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).

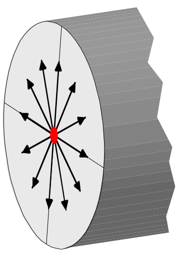

Figure 1:
All centrifugal force vectors compensate each other. The rotor is balanced.

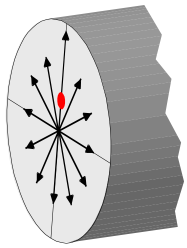

Figure 2:
The centrifugal force vectors do not compensate each other. A centrifugal force is produced causing an unbalance.

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 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 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.

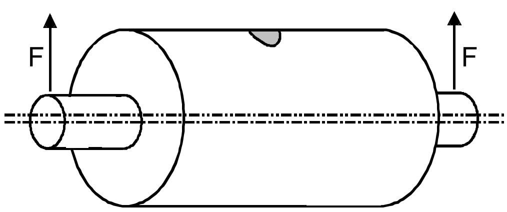

Figure 3: Static unbalance

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- **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.

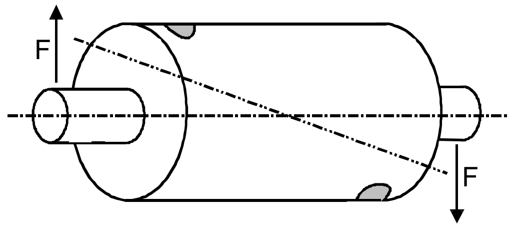

Figure 4: Couple unbalance

- **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.

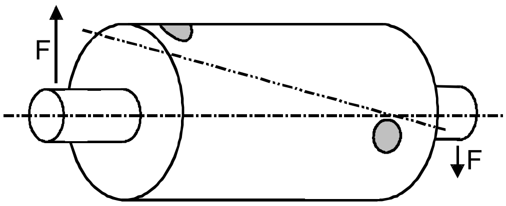

Figure 5: Dynamic unbalance

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:

- 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, 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 IEPE 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.

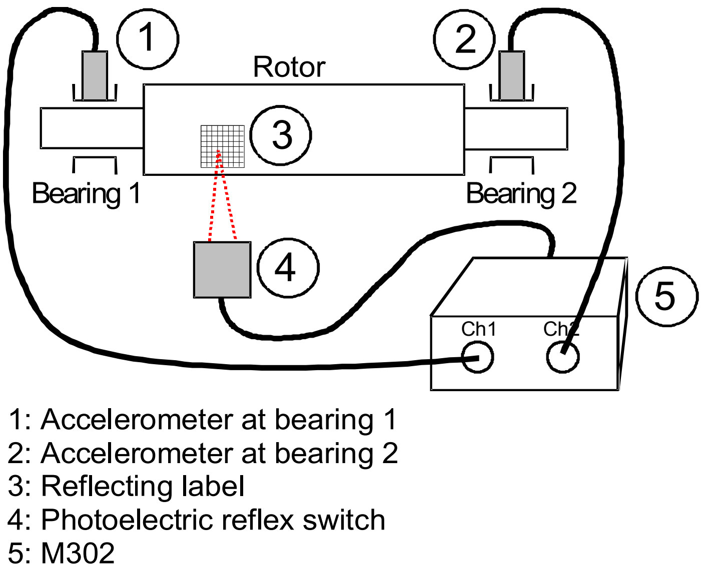

Figure 6: Balancing instrumentation

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.

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VM-BAL Application Example

In the following example a long rotor is balanced in two planes.

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

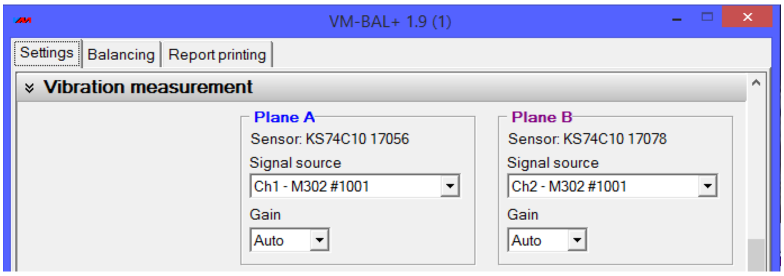

Figure 7: Settings for vibration measurement

The correct measuring channels are automatically selected provided that only one M302 is connected to your PC. 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 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.

Open Settings / Rotor. Select *Two-plane balancing*.

