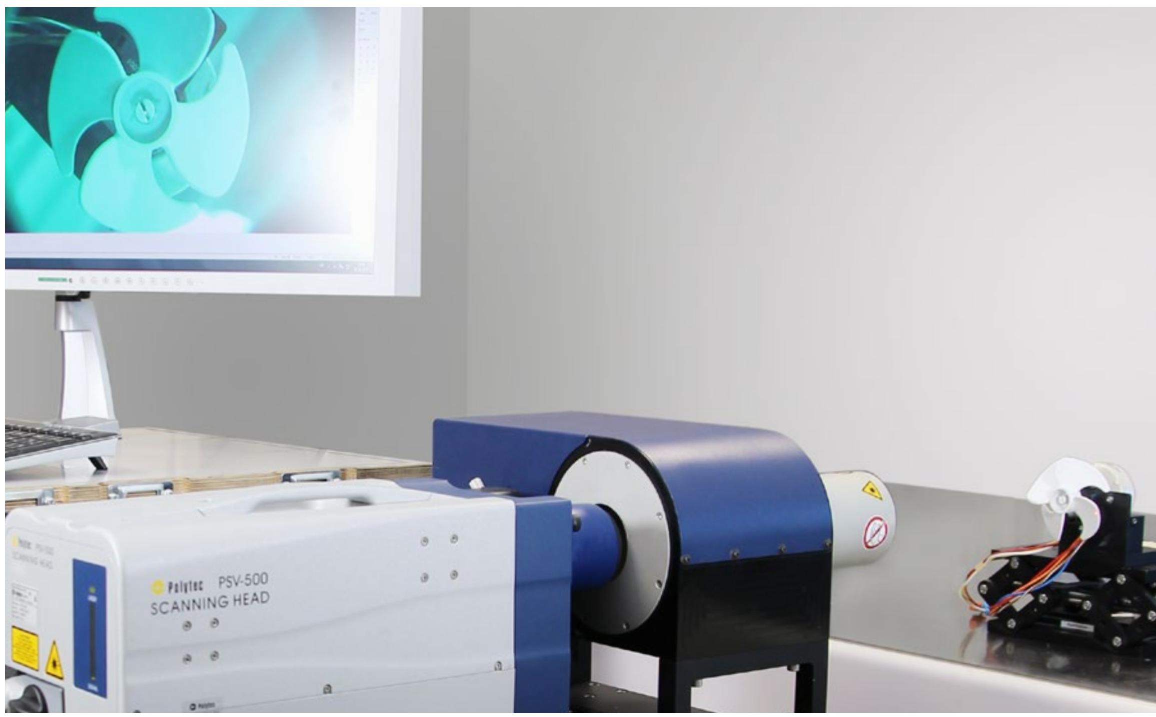
