Under water measurements with laser vibrometers

Influence of surrounding water on the vibration behavior by means of 3D scanning vibrometry

Application note

For some applications, vibration measurements need to be performed under water. Some prominent examples are ultrasonic medical transducers for diagnostic purposes or sonar sensors for defense applications. Another group of measurements to be performed under water is scaled model characterization for e.g. marine or submarine development. This application note reports on the specific changes in the vibrational characteristics when a vibrating specimen is immersed into water to enable subsequent simulation model validation.

As a model test object, a simple metallic beam is chosen. Vibrations are excited by a small, lightweight Piezo disk, glued to the sample. The complete vibrational behavior of the sample is measured in a non-contact way by a 3D laser Doppler scanning vibrometer PSV-500-3D. The measurement is first performed in air, then the sample is immersed and measurements are repeated with exactly the same setup and excitation. In this way, changes induced by the immersion can clearly be observed.

Experimental setup

A Polytec PSV-500-3D Scanning Vibrometer is used to characterize the structural dynamics of the device under test (DUT) in 3D.

Polytec offers two models of the actual interferometer to cope with different application field: The first model of the scanning head, the Xtra series, is equipped with an infrared laser source. Its wavelength of 1,550 nm is chosen because it allows 10 mW output power and thus an enhanced signal-to-noise ratio for critical measurements, e.g. at larger stand-off distances or low reflective targets. As the laser light is absorbed in water very quickly and does not reach the retina of the eye, it allows a safe operation in laser class 1. The downside is obviously that measurements in water are impossible.

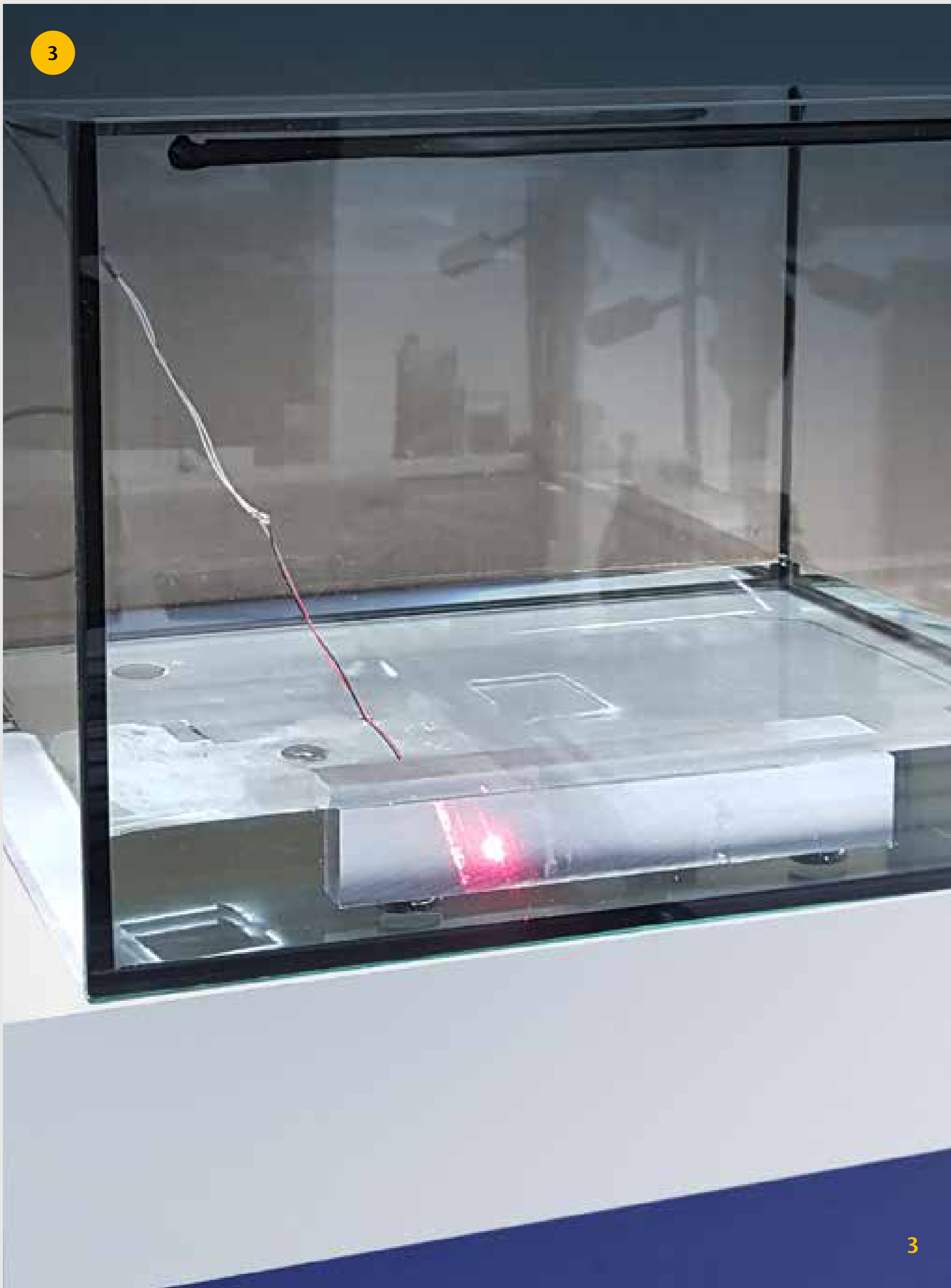
The second model is equipped with a 633 nm red Helium-Neon laser source. The output power at this wavelength has to be limited to 1 mW to stay in a safe laser class 2. At 633 nm there is a very low attenuation of the laser power in water, which makes it the perfect tool for under water measurements.