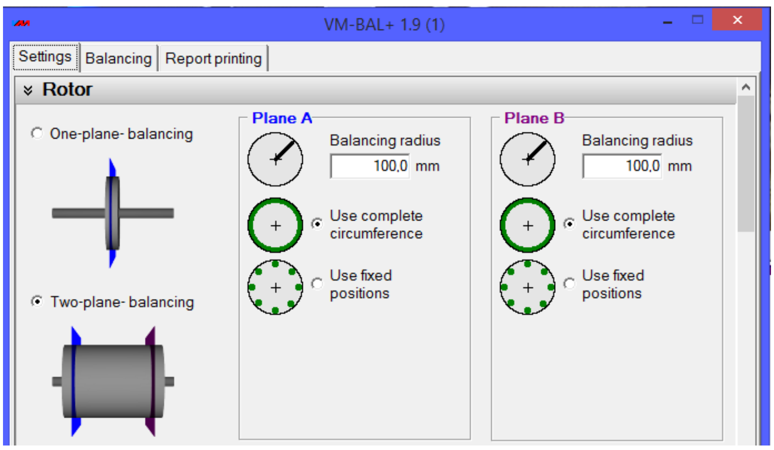

Figure 8: Rotor settings

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Enter for each plane the radius where you intend to add or remove mass. Note that this is not always the radius of the rotor itself.

In some cases, like a fan or propeller, it is not possible to make changes at any angle. For such cases you may enter fixed angle positions.

In the menu Settings/Balancing aim you choose whether you want to obtain the result in units of unbalance (mass x radius) or as a mass. Version VM-BAL++ of the software offers additional balancing aims such as balancing quality to ISO 1940, displacement, velocity and acceleration. We select "Vibration velocity" and enter for both planes the target unbalance which we want to achieve.

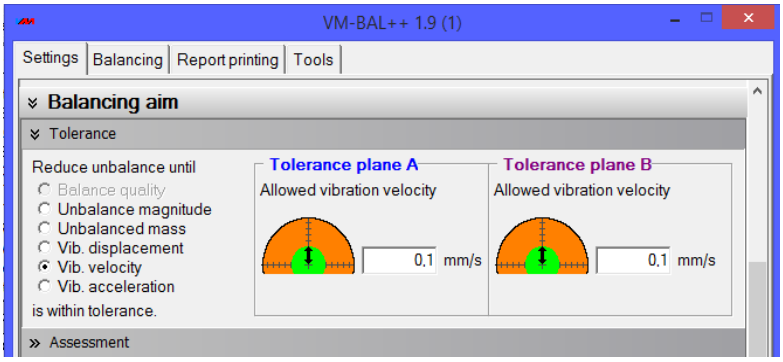
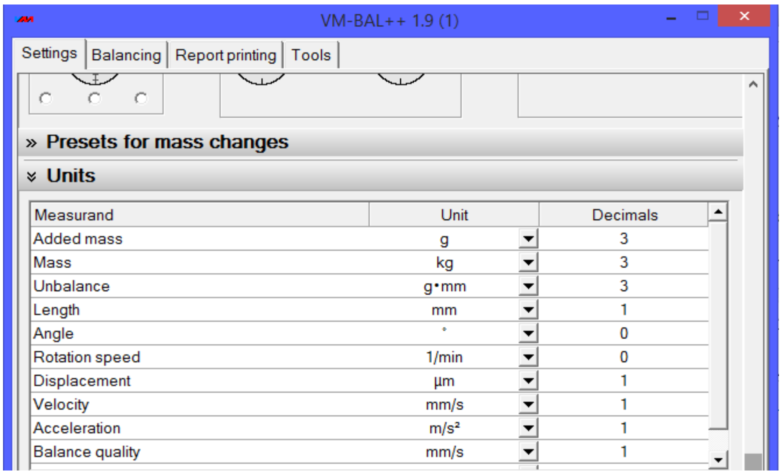


Figure 9: Balancing aim

Under Settings / Units you may change the measuring units for unbalance, length and angle. These settings can also be changed later during balancing.



Measurand	Unit	Decimals
Added mass	g	3
Mass	kg	3
Unbalance	g•mm	3
Length	mm	1
Angle	°	0
Rotation speed	1/min	0
Displacement	µm	1
Velocity	mm/s	1
Acceleration	m/s²	1
Balance quality	mm/s	1

Figure 10: Display units

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.

