PRÜFTECHNIK
Machinery Service

Mobile field balancing reduces vibrations in energy and power plants

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Rotating components in modern energy and power plants are generally complex vibration-capable systems. To maximize the service life, both the housing vibrations and the shaft vibrations on these components should be as low as possible. In this connection, imbalances on rotors are a frequent source of undesired vibration excitations, because they increase the vibration level unnecessarily and excite natural frequencies, which can sometimes cause destructive resonance effects. In newly installed or modified rotors, therefore, the balance grade must always be checked with measurement hardware and corrected, if necessary. If there is a risk of imbalance the required balance grade must be increased or the permissible residual imbalance must be reduced. Mobile field balancing with VIBXPERT or SmartBalancer is currently considered one of the most efficient methods of actively reducing and even preventing resonance excitations. Consequently, experienced and sufficiently qualified technicians are needed in order to avoid the dangers involved in balancing and to take advantage of all the features of modern measurement hardware. Generally acknowledged certification of the balancing personnel will therefore be inevitable in the long run.

1. Balancing of machines and systems

According to ISO 1940-1:2004 balancing is a "Procedure by which the mass distribution of a rotor is examined and, if necessary, corrected to ensure that the residual imbalance or the rotational vibrations of the bearing journals and/or the bearing forces are within defined limits at operating speed." /1/ In case of imbalance the 'gravity axis' and rotating axis of the rotor are different.

Balancing of rotors is generally very widespread in machine and plant construction. It is performed on balancing machines or by balancing in the machine or plant itself. In-situ balancing is generally referred to as field balancing. In large plants it is often the only possibility of achieving the necessary balance grade within the plant as a "unit".

ISO 1940 defines the required balance grades separately for many machines types. In field balancing the vibration velocities according to ISO 10816-3 and increasingly also the shaft vibrations according to ISO 7919/3/ are used as the required balance grade. With reference to the centrifugal pump standard ISO 10816-7 this is also the normal method of achieving a lower vibration level in pumps with high requirements for availability.

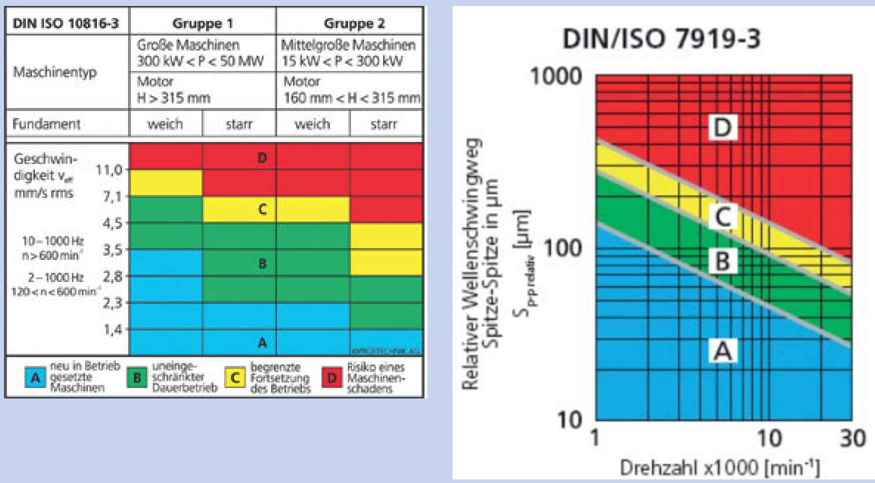

Fig. 1: Overall vibration values according to ISO 10816-3 for general rotating machines and ISO 7919-3 for coupled industrial machines.

2. Balancing in energy and power plants

Motors, gearboxes, clutches, brake disks, impellers and rotors are normally balanced in the factory on balancing machines. The single components are balanced to specifications at the selected balancing speed, although this is not always possible at the operating speed. The vibration behavior also changes in assembled state. The vibration from imbalance often increases, and resonances can also occur. Field balancing can be used to efficiently compensate for this.

In very large machines, and also in rotor blades in wind turbines, it is not possible to balance the components on balancing benches. Field balancing is the only way to reduce imbalances.