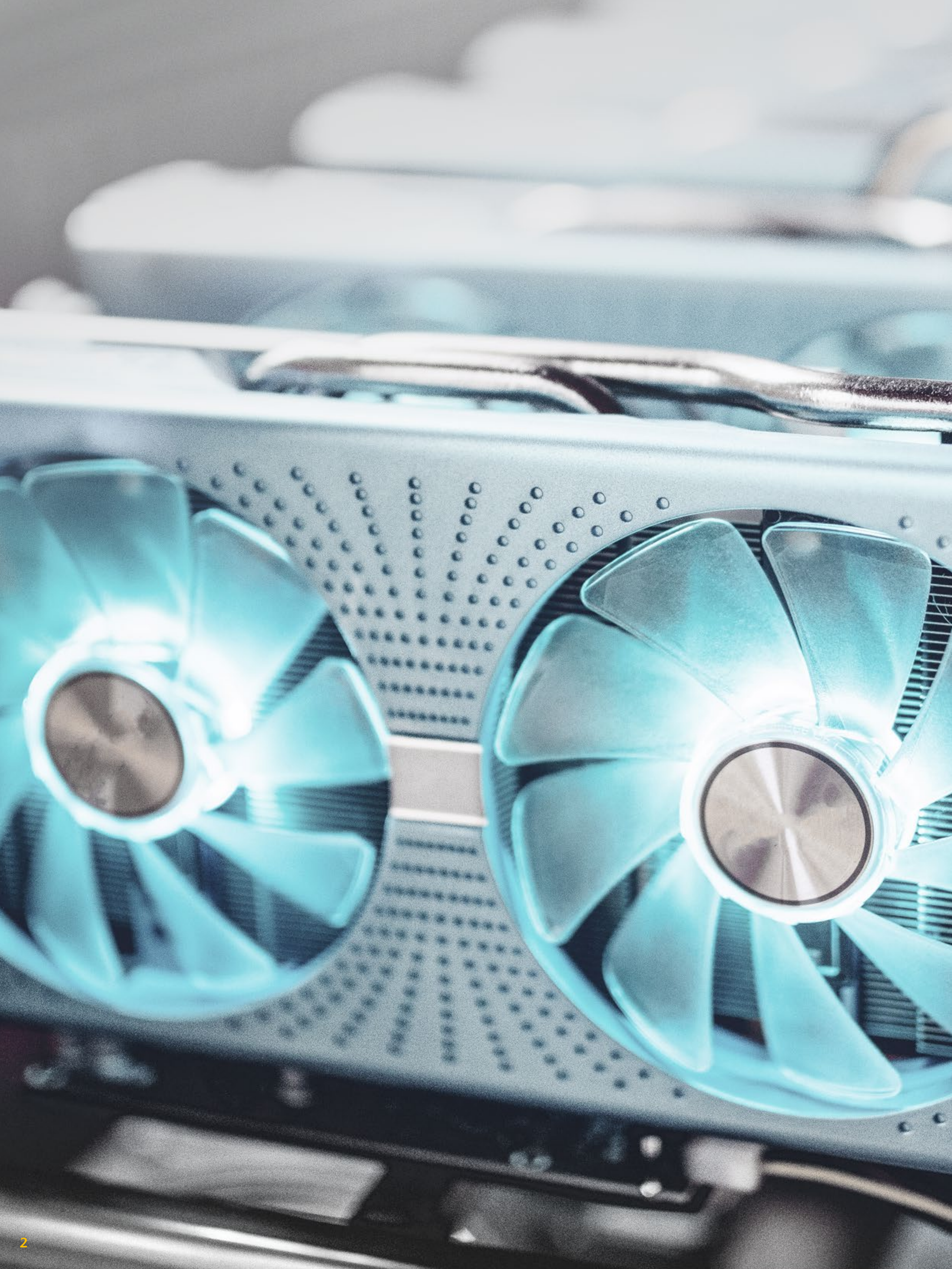


