
- Enter now the test mass for plane B. attach it to the rotor and confirm your changes.

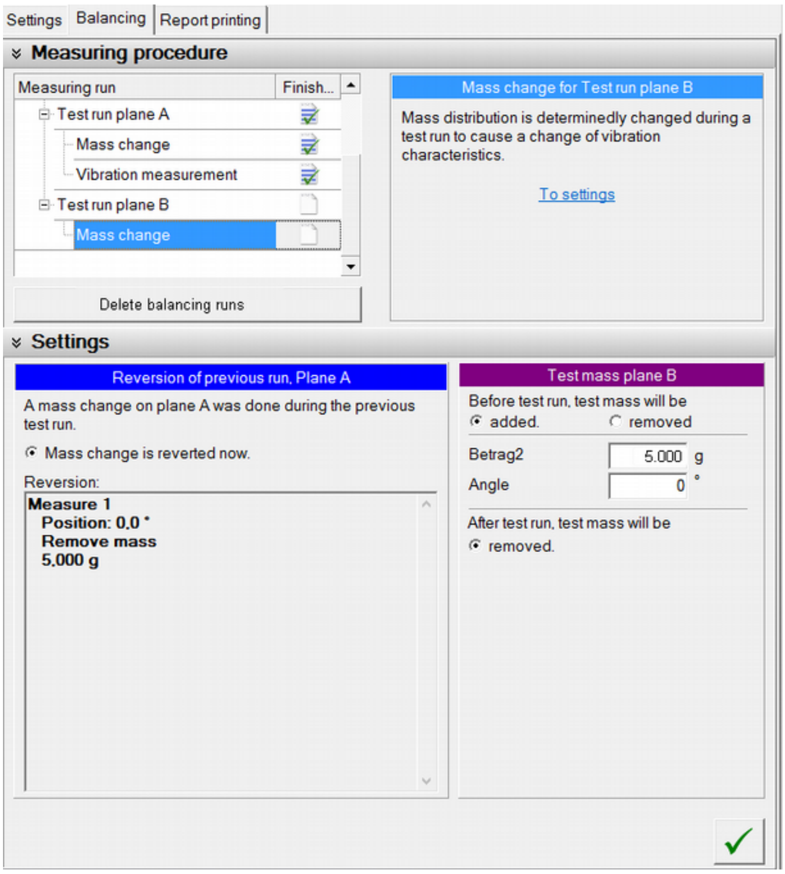

Figure 17: Test mass for plane B

Test run with test mass for plane B and evaluation

- Start rotation.
- Select “Test run plane B” / “Vibration measurement” and click “Start measurement”. VM-BAL shows the polar diagrams of the resulting unbalance with a test mass at plane B for both planes.
- You will see an evaluation of the measured unbalance with reference to your balancing aim.