Meanwhile, there is increasing evidence that energy and power plants are also unnecessarily subjected to imbalance and higher rotational vibrations. In variable-speed machines, natural frequencies pose an additional risk, since they are more prone to excitation and, in the case of power plants, can also result in resonance. Especially in coal mills, vibrations from imbalance can occur more quickly than is normally assumed.

Figure 2 shows a summary of the causes of imbalance in wind turbines. In addition to mass imbalance, aerodynamic imbalance is an important factor affecting rotor blades in wind turbines. It can be reduced by correcting the blade angle, for example. However, aerodynamic imbalance can also occur in axial flow fans in power plants.

Field balancing should always be carried out at comparable running speeds and operating conditions. It is absolutely necessary to have a very precise RPM measurement as well as sufficiently long measuring times for the amplitudes and phase position of the rotor vibration. This requires high-quality sensors, especially in the case of very high and very low RPMs, and also if beats are present. PRÜFTECHNIK has met these challenges with a specially developed generation of sensors.

Possible measurement quantities are vibration velocity, vibration acceleration and vibration displacement. Suitable sensors are shaft vibration sensors, displacement sensors, accelerometers, vibration velocity sensors and force sensors. If the measuring device features automatic signal processing, the actual values of the balance state can be estimated on-site and the balance weights recommended by the device can be mounted on the rotor.

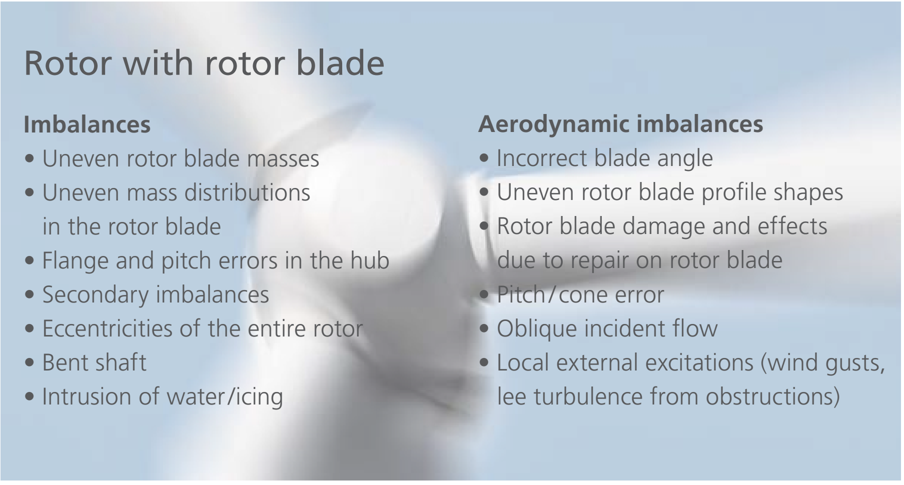

Fig. 2: The causes for imbalance in wind turbines are diverse /2/

3. How is the required balance grade defined?

A good balance state can be felt subjectively in the machine or in the pod of the wind turbine. Quantitatively, the permissible residual imbalance can be derived from nomogram (Fig. 3). The nomogram at the right was extrapolated by PRÜFTECHNIK from 20 RPM to 2 RPM and the balance grade G1 to G100 was entered. The balance grade G16, which is also used for propeller shafts and with which PRÜFTECHNIK has had positive experiences in service calls on wind turbines was especially emphasized.

The nomogram can also be used to assess whether it is possible to influence the vibrations by attaching additional weights near the rotor hub, or whether it will be more effective to add the additional weights in the rotor blades.

The general procedure for field balancing is described below:

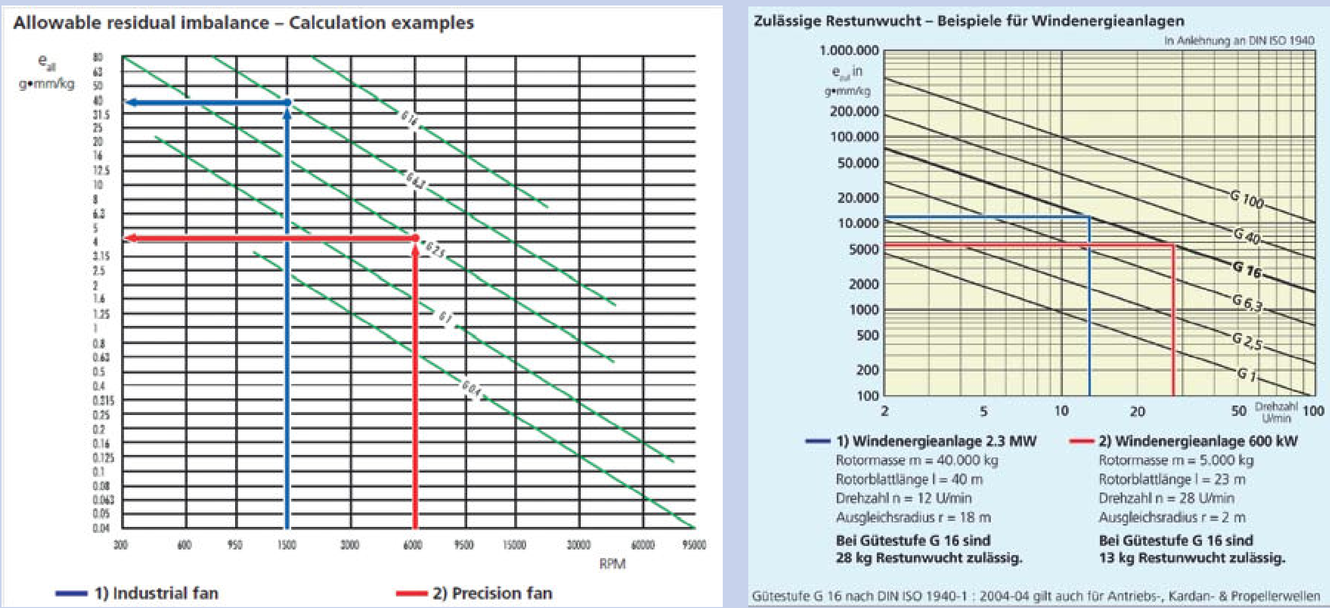

Fig. 3: Balance grades according to ISO 1940 for standard machines and extrapolated for wind turbines (bottom)

4. General procedure for field balancing

First, a reflector tag is affixed to the rotor shaft, as near to the key as possible. The RPM sensor is aligned to the reflector tag and a suitable accelerometer is mounted on the main bearing, preferably in horizontal axis. Then a diagnostic measurement is conducted, to check whether the rotor speed actually dominates in the frequency spectra. If yes, balancing can begin; otherwise, it is necessary to find a measurement location with significant amplitudes.

If the vibration characteristics of the plant are unknown, coast-down spectra should be measured throughout the operating speed range of the plant before balancing. To do this, the plant has to be slowed down and the frequency is then measured continuously this range. Such measurements are also used to document the initial state of the plant before balancing.

In the next step, balancing mode is started in VIBXPERT. In the corresponding Machinery Manager it is necessary to enter the rotor masses, the balance radii and the desired balance grade.

Actual field balancing can now begin, during which the following steps take place:

- **Determination of initial imbalance**
  Initial imbalance is the imbalance present in the entire rotor prior to balancing.

- **Determination of the trial weight and measurement of its effect**
  The required trial weight is determined by VIBXPERT and defined based on the number of rotor blades, e.g. as a fixed position correction. Mounting (or reducing) the trial weight also serves to become familiar with the “balancing system” and its response to the trial weight. The trial weight must sufficiently change the amplitude and angle in the vibration indicator in order to calculate the actual mass compensation on the rotor.
  VIBXPERT then recommends balancing weights, and also allows you to enter the weights that are actually added.

- **Mounting balancing weights and executing trial runs**
  The balancing software in VIBXPERT is used for the trial runs that follow. The recommended balancing weights are mounted and the balancing run is repeated. Similar to balancing of industrial plants, it takes two to four runs to find the suitable balancing weights. In the end there will of course be a certain residual imbalance, which is estimated by comparative diagnostic measurements.

