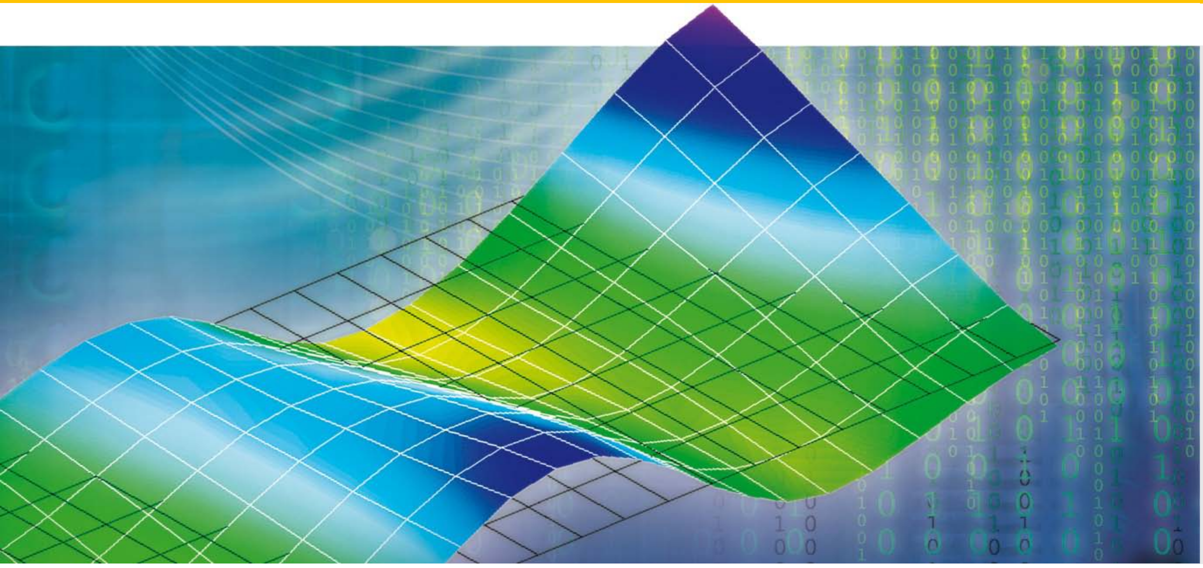
Application Note
VIB-G-19

Importance of Video Triangulation for the PSV-3D Scanning Vibrometer



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Introduction

Working principle of the 3-D scanning Laser Doppler Vibrometer

The PSV-3D acquires 3-D vibration data on a series of scan points on an object's surface. In order to get 3-D data, 3 laser beams emitted from 3 scan heads (top, left and right) having 3 different angles of incidence have to intersect on each measurement point. The backscattered light of each beam is Doppler-shifted due to the surface movement in beam direction. Therefore, each of the 3 beams is sensitive only to the vibration component along its axis. Using 3 beams with a known mathematical description allows the calculation of the x, y, z vibration components. The orientation of the coordinate system and the exact position of the heads therein is defined by a process named 3-D alignment, which is valid for one head configuration and one coordinate system.

Need for geometry measurements

One precondition for an exact calculation of these orthogonal vibration components is the intersection of the 3 beams on the designated measurement points on the object surface. This is only possible, when the exact coordinates of the measurement points are known. To this means, a geometry sensor is integrated into the 3-D scanning system, which measures the distance to one of the heads, usually the top head. This distance, together with the known position of the head (out of the 3-D alignment) and the angles of the scan mirror to meet this point, defines its coordinates unambiguously.

Problem

Precision of intersection of beams and of decomposition into x,y,z components of vibration

If the coordinates of the measurement point are not determined exactly, the beams do not intersect perfectly on the measurement spot. An error in the distance measurement therein leads to an intersection of the beams "in front of" or "behind" the surface. Furthermore, if the positions of the heads are not precisely determined, the 3 beams will not intersect, but will only approach each other within a certain radius on the measurement surface. This error is firstly due to imperfections in the 3-D alignment. A second effect that leads to non-intersecting beams after a certain period of time is the inevitable very small, but noticeable, drift of the beam positions over time.