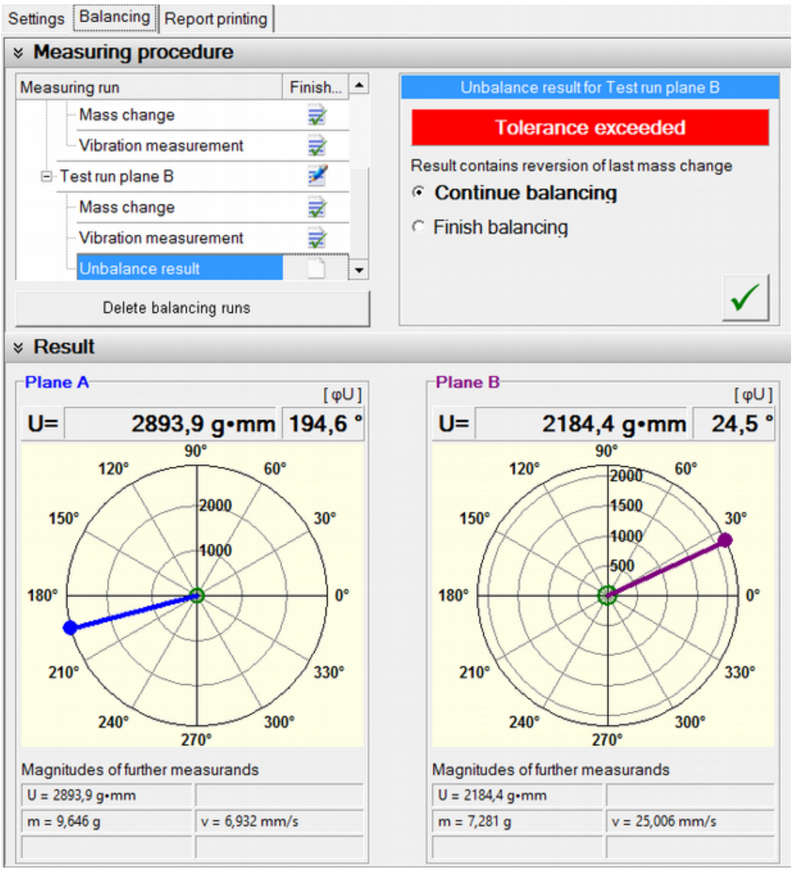

Figure 18: Results of test run for plane A and evaluation

- Stop rotation.

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- After finishing the test runs we will now begin with the actual balancing to bring the unbalance under the desired limit. Choose "Continue balancing" and confirm.
- You will reach next step "Verification run 1" / "Mass change"
- VM-BAL shows you the necessary changes for both planes ("A>>" or "B>>"), i.e. on which positions how much weight needs to be added (or removed). In plane B you will be reminded under "Reversion" to remove the test mass from the previous step before you continue to "Execution".

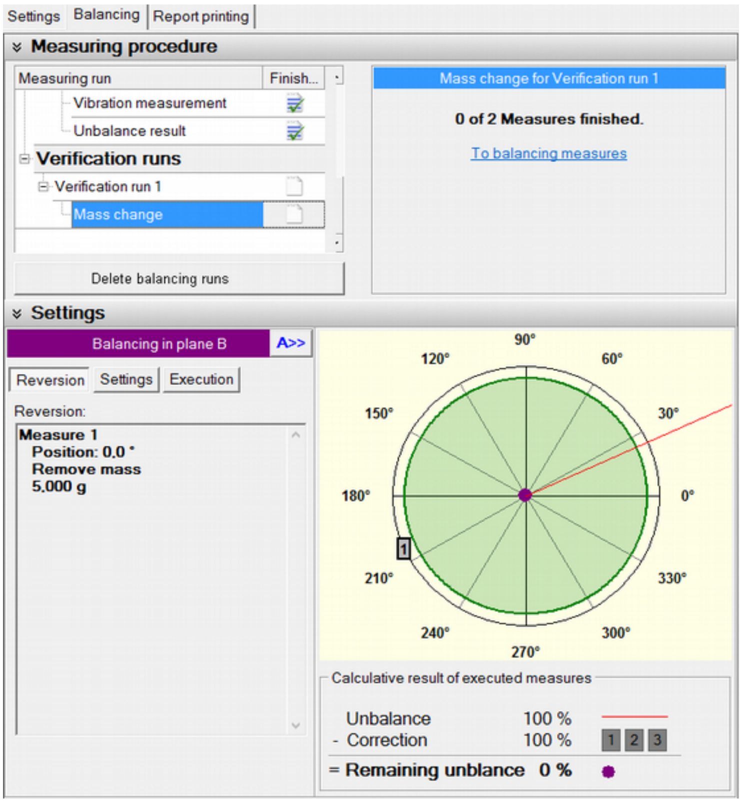

Figure 19: Balancing measures

- After confirming the done corrections start rotation again and click "Start measurement".

- As mentioned you will often not reach the final result at the first verification run.