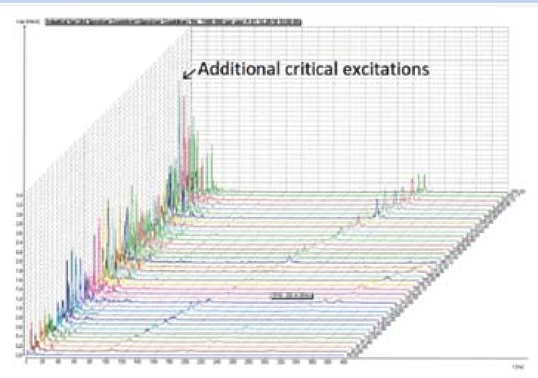

Fig. 4: Coast-down spectra of the vibration velocity of a mill sifter

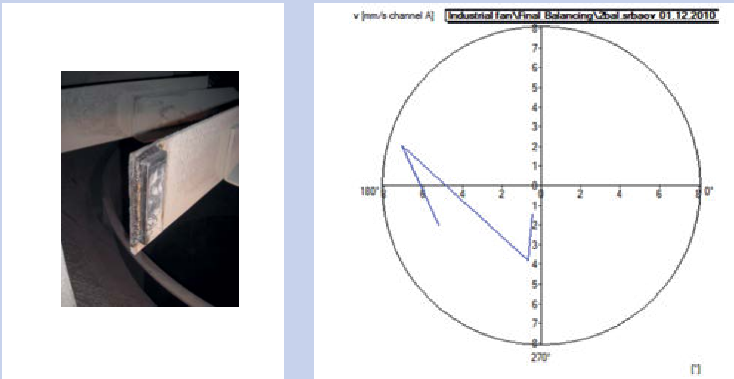

Fig. 5: Balancing weights mounted and balancing diagram (polar plot)

with a frequency analyser – such as VIBXPERT (Figure 4). By applying the spectra based on the speed, it is possible to determine which speeds can be balanced without exciting interfering natural vibrations. The example below shows that field balancing is easily possible below 210 RPM. Speeds above 230 RPM should be avoided, since there are resonance rises in

- **Repeat of diagnostic measurements**
  After completion of the trial runs the coast-down spectrum is measured again and compared with the initial state. If the rotational frequency excitations were reduced, the balancing was successful. Often, the natural frequency excitations will be lower as well.

Step	Mass in kg	Rotor blade	Velocity in mm/s	Add/remove
1	–	–	5.57	–
2	2.1	01	7.36	Remove
3	2.1	16	3.87	Add
Result	1.25	23	1.51	Add

Tab. 1: Documentation of the balancing steps

5. Reducing vibrations on horizontal machines with field balancing

If the rotor is balanced in mounted condition, the rotational axis will normally be different from the gravity axis in the first step, as a result of bearing play. If the coupling hub or belt pulley is then mounted, there are additional deviations that have to be taken into account.

Manufacturers of plant and drive technology have clear requirements for balancing, for example where to mount balancing weights or where to drill holes. It is even better if the machine design and the balancing weights are already prepared at the factory.

5.1. Field balancing reduces housing vibrations

The following example shows an irregular induced draft fan in which the vibration level was reduced considerably by field balancing. To document the improvement of the running behavior, a spectrum was measured before ('as found') and after ('as left') each balancing process. In horizontal machines it is also recommended to record the vibration vector in a second control level.

5.2. Field balancing reduces shaft vibration

In larger journal bearing machines, shaft vibrations are an indicator for the machine running performance. Plant manufacturers therefore must achieve corresponding shaft vibrations in accordance with standards, such as the following example of a feed water pump.

A measuring device determined excessive shaft vibrations for this machine type. The required vibration level was achieved only after precise balancing (Tab. 2). Both the housing vibrations and the shaft vibrations measured by the measuring device were taken into account.



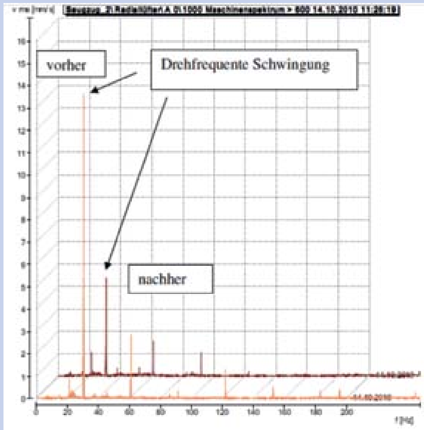

Fig. 6: Induced draft, measurement locations on the bearings and FFT spectra before and after balancing