The precision of the geometry measurement depends on the backscatter properties of the surface and is typically within 1-2 mm. The precision of the head position depends

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on the quality of the 3-D alignment that has been performed and is typically in the 1 mm range. Beam drift over time depends on working distance and varies from one measurement head to the other and from one set of working conditions - especially changes in temperature - to the other. It can be found typically in the 1-3 mm range.

All these effects together lead to a radius of intersection of typically 1-4 mm. This precision is largely sufficient for measurements e.g. on car bodies or components which vibrate with frequencies up to a few kHz. The beam spread is smaller than the footprint of a standard triax accelerometer. For higher frequencies, by choosing a smaller working distance, improving the 3-D alignment process by using a precise reference object and optimising signal level for distance measurements, a precision of about 1-2 mm can be reached.

Spatial resolution and crosstalk out-of plane to in-plane

It is obvious that for devices and vibration frequencies with spatial wavelengths below the cm range, the small position inaccuracy of the beams can lead to incorrect measurements results. Fig. 1 illustrates the situation.

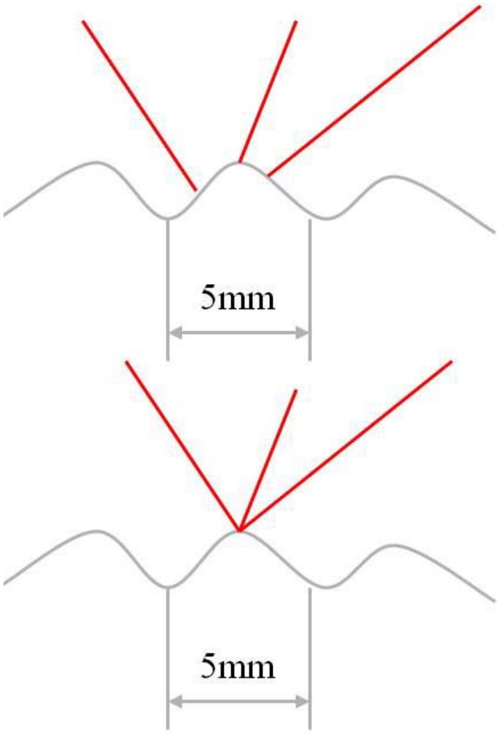

Fig. 1: beam intersection with standard 3-D coordinate measurement as compared to ideal case.

As an example, a vibration with a spatial wavelength of about 5 mm is shown, a typical value for steel at 1 MHz. With a standard geometry measurement, one beam might measure on a vibration maximum; the second and third one might measure at a position with lower amplitude. Then, the decomposition into x,y,z components is obviously erroneous. The maximum out-of-plane amplitudes are reduced, but the errors in the in-plane vibration components are even bigger. If the out-of plane component of the vibration is a lot stronger than the in-plane components, the in-plane components can appear by far larger than they really are. This effect is hereafter called crosstalk from out-of-plane to in-plane.

Therefore, especially three situations need special care:

- measurements of vibrations with small spatial wavelengths (< cm range);
- dynamic strain measurements;
- measurements on small objects, where it must be assured that all three lasers hit the object.

A strain measurement with the PSV 3D consists of the following main steps:

- The coordinates of the measurement points have to be defined precisely, as the distances between the points are calculated to define the base length L_o.
- The 3-D vibration vector for each point is measured with the PSV-3D.
- Local in-plane components are calculated.
- Out of the difference δ of the local in-plane components of neighboring points and their distance L_o, strain is calculated (Fig. 2).

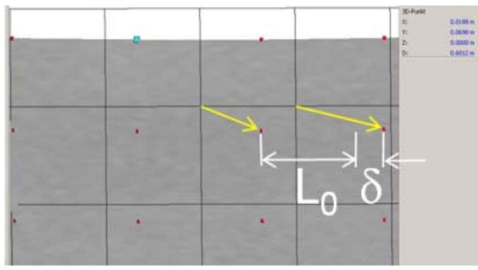

Fig. 2: Calculation of strain.