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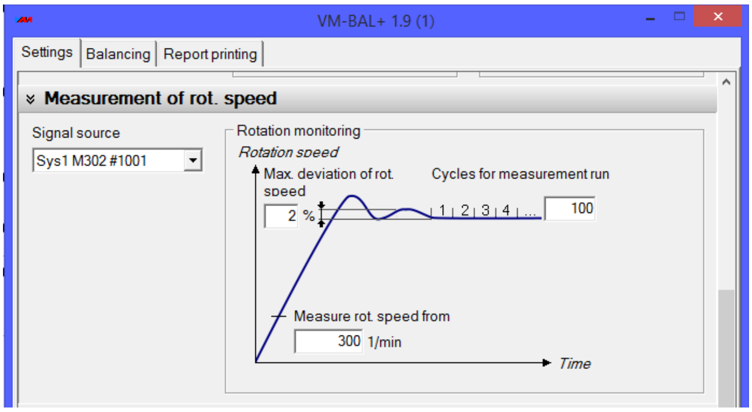

Figure 11: Settings for rotation speed measurement

Here you can enter the maximum allowable deviation of rotation speed in percent.

You can 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.

☞ Balancing at rotation speeds where resonances occur should be avoided.

Version VM-BAL++ of the software includes a "Pilot survey" feature which helps to find suitable rotation speed values for balancing.

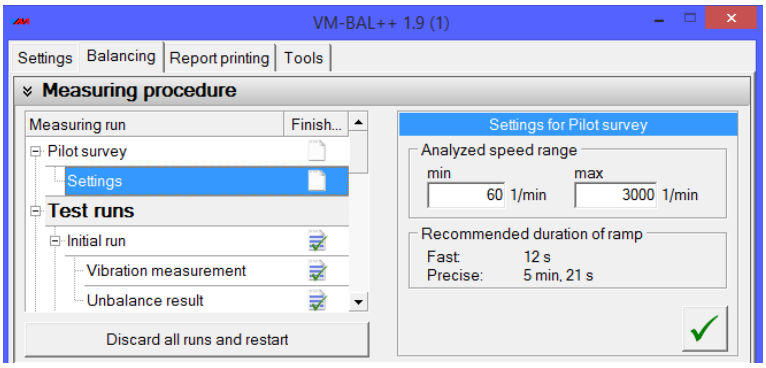

Figure 12: Pilot survey of VM-BAL++

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 first test run the system determines the initial 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.

Angle The convention for angle measurement in VM-BAL is: Positive angles are measured in the oppo-

convention site direction of rotation. Start angle (0°) is an arbitrarily set position at the rotor.

Initial Unbalance

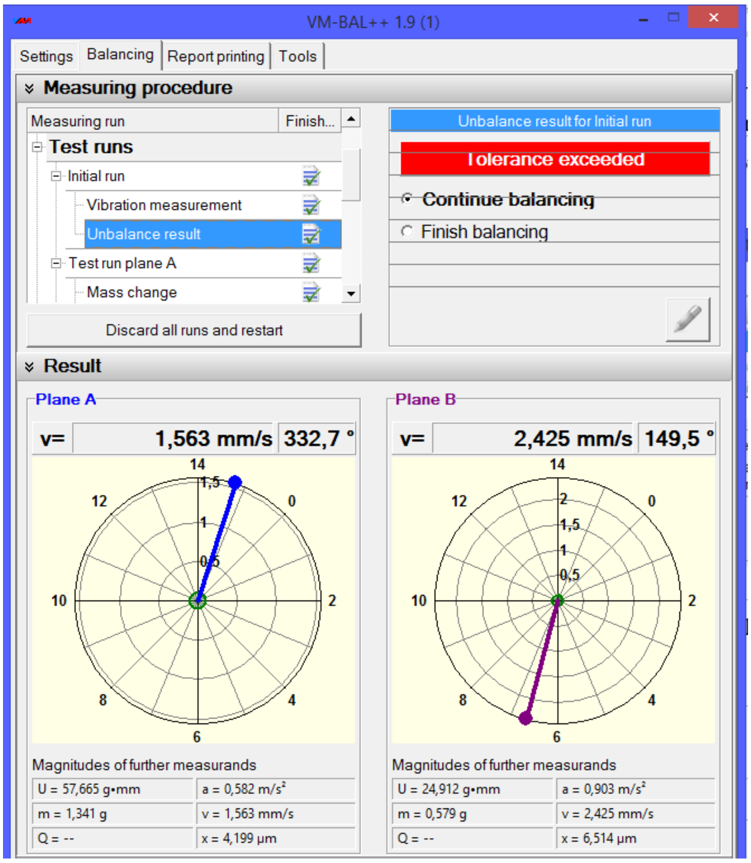

Figure 13: Results of initial run

First of all the system will measure the as-is condition of the rotor for both planes. This step is called “initial run”. Start rotation and VM-BAL will automatically perform the necessary measurements.