For 3D measurements three scanning heads are incident on the DUT with different angles. A common software control guarantees an overlay of the three laser focus points on the DUT allowing to extract the X,Y and Z vibration vector in all measurement points. Figure 1 shows the setup of a 3D scanning vibrometer.

Figure 1:
Polytec PSV-500-3D
Scanning Vibrometer

The DUT is a simple aluminum beam of 150 mm length and 12 x 12 mm cross section (Figure 1). The vibration excitation is done via a small Piezo disk (PI Ceramicy, PRYY series), of 10 mm diameter and a thickness of only 0.2 mm. This disk is glued to the surface by simple instant glue. This excitation also works under water, if the electrical conductivity is not too high and if the voltages are moderate. To be on the safe side a thin layer of electrically insulating conventional household glue was applied and the voltage was limited to 40 V.

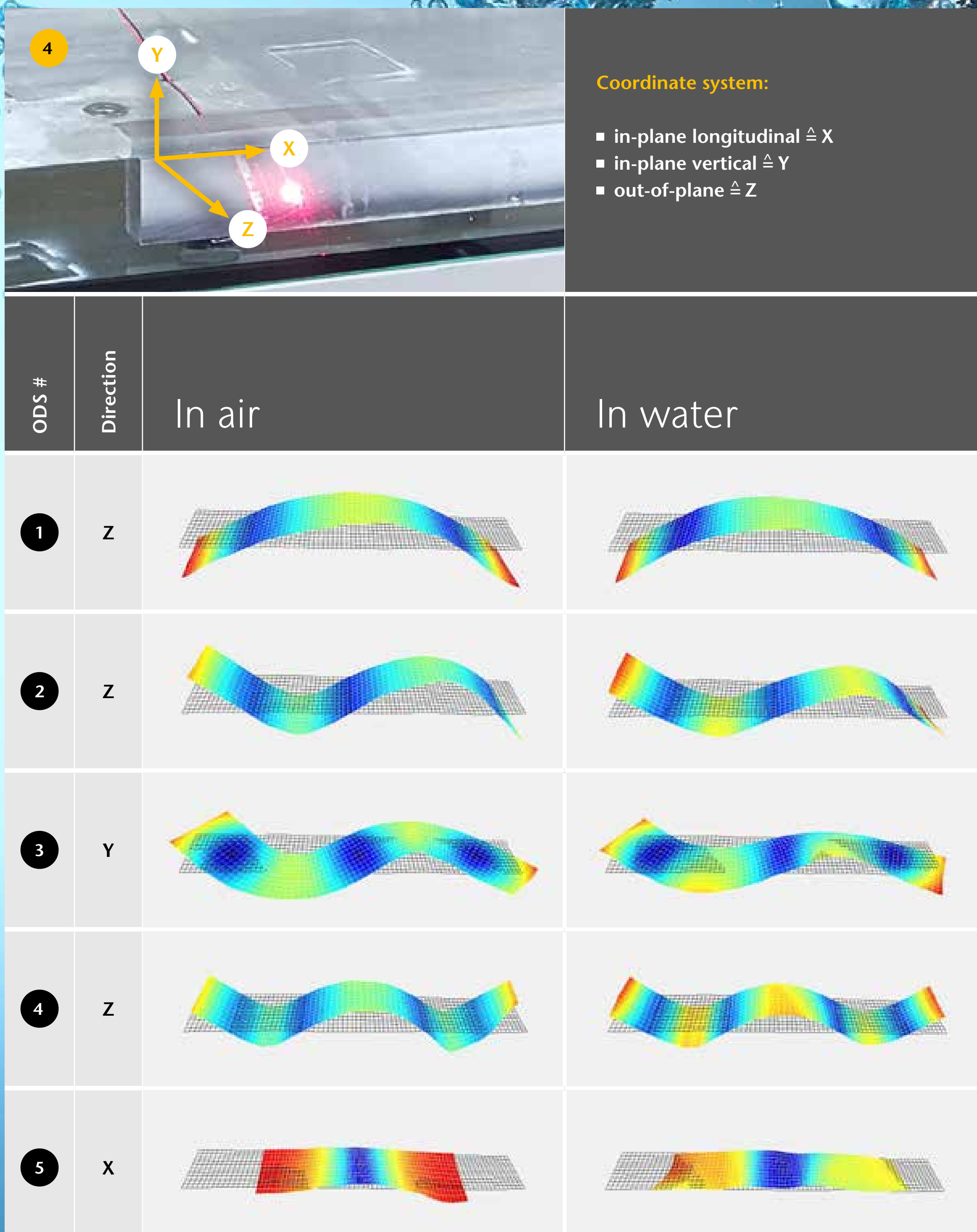