Quite often, the main vibration direction is out-of plane, e.g. a bending or torsional vibration of a turbine blade.

Strain is calculated out of local in-plane components. Therefore, a crosstalk of the strong out-of plane to the weak in-plane components is challenging for strain measurements.

Solution: VideoTriangulation

A solution to this problem is a new feature called VideoTriangulation. The basic idea is to identify the positions of the 3 beams in the video image by image processing, and then apply a correction to the mirror angles until the beams match exactly. Out of the corrected scanning mirror angles and the existing 3-D alignment, the coordinates of the measurement spots can now be determined with a high precision. Hence the name of the method which indicates that the positions in the video image are matched and the geometry is then calculated via triangulation. The quality of the beam intersection is typically in the range of the beam diameter, below 100 µm.

For best results, VideoTriangulation needs an additional high resolution digital camera, Polytec A-CAZ-1000. The method also works with the built-in analog camera of the measurement heads, but the precision and reliability of the VideoTriangulation is inferior.

Using VideoTriangulation and the digital camera, the beams intersect with such a high precision that the three beams look as if they were one. This enables measurements which need a high spatial resolution. Furthermore, crosstalk between out-of plane and in-plane components is dramatically reduced, enabling reliable strain measurements and measurements of weak in-plane components on top of a strong out-of plane component.

VideoTriangulation can be performed with two automated modes: fast and standard. In the standard mode, the process is performed on each measurement point during the scan, immediately before the vibration measurement itself. In the fast mode, the process is done only on every 10th point and the determined correction vector is applied to the next 9 points. The fast mode assumes that the geometry perfectly matches the object, it is mainly designed for consecutive measurements on the same object. For applications with high demands for geometry precision, like strain measurements, the standard mode is recommended.

Last but not least, VideoTriangulation is done on each point immediately before the measurement; therefore beam drift processes are eliminated.

Examples:

Fig. 3 shows a high frequency measurement on a thin membrane of an ultrasonic device. Fig. 3a. has been measured without VideoTriangulation, Fig. 3b with VideoTriangulation.

Fig. 3c and 3d show only the in-plane components, respectively without and with VideoTriangulation. It can clearly be seen that the in-plane components without VideoTriangulation are by far too high. In this specific example, they even seem to appear to dominate the vibration behavior at this frequency. The measurement with VideoTriangulation shows the high in-plane components of Fig. 3c are a measurement artifact, due to the inaccurate beam positioning. Fig. 3e shows the averaged spectrum of the x vibration components (in-plane) for the two cases. It can be seen that the differences between the "true" spectrum with VideoTriangulation and the apparent spectrum without tend to grow at higher frequencies. This is well explained by the fact that the spatial wavelengths get smaller at higher frequencies and therefore the crosstalk effect gets stronger. For a measurement like the presented example with very small spatial wavelengths, VideoTriangulation is therefore mandatory.

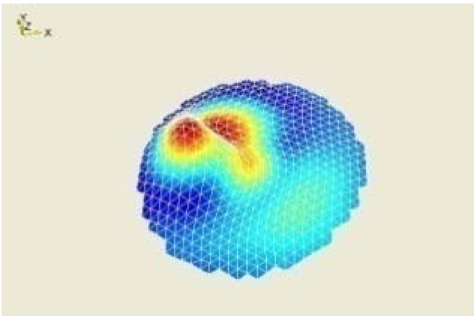

Fig. 3a) 3-D vibration at 102 kHz without VideoTriangulation.