Optical Derotator

Full-field vibration testing on rotating objects

Application note



Non-contact analysis of operational deflection shapes on rotating components using the PSV-A-440 Optical Derotator

Scanning Vibrometers are used extensively to accurately measure deflection shapes of static structures by using a laser beam to scan a previously defined grid of points. The structural vibration response is then acquired point-by-point with a heterodyne interferometer. Measurements of deflection shapes on rotating objects were not possible until now. Using the new Optical Derotator, rotating structures are made to look stationary, allowing a Scanning Laser Vibrometer to measure deflection shapes and run-ups. This measurement data can then be used as input data for experimental modal analysis.

Predicting a structure’s vibration characteristics using today‘s simulation methods is still restricted by limited knowledge of the material parameters of the real object. By using an experimental modal test, the calculated and measured deflection shapes, Eigen frequencies and modal damping can be compared and the parameters used in the model corrected.

The modal parameters of rotating parts change through stiffening so that the Eigen frequencies measured while at a standstill generally do not correspond to those that occur under operating conditions. In addition, the actual excitation during operation is difficult to predict. Thus, determining the accurate operating deflection shapes and Eigen frequencies on rotating parts has been very difficult without considerable effort and nearly impossible for segmented rotating parts.

Operating principle

The Optical Derotator allows you to make measurements using a Scanning Vibrometer to directly determine the deflection shapes of rotating parts, such as cooling fans for consumer products, turbines, impellers or tires, under real excitation conditions at rotational speeds of up to 24,000 RPM. The effects of stiffening can be determined from the observed changes in deflection shapes, resonant frequencies and amplitude response.

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Components of the PSV-A-440 Optical Derotator

- Rotation unit
- Controller
- Base frame with height, angle and lateral position correction, enabling the alignment of sample rotation axis with the derotator axis
- Sensor technology

To do this, the laser beam is made to follow the rotating object with a precision controlled optical rotation unit. Flexible control for fixed rotational speeds or run-ups which is achieved by coupling the derotator to an encoder signal that comes from the rotating test structure. Synchronized and locked to the encoder signal, the Optical Derotator compensates for the rotation and makes the rotating test structure appear stationary when viewed through the prism. The Scanning Vibrometer measurement can proceed normally with the definition of the measurement grid and subsequent scanning process. A single point laser vibrometer, whose beam also runs through the derotator, serves as a phase reference to show the deflection shape. If the Scanning Vibrometer is used in Single Point mode, then run-up and run-down trials can be carried out for an order analysis.

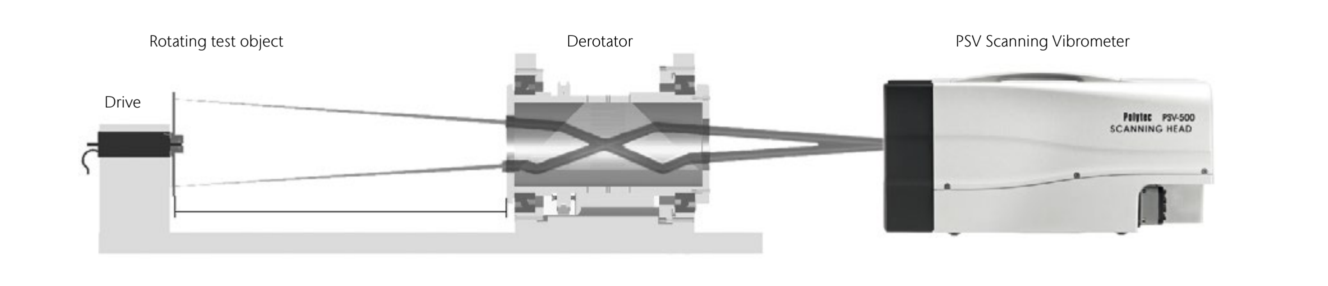
The main element of the PSV-A-440 Optical Derotator is the rotation unit. It contains a Dove prism which rotates at half the speed of the object under investigation. The operating principle of the optics is shown in Figure 2. The rotation unit is connected electronically via a controller to the object under investigation.

The rotational speed of the object is provided by an encoder. To attain complete optical derotation, the rotation axis of the measurement object and that of the rotation unit must match. For this purpose, the rotation unit is adjustable in four degrees of freedom using the scanning head and the reference laser as alignment points.

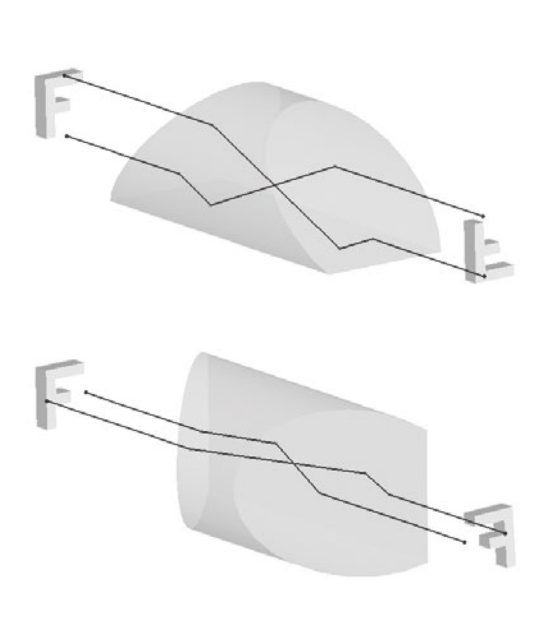
Comparison of standard measurement with derotational measurement

In order to compare the results of a measurement with and without the derotator, an object with a smooth, flat, featureless surface must be selected. Segmented objects, such as cooling fans and turbines, represent the main field of application for the derotator and cannot be measured without it. A disc-shaped object was selected for the comparision. In this case, it is a CD attached to a motor with a rotary encoder (500 counts/rotation).