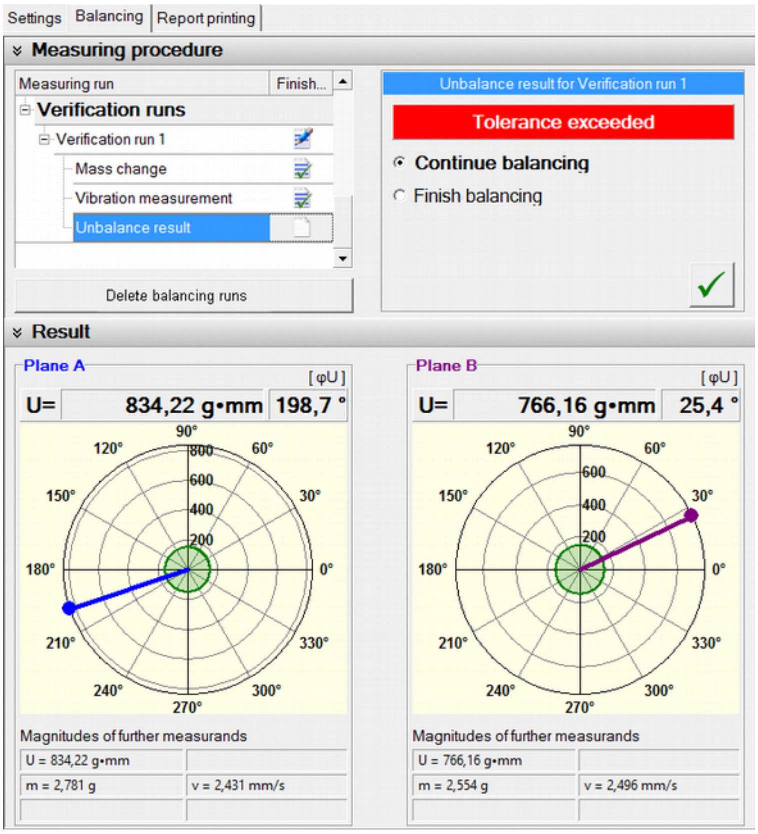

Figure 20: First verification run

- You can continue the balancing procedure and perform further corrections until you are satisfied with the result.

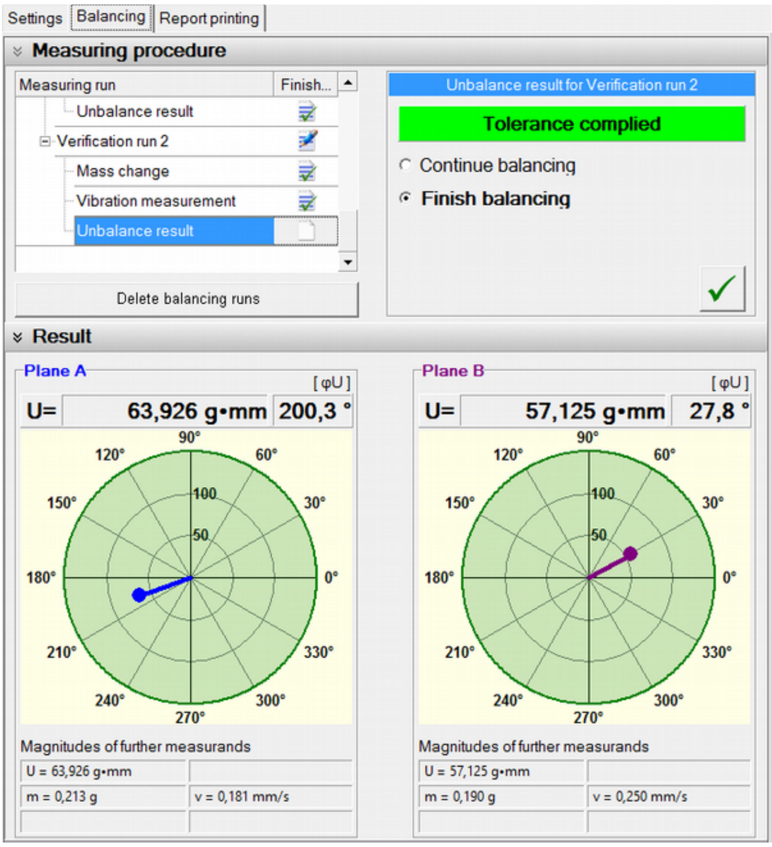

Figure 21: Second verification run

Additional features of VM-BAL++

The above description is based on the program version VM-BAL+.