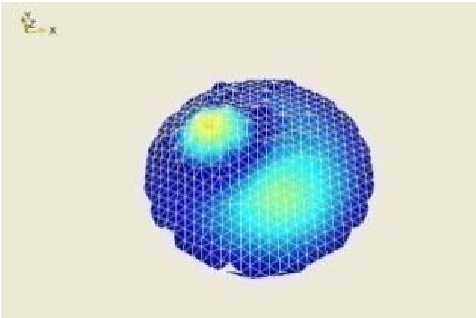

Fig. 3b) 3-D vibration at 102 kHz with Video-Triangulation.

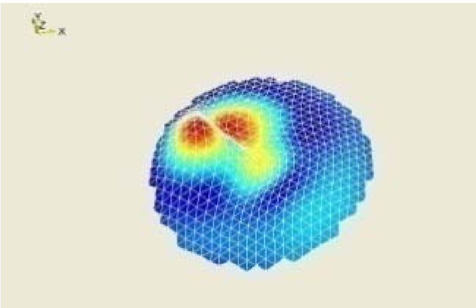

Fig. 3c) in-plane vibration at 102 kHz without VideoTriangulation.

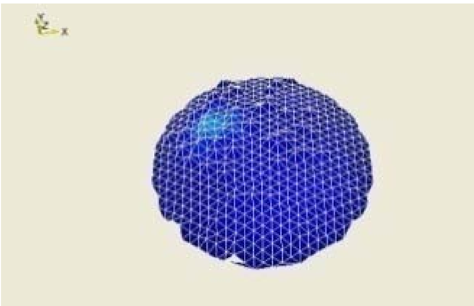

Fig. 3d) in-plane vibration at 102 kHz with VideoTriangulation.

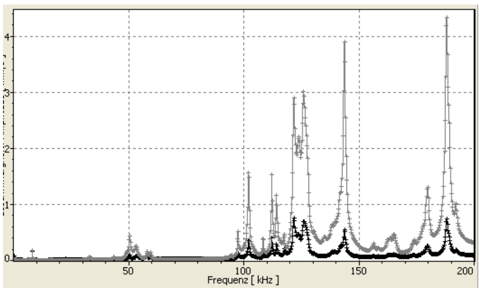

Fig. 3e) in-plane vibration spectrum with (black) and without (grey) VideoTriangulation.

Second example: strain measurement on a turbine blade

Two deflection shapes are analyzed, one at 512 Hz (first bending) and a higher one at 18,100 Hz.

Fig. 4a shows the deflection shape measured without VideoTriangulation at 512 Hz, 4b with VideoTriangulation.

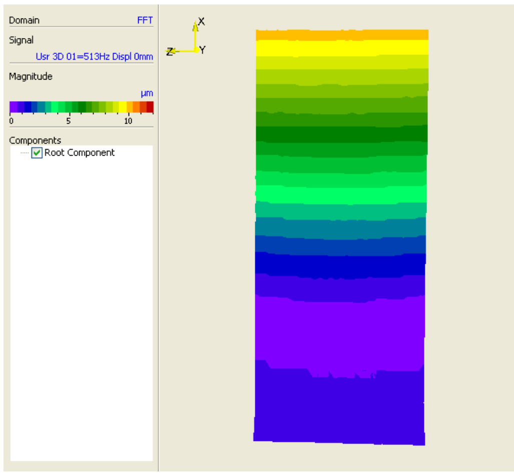

Fig. 4a) displacement at 512 Hz without VideoTriangulation.

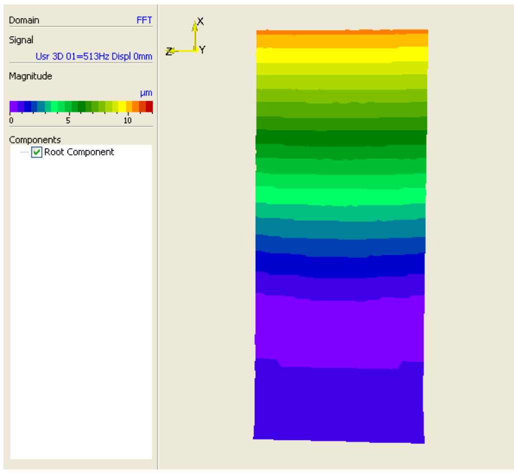

Fig. 4b) displacement at 512 Hz with VideoTriangulation.