The results are shown as amplitude (in this case velocity) and angle values and as vectors in a polar diagram.

Test run In a next step we add or remove a known test mass at a certain angle position. This needs to be done for both planes subsequently.

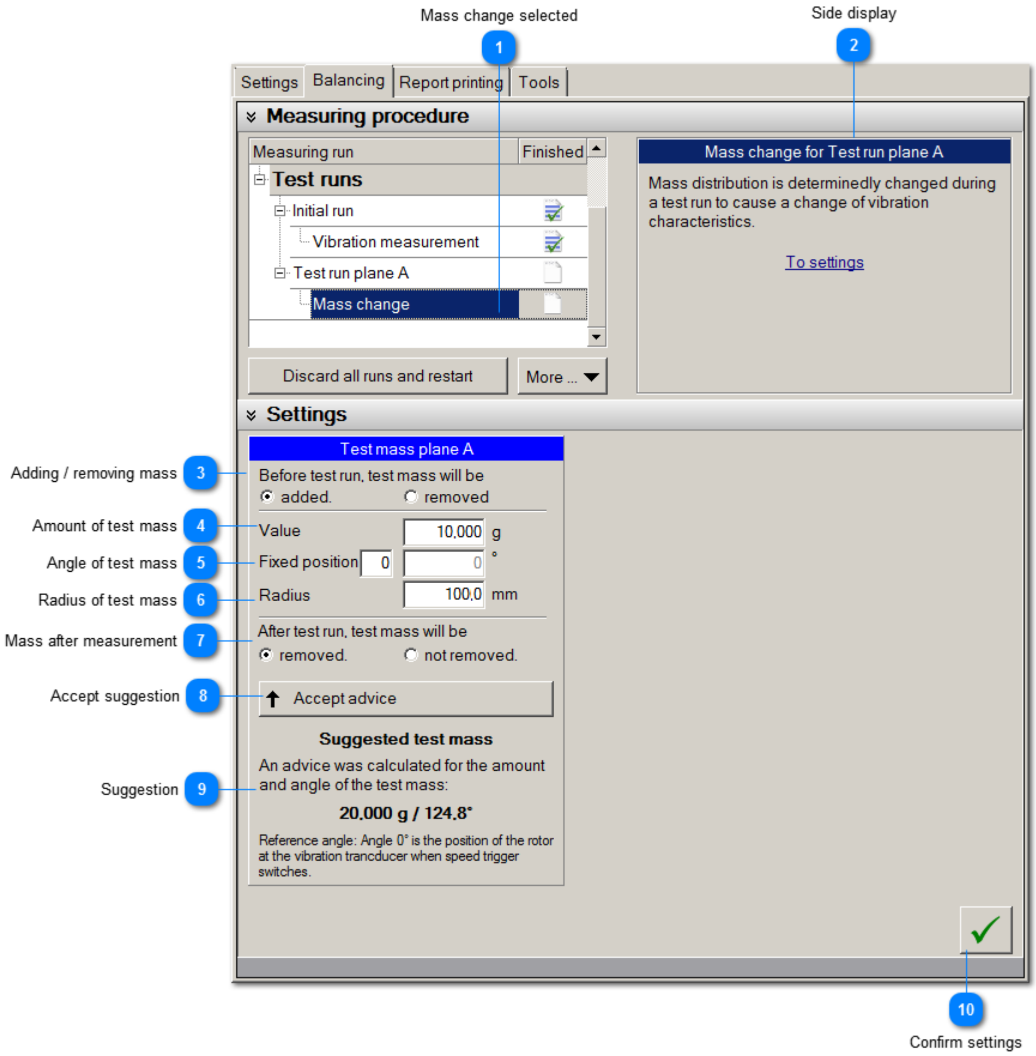

Figure 14: Test mass menu

Enter the angle and the radius where the mass change is done and the mass itself.