The DUT is first placed into an empty glass basin supported on soft rubber dampers. The measurement with the 3D Scanning Vibrometer is performed through the glass of the sidewall of the basin. For the measurement under water, the basin is then simply filled with distilled water. Therefore the entire setup stays completely unchanged, except for the presence of the water. Figure 2 shows the complete setup with filled water basin and the incident red laser beams.



Experimental results

Figure 4 shows selected resonant deflection shapes.

On the left measurements in air are shown, on the right the equivalent deflection shape in water. It is clearly visible that the same shapes appear but at different frequencies.



A closer look at the data shows the differences due to the presence of the surrounding water. The following Figures 5 and 6 show the average spectra of both measurements, left in air, right in water.

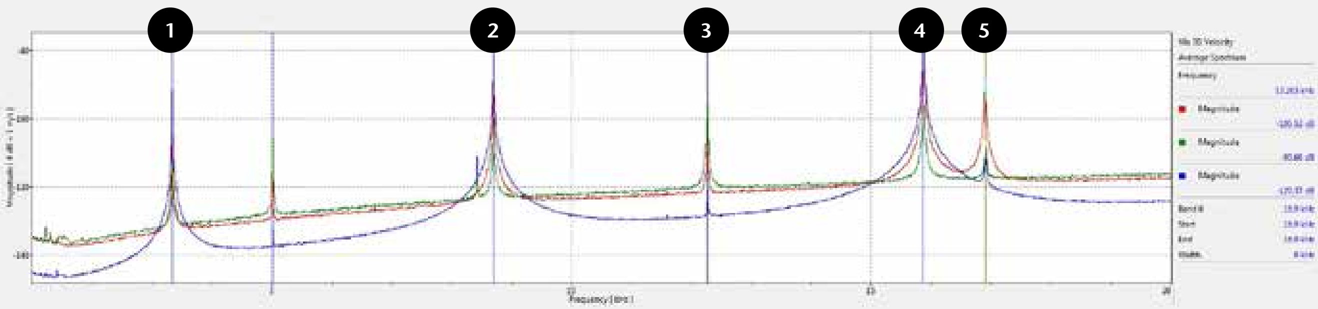
The changes that occur when immersing the sample into water are:

- A downshift of the resonance frequency peaks
- A strong increase in damping, visible as an important broadening of the peaks.

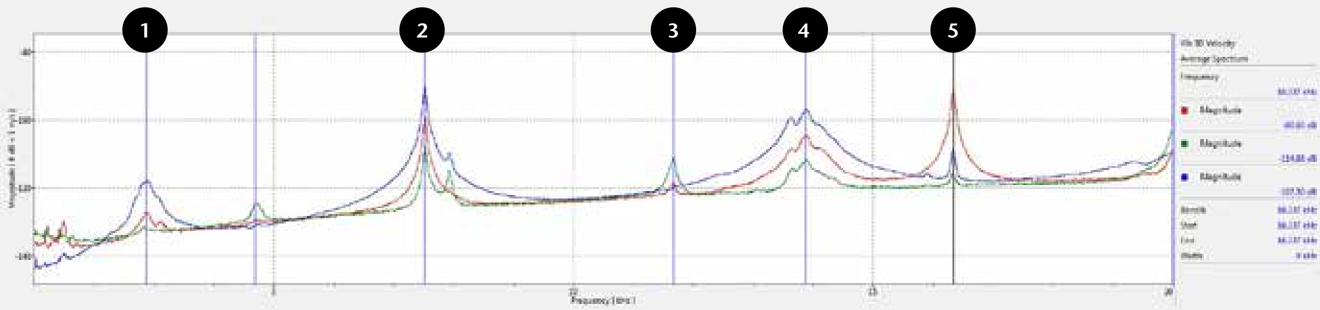
Color coding

red ≙ X | green ≙ Y | blue ≙ Z

In air



In water



Therefore, while the resonance deflection shapes remain largely unchanged, their resonance frequencies are lower in water than in air.

The damping is considerably higher in water, which seems, of course, reasonable. It is interesting to note that the longitudinal resonance deflection shape (lowest line in Figure 4) has the smallest downshift in frequency and also the smallest increase in damping. This can probably be explained by the fact that only the small front and back surfaces of the rod really have to apply pressure to the surrounding water. At all the transverse resonances, the entire (long) surface of the rod has to move water and a larger effect is therefore produced.

For completeness sake, it should be noted that the absolute values of the out-of-plane amplitudes should be divided by the index of refraction of water (about 1.3), while the in-plane components remain unchanged. (This is an approximation for small angles of incidence.) This correction has a small influence on the absolute values of the amplitudes, its influence on the general form of the deflection shapes can be neglected in our case.

Correction of the index of refraction

The measurements shown above represent raw values. If absolute magnitudes are the goal of the measurement the refractive index of water needs to be taken into account when measuring into water.