VM-BAL++ offers some additional functions:

- A **Pilot survey** helps to find the optimum rotation speed for balancing

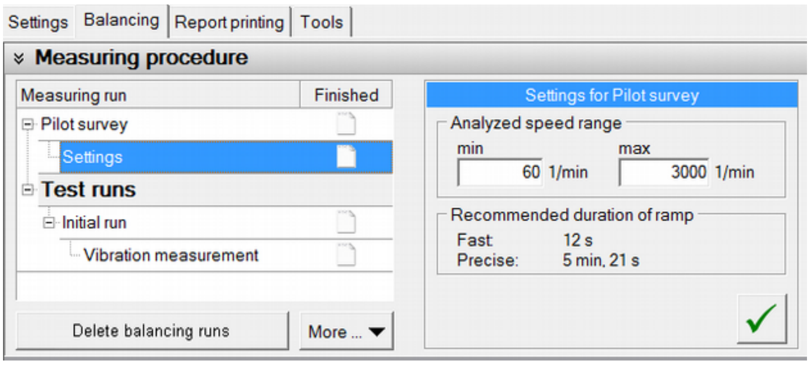

Figure 22: Pilot survey

- Comprehensive balancing methods:

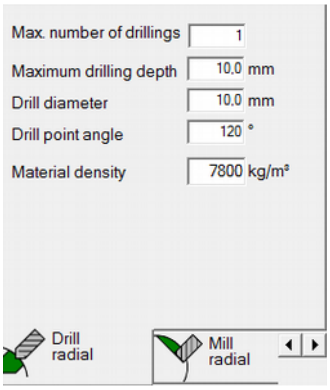

Figure 25: Radial drilling

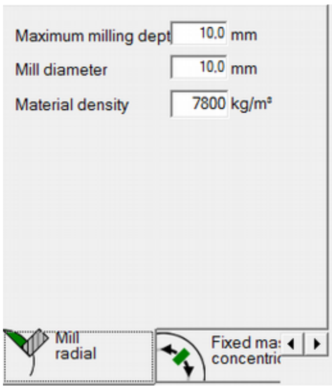

Figure 23: Radial milling

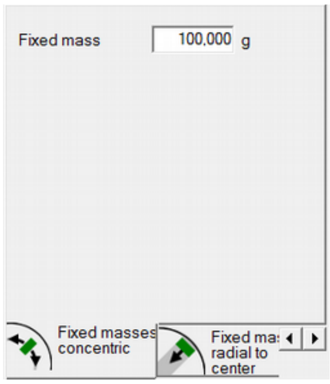

Figure 24: Concentric mass

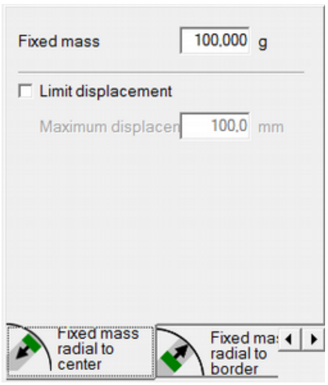

Figure 26: Radial mass (1)

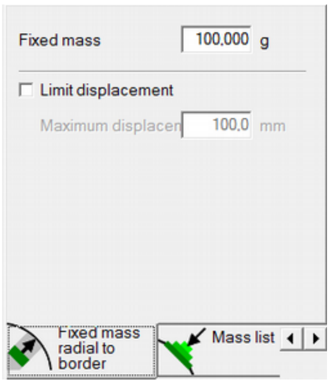

Figure 28: Radial mass (2)

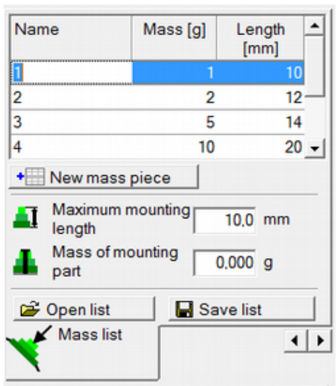

Figure 27: Mass list

- Additional balancing aims: Balancing quality to ISO 1940, vibration displacement, velocity and acceleration

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