In most cases the test mass will be removed again after the test runs. In some cases, for instance if the test mass is welded, it may practical to leave it at the rotor. This option is available in VM-BAL++. This version also offers suggestions for selecting an optimum test mass and angle.

After applying the test mass we can proceed to the next test run.

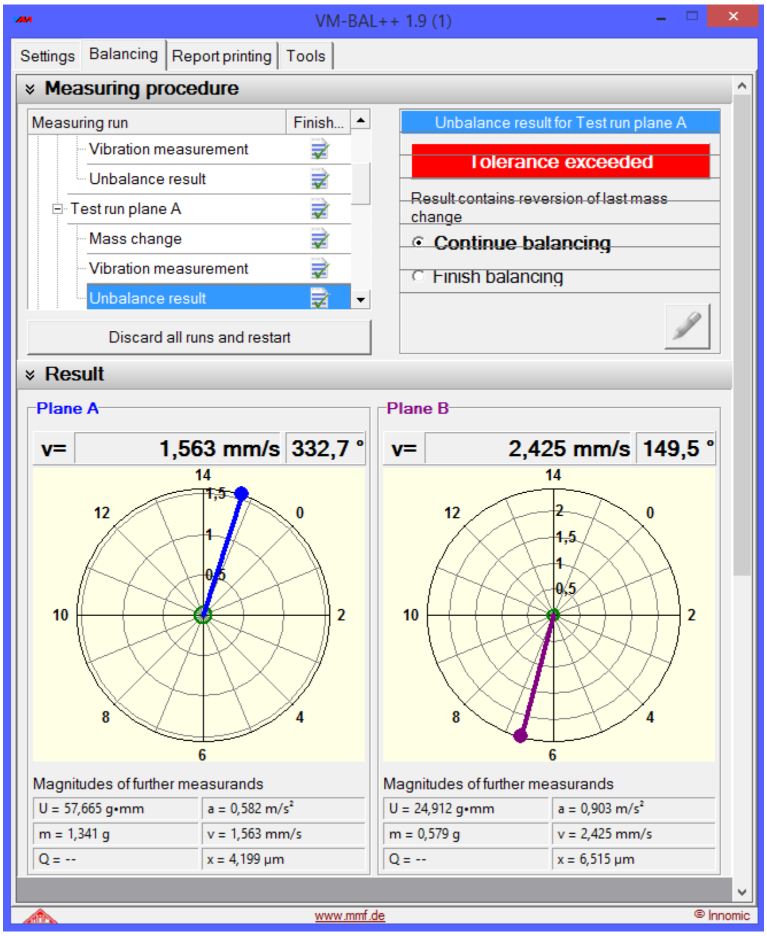

Figure 15: Test run after mass change

Based on the test mass measurement VM-BAL is able to calculate the necessary corrections for reducing unbalance. Based on your version of VM-BAL these can be adding or removing mass, drilling, milling, balancing rings, set screws or mass pieces from an assortment of masses.

Each method has advantages and drawbacks:

Balancing rings	fast but relatively coarse compensation
Assortment of masses	↓
Setscrews	
Drilling	
Milling	
Free mass	slower but fine compensation

☞ Please make sure to remove or keep the test mass after this run according to the settings you have made in the test mass menu.