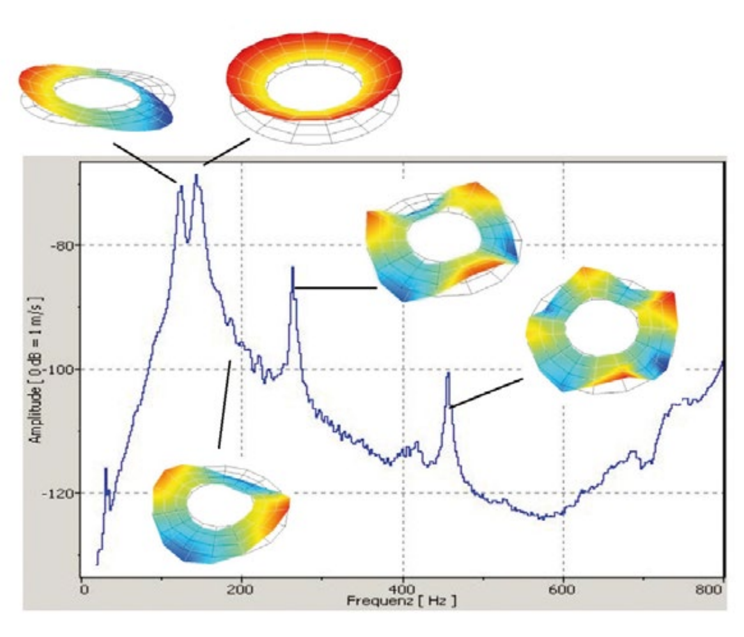
1
Typical set-up of the PSV-A-440 Optical Derotator



2
left: Operating principle of a Dove prism: when rotated by 90° the image is rotated by 180°



3
right: Spectrum and deflection shapes of CD at rest

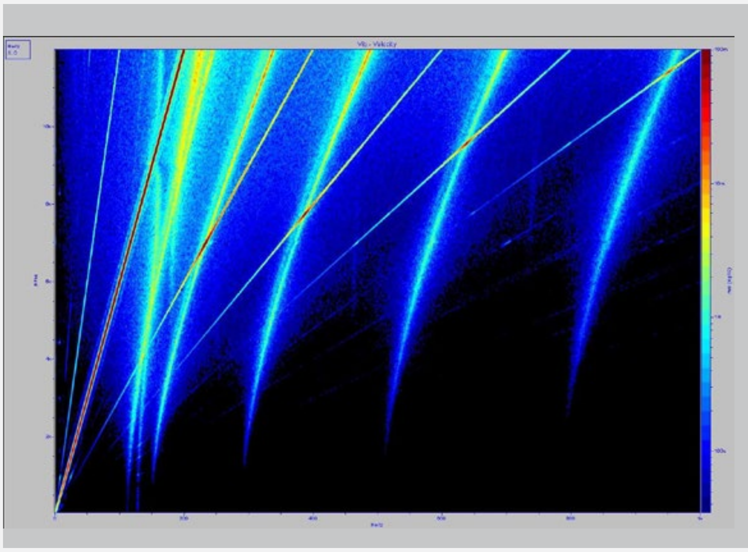


❶ CD at a standstill noise excitation
As a basis for the following investigations, the CD is measured at rest so that its natural deflection shapes and Eigen frequencies are captured in this state. Broadband acoustic excitation from a loudspeaker was used. The results are shown in figure 3. In addition to the resulting average spectrum across the scan points, the measured deflection shapes belonging to the resonances are also shown.