Fig. 7: Measuring device for shaft vibrations; special water pump and mounted balancing weights

		AS bearing (Motor DE)		BS bearing (Motor NDE)		Exciter (Exciter)	
RPM	Measurement	1	2	1	2	1	2
4330	Shaft vibration	75 µm	100 µm	50 µm	65 µm	75 µm	80 µm
	Housing vibration (horizontal)	3.8 mm/s		2.9 mm/s		2.5 mm/s	
		AS bearing (Motor DE)		BS bearing (Motor NDE)		Exciter (Exciter)	
RPM	Measurement	1	2	1	2	1	2
4300	Shaft vibration	50 µm	60 µm	25 µm	20 µm	45 µm	45 µm
	Housing vibration (horizontal)	2.2 mm/s		0.8 mm/s		1.6 mm/s	

Tab. 2: Shaft vibrations and vibration velocities before and after balancing

5.3. Field balancing reduces excitation due to natural frequencies

Severe resonance excitations were detected on a coal conveyor belt; they spread throughout the entire belt drive so that continuous operation was not permissible. Based on measuring technology analyses it was determined that the rotational frequency on the motor side was the dominating exciter (Fig. 8 and Fig 9). Through fine balancing on the motor-side coupling flange, vibrations both on the motor side and on the gearbox side were reduced so much that the natural frequency no longer had an amplifying effect. The plant was able to commence continuous operation.

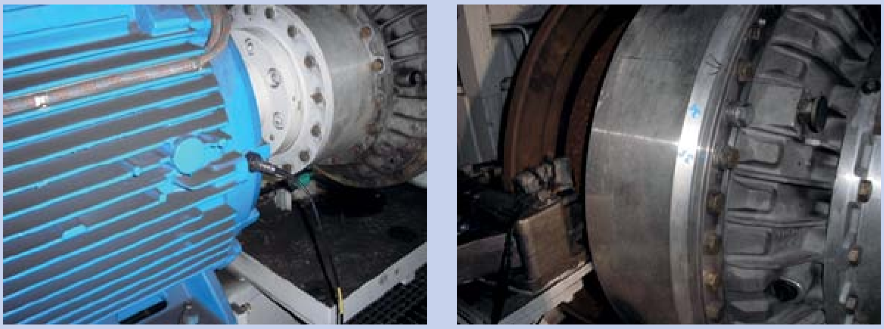

Fig. 8: Conveyor drive motor with accelerometer; hydraulic clutch with washers as balancing weights

6. Reducing vibrations on vertical machines with field balancing

As a result of the lack of gravitational force in vertical machines, the rotational frequency housing vibration orbit and/or the rotational frequency shaft vibration orbit should always be measured and analyzed in the first step. Only then can directional displacements and vibrations be reliably taken into account and the balancing process can be conducted as with the horizontal rotors.

6.1. Field balancing reduces housing vibrations

The balancing process on a cooling tower fan is illustrated in Figure 10. The very high vibrations were reduced significantly by selective mounting of the balancing weights. It can be seen in the frequency spectra of the vibration velocities that the natural frequency excitations in the gearbox also were reduced significantly. The balancing process itself was completed after three runs in this example.