No noticeable difference between the two deflection shapes can be seen. This is to be expected, as the out-of-plane component is dominant.

Nevertheless, for strain measurements, even the very small residual crosstalk, which passes completely unnoticed in a "normal" deflection shape measurement, cannot be tolerated. In fact, strain is calculated out of the in-plane components. Therefore, if the in-plane components are erroneous due to crosstalk, strain values are erroneous, too.

This shows that even small residual cross-talk, that does not appear in the “normal” deflection shapes, which are often dominated by out of-plane components, can not be tolerated in strain measurements.

Fig. 4c and 4d show the strain result along the long axis of the blade, respectively without and with VideoTriangulation.

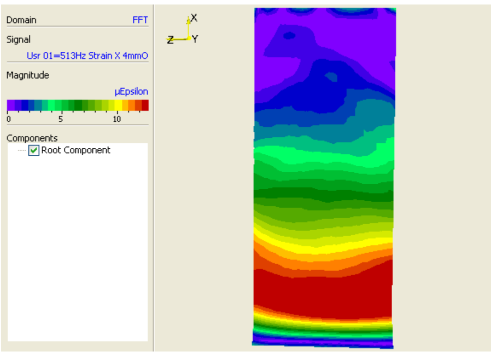

Fig. 4c) Strain along the long axis of the blade at 512 Hz without VideoTriangulation.

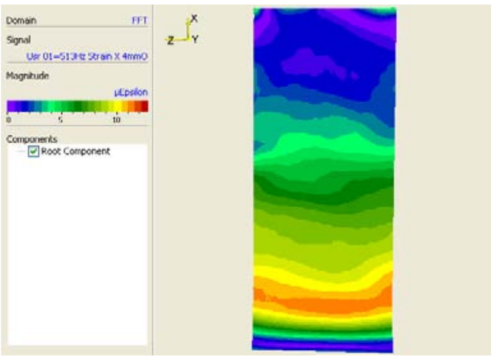

Fig. 4d) Strain along the long axis of the blade at 512 Hz with VideoTriangulation.

The differences in strain distributions and amplitudes are obvious.

The displacement at 18,100 Hz is shown in Fig. 5a without VideoTriangulation, in Fig. 5b with VideoTriangulation.

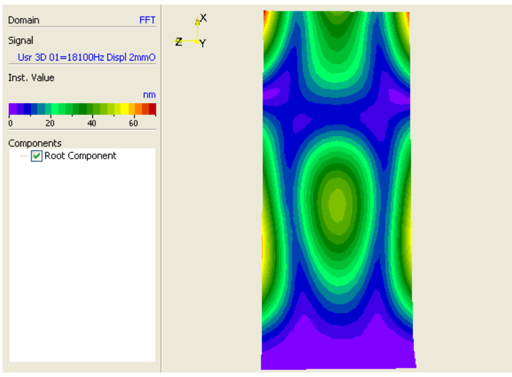

Fig. 5a) Displacement at 18100 Hz without VideoTriangulation.

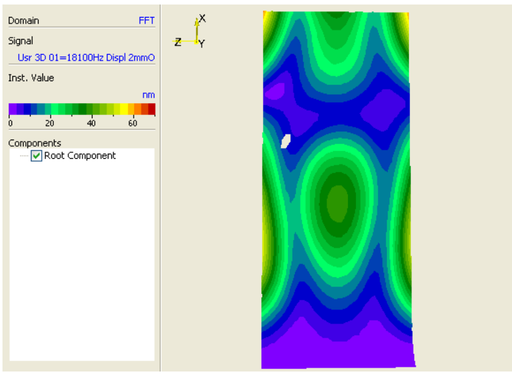

Fig. 5b) displacement at 18,100 Hz with VideoTriangulation.

Again, no noticeable difference between the two deflection shapes can be seen.