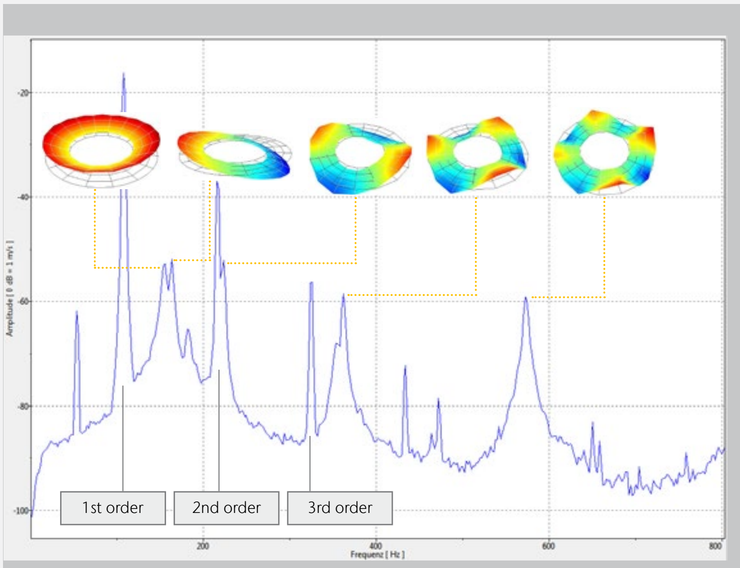
❷ Run-up trial with derotator
Next, a run-up trial using the derotator is carried out. The laser beam is moved with the rotating object and remains on a fixed point on the surface, which allows the vibration to be measured in the same way as on a non-moving part. The Campbell diagram (Figure 4) shows both the orders (straight lines that intersect at the origin), i.e. multiples of the rotational frequency which lead to forced vibrations through a strong excitation, and the structural resonances. The structural resonances are not vertical lines, but bend as the rotational speed increases to higher frequencies. This bending behavior comes from a stiffening of the relatively soft polycarbonate material due to increasing centrifugal forces. This result shows very clearly the advantage of using the derotator - both the amplitude and the stiffening effect are captured under operating conditions.

❸ Deflection shapes under load/rotation
A scan using the derotator was carried out at a fixed rotational speed of 6500 RPM, to reveal the operating deflection shapes corresponding to the shifted resonant frequencies. As expected, this results in the same deflection shapes as seen with with loudspeaker excitation at rest; however, the shifted frequencies of the deflection shapes are visible in the spectrum at 6500 RPM (Figure 5).

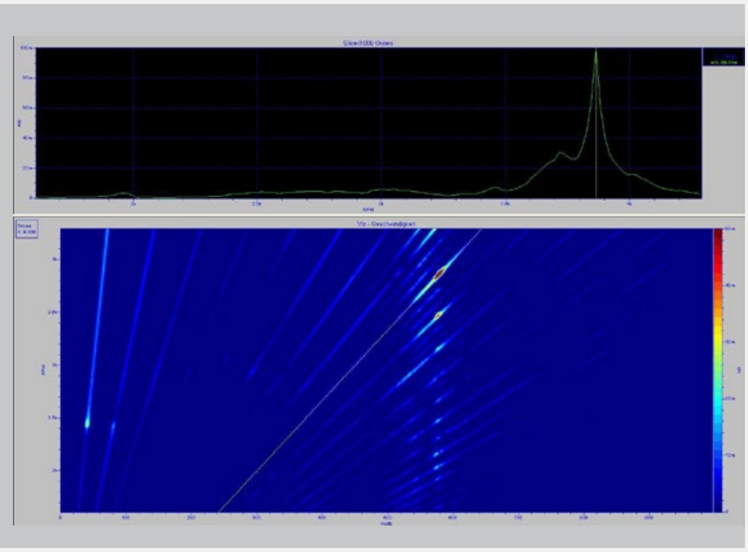
A resonance line appears at the frequency of the first order from left to right in the spectrum (after one line at half the RPM). This corresponds to a forced vibration on the basis of the strong excitation by the 1st order. The next one to appear is the rotationally symmetrical deflection shape which, with excitation at rest, was at a higher frequency than the deflection shape with a single maximum. This also becomes apparent in the Campbell diagram: the resonance with a single maximum changes its stiffness more that the rotation symmetrical one, so that both lines cross each other at approx. 5000 RPM.