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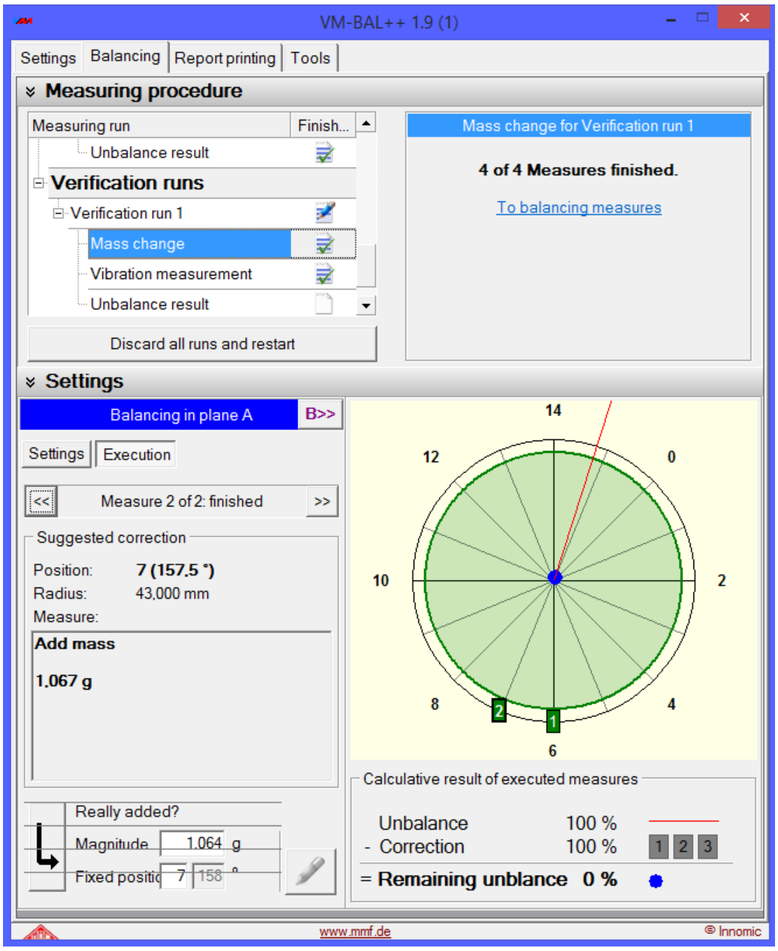

Figure 16: Correction menu

The final step is called verification run. Unbalance is measured again after the corrections have been made. The unbalance results are compared with the acceptable unbalance (see balancing aim).

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.

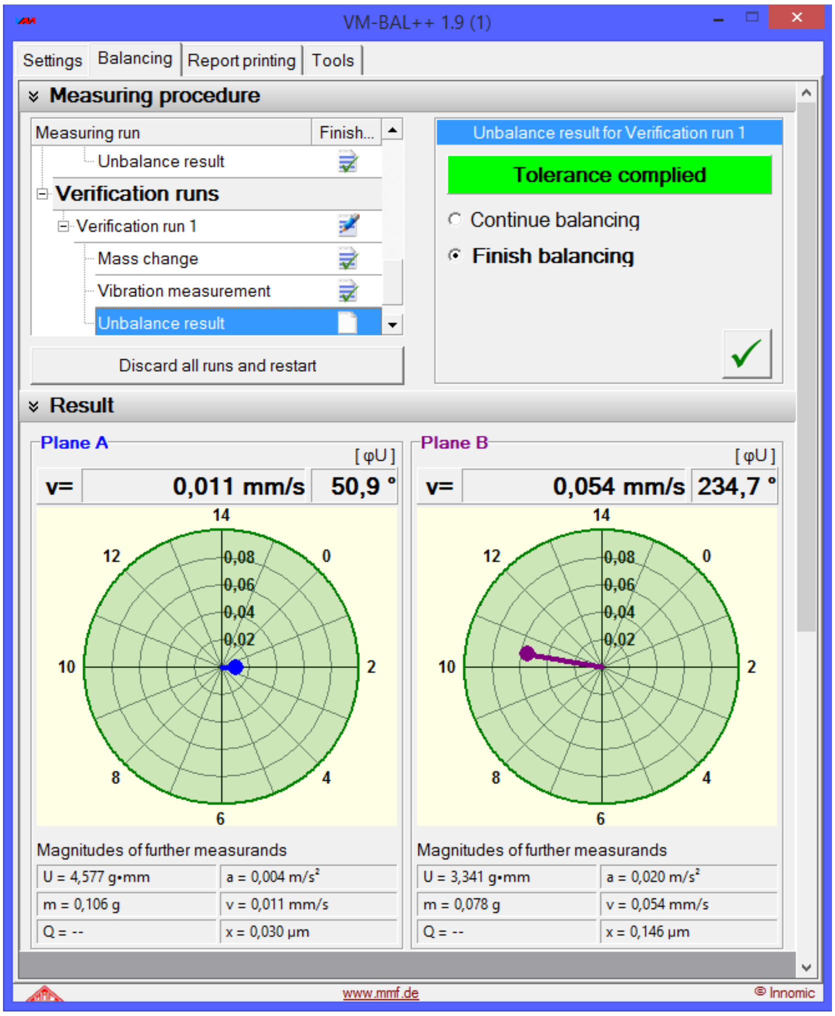

Figure 17: Verification run

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

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