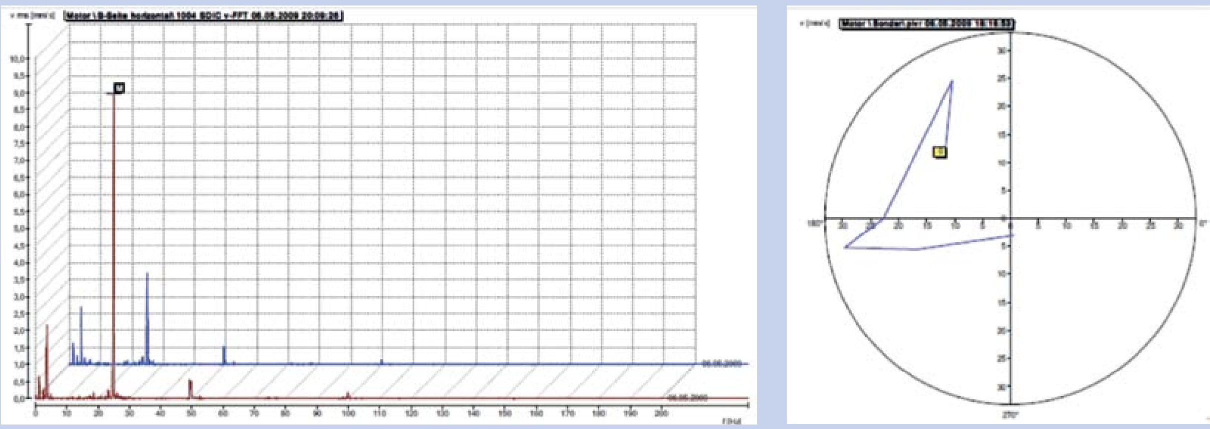

Fig. 9: Frequency spectra before and after balancing and balancing diagram

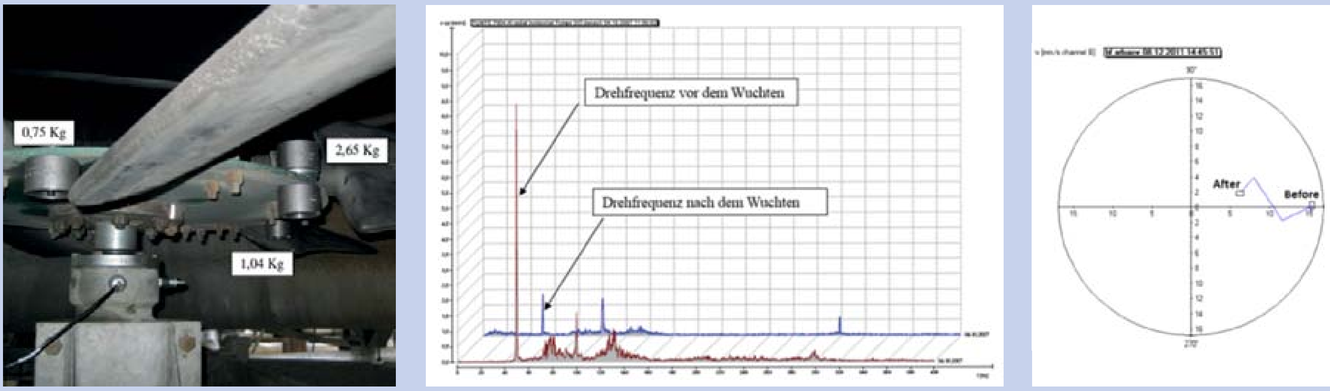

Fig. 10: Cooling tower fan with balancing weights and measurement results

6.2. Field balancing reduces shaft movements

In the next example a mixer shaft was able to be balanced only after recording the shaft motion and on the basis of the rotational frequency shaft orbit. Beforehand, the structure-borne sound paths up to the accelerometers were too far and the amplitudes were too low. It turned out to be useful to use the smax values of the rotational frequency shaft orbits during balancing (/3/).

6.3. Field balancing reduces excitation due to natural frequencies

The client required that two new high power motors remain in the green range in accordance with ISO 10816-3 throughout the entire operating range. However, this proved to be difficult during commissioning. The client requested that the manufacturer ensure ISO-compliant vibrations throughout the entire operating range. Vibration specialists from PRÜFTECHNIK were commissioned with this task. Mobile measuring quickly showed that two adjacent natural frequencies were mutually affecting each other. Although the motors were of identical design the fundamental natural frequency in motor 1 was above the bending natural frequency and in motor 2 it was below the bending natural frequency. Of course, this circumstance also affected the balancing process. While it was possible to achieve ISO-compliant vibration conditions in motor 1 by mounting additional weights on the A side, it was necessary to mount additional weights also on the B side in motor 2 to take away excitation energy from both natural frequencies. Figures 13 and 14 show the results before and after balancing in each case. The machines were then able to be used in continuous operation.