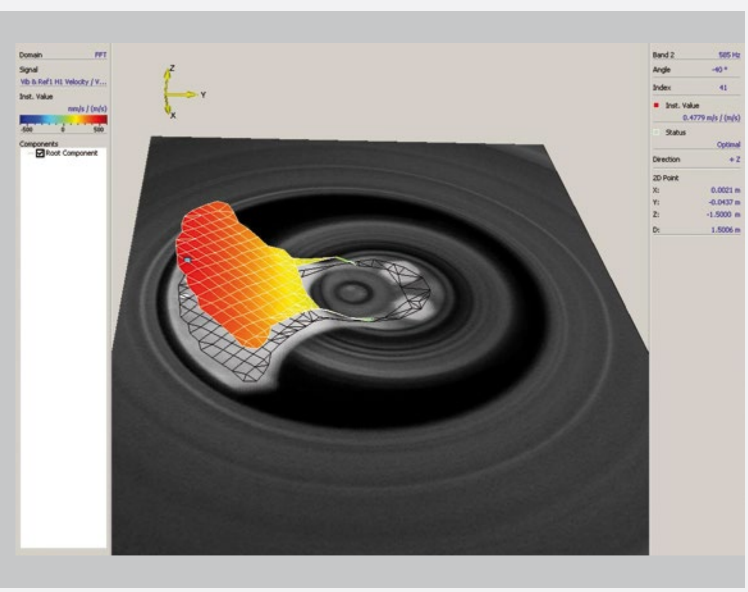
4
Run-up with Derotator



5
Deflection shape and spectrum with derotator at a fixed rotational speed, 6500 RPM



6
Campbell diagram of the measurements made on an impeller.



7
Corresponding deflection shape of the counter-weight

At higher rotational speeds therefore, the rotation symmetrical resonance occurs at lower frequencies. This is confirmed by the scan which of course shows the deflection shape directly. This makes the interpretation of the data much easier and clearer. Towards higher frequencies the next feature that appears is the deflection shape with a single maximum, and then the forced vibration caused by the 2nd order, directly above the resonance with two maxima on one circumference. Its amplitude is therefore also quite high at this rotational speed because a strong excitation (near the 2nd order) meets the structural resonance (at this rotational speed, consider the change in stiffness). This can be difficult to predict in simulations. The measurement using a derotator provides a clear and quantitatively correct result for amplitude, deflection shape and resonant frequencies.

Next, the resonance with three maxima appears, then the vibration forced by the 3rd order and finally, at about 560 Hz, the resonance with four maxima. This last resonance was found to be about 460 Hz for a structure at rest and using loudspeaker excitation. A significant advantage of scanning vibrometry is that the shifted resonance points are easy to allocate on the basis of the deflection shapes.