Fig. 5c and 5d show the strain along the long axis of the blade, respectively without and with VideoTriangulation.

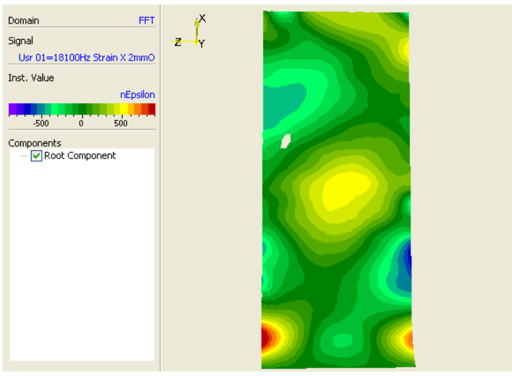

Fig. 5c) Strain along long axis at 18100 Hz without VideoTriangulation.

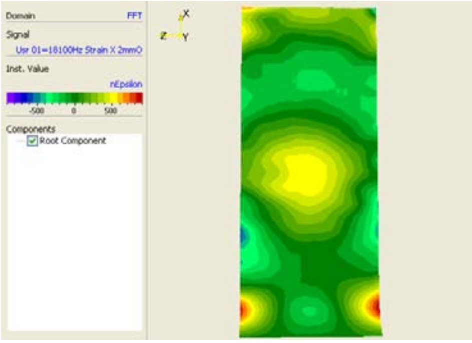

Fig. 5d) Strain along long axis at 18100 Hz with VideoTriangulation.

Differences in the strain distribution can be observed. Fig. 5d is close to the distribution that is theoretically expected, while 5c shows some artifacts due to crosstalk, as outlined above.

This gets even more obvious in Fig. 5e and 5f, which respectively show the strain along the shorter side of the blade without and with VideoTriangulation.

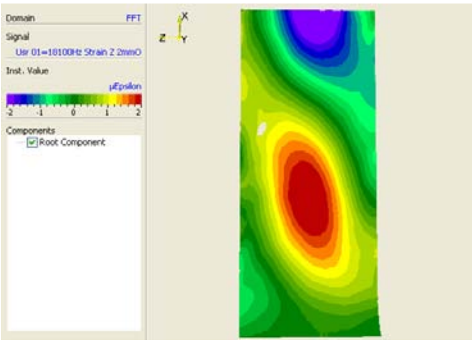

Fig. 5e) Strain along short axis at 18100 Hz without VideoTriangulation.

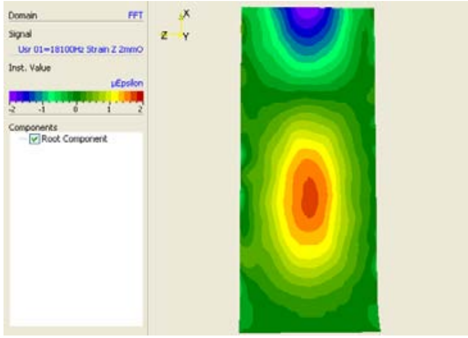

Fig. 5f) Strain along short axis at 18100 Hz with VideoTriangulation.

Conclusion

In conclusion, it can be said that Video-Triangulation is a valuable tool for high frequency and dynamic strain measurements with the PSV 3D. It leads to an overlap of the 3 beams with such a high precision that they look as if they were one. This is important for high-frequency measurements which need high spatial resolution.

It reduces significantly crosstalk between in-plane and out-of plane components. This is especially important for strain measurements, but also for measurements of a weak in-plane component in the presence of a strong out-of plane component.

Finally, it is a remedy against the inevitable small beam drift over time which might occur during long measurements or strong temperature changes.

VideoTriangulation is available as a software option of the PSV software. It works best with the external high resolution digital camera PSV-A-CAZ-1000.

More Info

You will find further information under **www.polytec.com/applications**, or let our product specialists advise you personally: **info@polytec.com** (North America); **oms@polytec.de** (all other countries).

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