The calculation is rather simple and for small angles it needs to be applied for the out-of-plane component only:

If …

v_{zw}: **out-of-plane velocity in water**

v_{za}: **out-of-plane velocity in air**

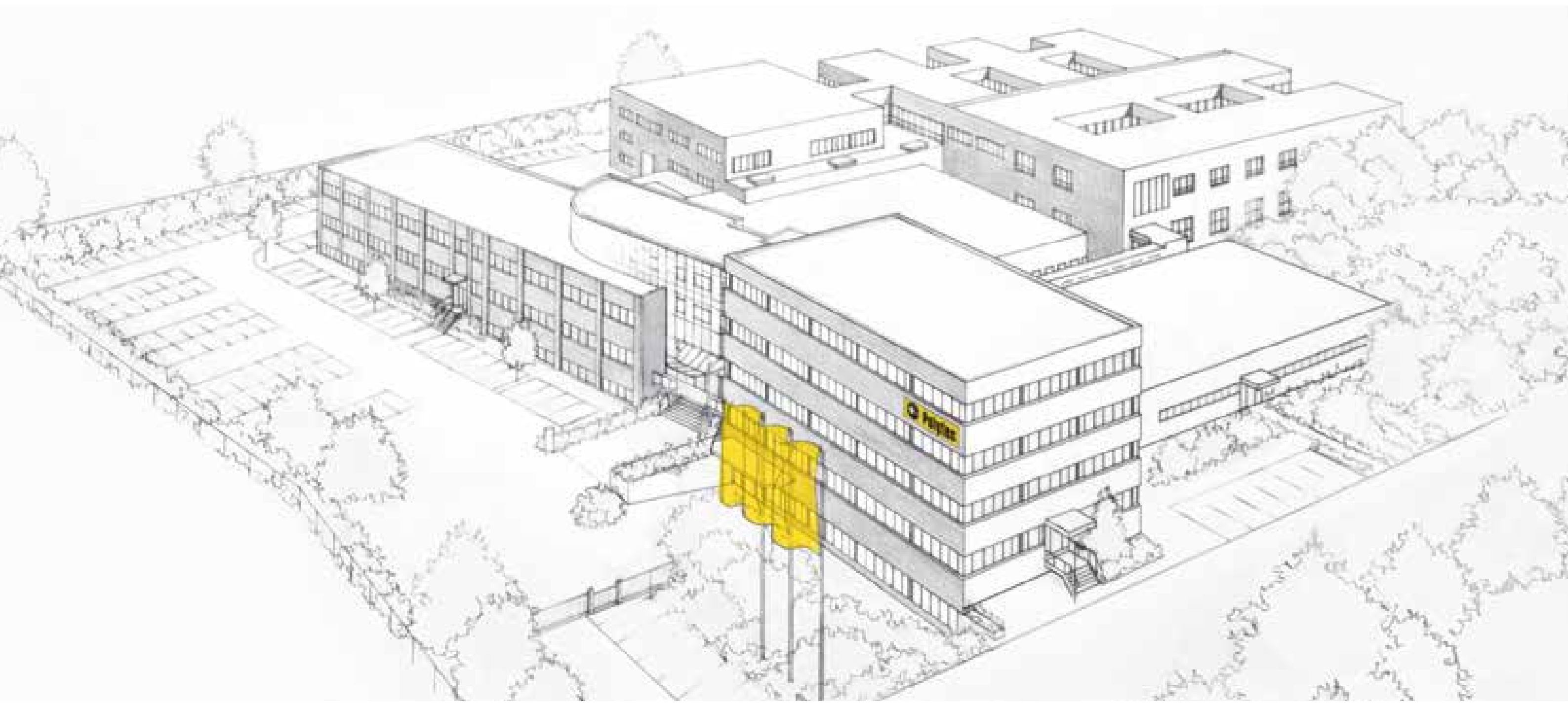
n_w: **index of refraction in water** ($n_w = 1.33$ @ 20° C)

$v_{zw} = v_{za} / n_w$

Conclusion

Exploiting the properties of the HeNe source of the PSV-500-3D Scanning Vibrometer it was demonstrated that measurements under water are feasible.

The set-up of the measurement guaranteed that only the influence of the surrounding water was measured as an influencing parameter of the structural dynamics of an aluminum beam. When comparing measurement results in air and in water, the influence of the surrounding water becomes evident. While the resonance deflection shapes are the same, their frequencies shift downwards lower values and their damping is strongly increased when the sample is immersed into water. The scanning vibrometer is an easy and efficient tool for vibration characterization under water.



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