Example of an impeller

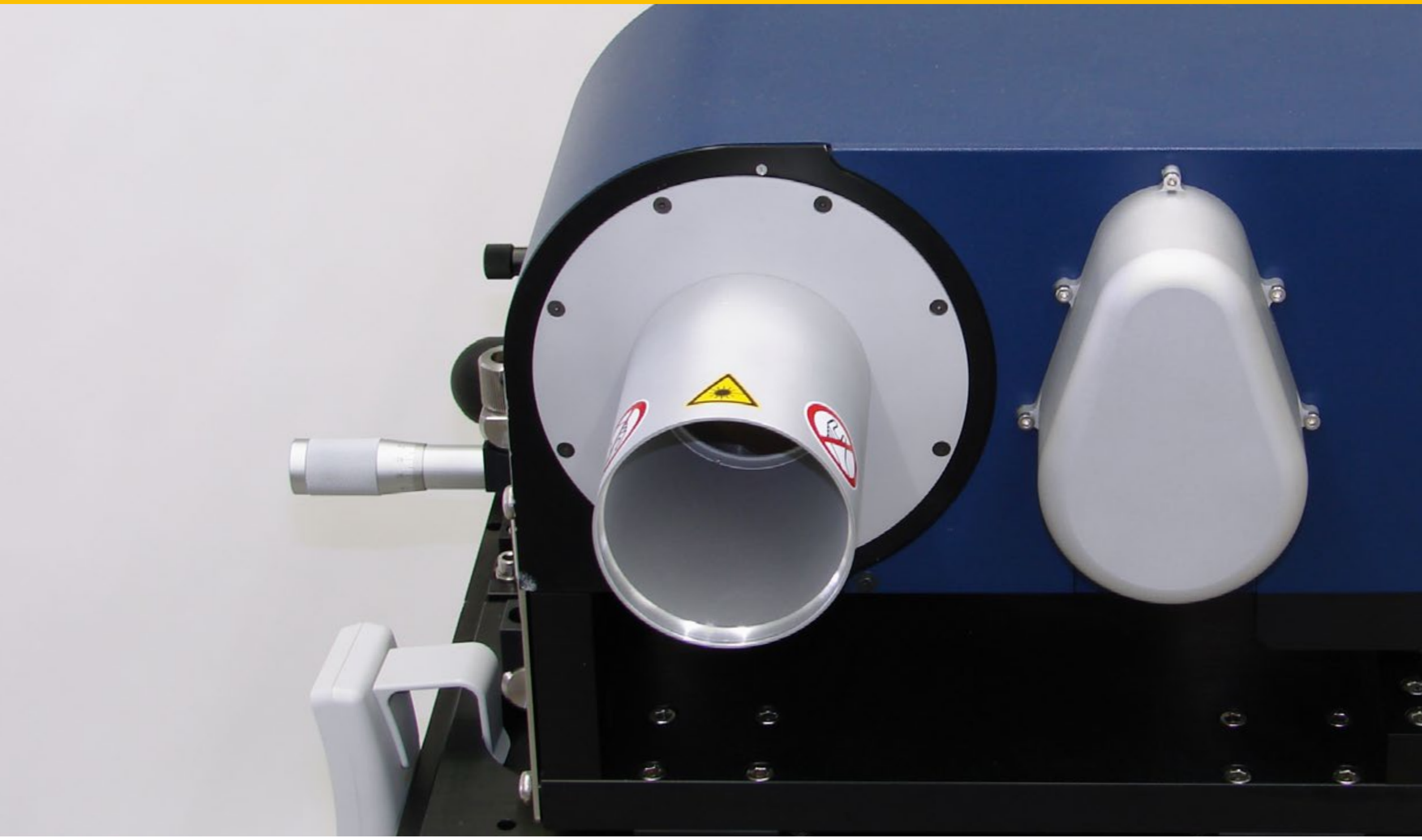
On a counterweight of an impeller, small cracks are appearing at the suspension point of the weight after many hours of operation. To investigate this cracking, run-up measurements are made with the Optical Derotator. To do this, a point is targeted with the scanning vibrometer and then the rotational speed of the impeller is increased up to the maximum test speed. While doing so, the derotator holds the position of the laser beam on the same point of the counterweight. The rotational speed is captured in parallel with the temporal data and evaluated with the program VSI Rotate (by Vold Solutions) which can directly read in the binary measurement data from the scanning vibrometer. In the Campbell diagram, it appears that among other things the 9th order excites an Eigen frequency.

To ascertain the precise effect of the resonance, a surface measurement with the Scanning Vibrometer is carried out. To do this, the rotational speed of the impeller is set to the one that excited the highest amplitude at the 9th order during the run-up.

The operating deflection shape at the previously ascertained resonance is a natural bending mode of the counterweight. As is shown by a subsequent measurement at rest, this Eigen mode is clearly there. Given the low level of bending stiffness at the joint, there are high deflections, thus leading to premature failure of the component.