Fig. 11: Balancing of a mixer on the basis of orbit measurements

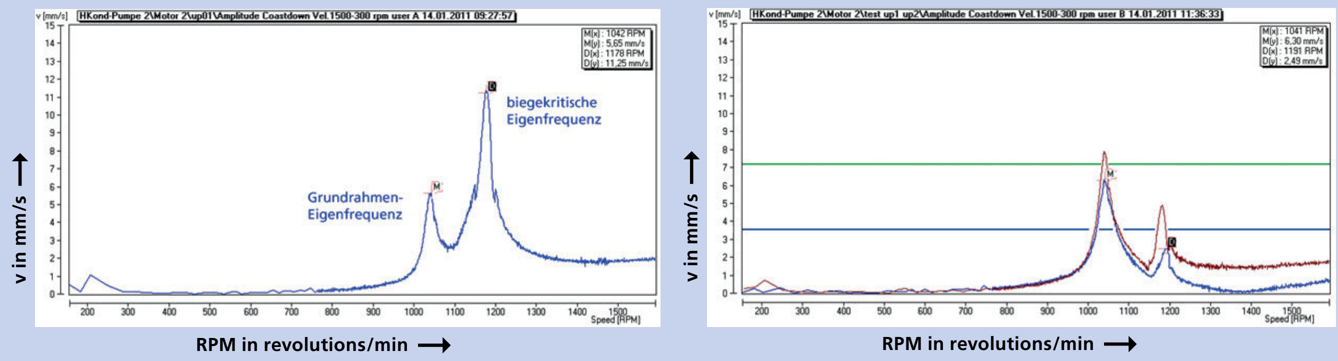

Fig. 13: Coast-down curves of a double resonating vertical motor before and after field balancing

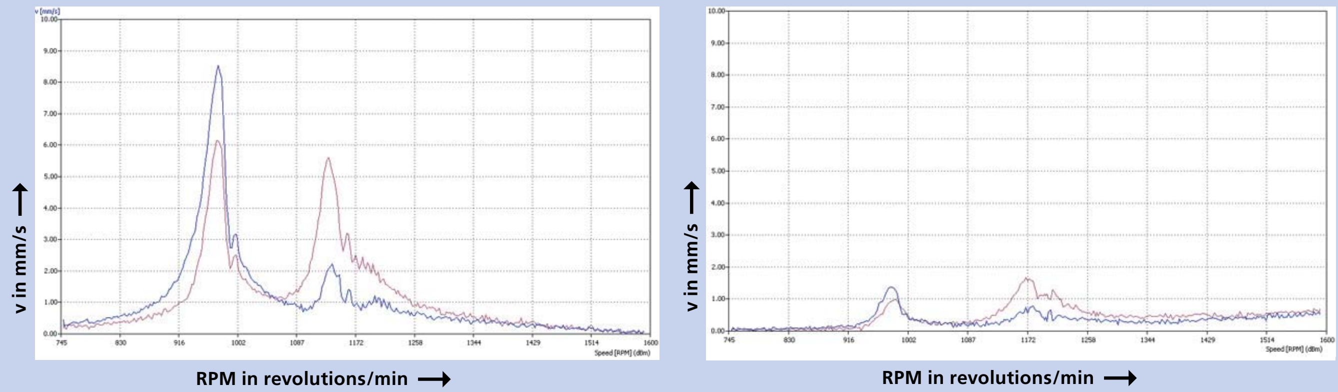

Fig. 14: Coast-down curves of an adjacent vertical motor, which required fine balancing

7. Field balancing requires certified balancing technicians

Field balancing can reduce vibrations so much that the effect of other interfering factors on the vibrations is also reduced. Therefore, caution and discipline are needed. Every balancing process must be documented completely and unambiguously, to rule out other errors as the cause for the increased vibration level. Effects that can be mistaken for imbalance are, for example, improper eccentricity, incorrect axis position, inadmissible rotor distortion or misalignment. The examples above show that balancing is not always an easy process and requires extensive experience and well-founded background knowledge. It is only a matter of time until balancing technicians will have to be certified, just as employees in non-destructive material testing.

8. Outlook

Balancing can reduce vibrations and take away excitation energy from interfering natural frequencies. In the end, such measures increase the reliability of the plants and reduce premature wear in the roller bearings and machine components.

[1] DIN ISO 1940-1, Version 2004:
Mechanical vibrations
Balance quality requirements for rotors in a constant (rigid) state,
Part 1: Specification and verification of balance tolerances

[2] www.telediagnose.com,
Volume 12 Wind turbines

[3] www.telediagnose.com,
Volume 13 Turbo machines

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