Summary

With the combination of non-contact scanning vibrometry and the Optical Derotator, it is possible to determine the cause of faults which would not have been visible with a static measurement. The measurement is made with zero mass loading of the object under investigation and under actual operating conditions so that suitable input data is available for checking the simulation. All of this is achieved without the drawbacks of slip rings or telemetry. Shifted resonances at higher rotational speeds, especially with components made of plastic, are easy to recognize and the excited deflection shapes can be compared with those from the modal test and can be quantified.



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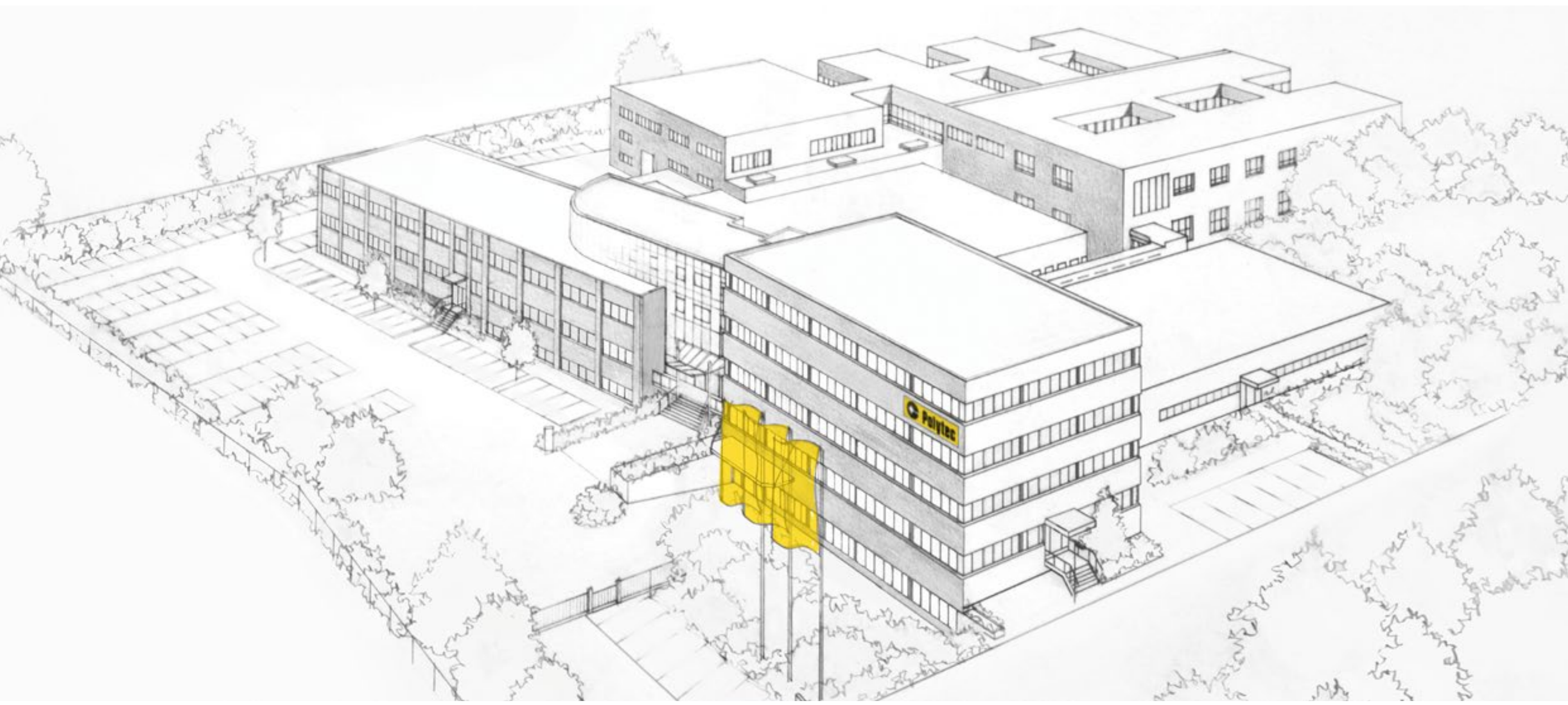

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