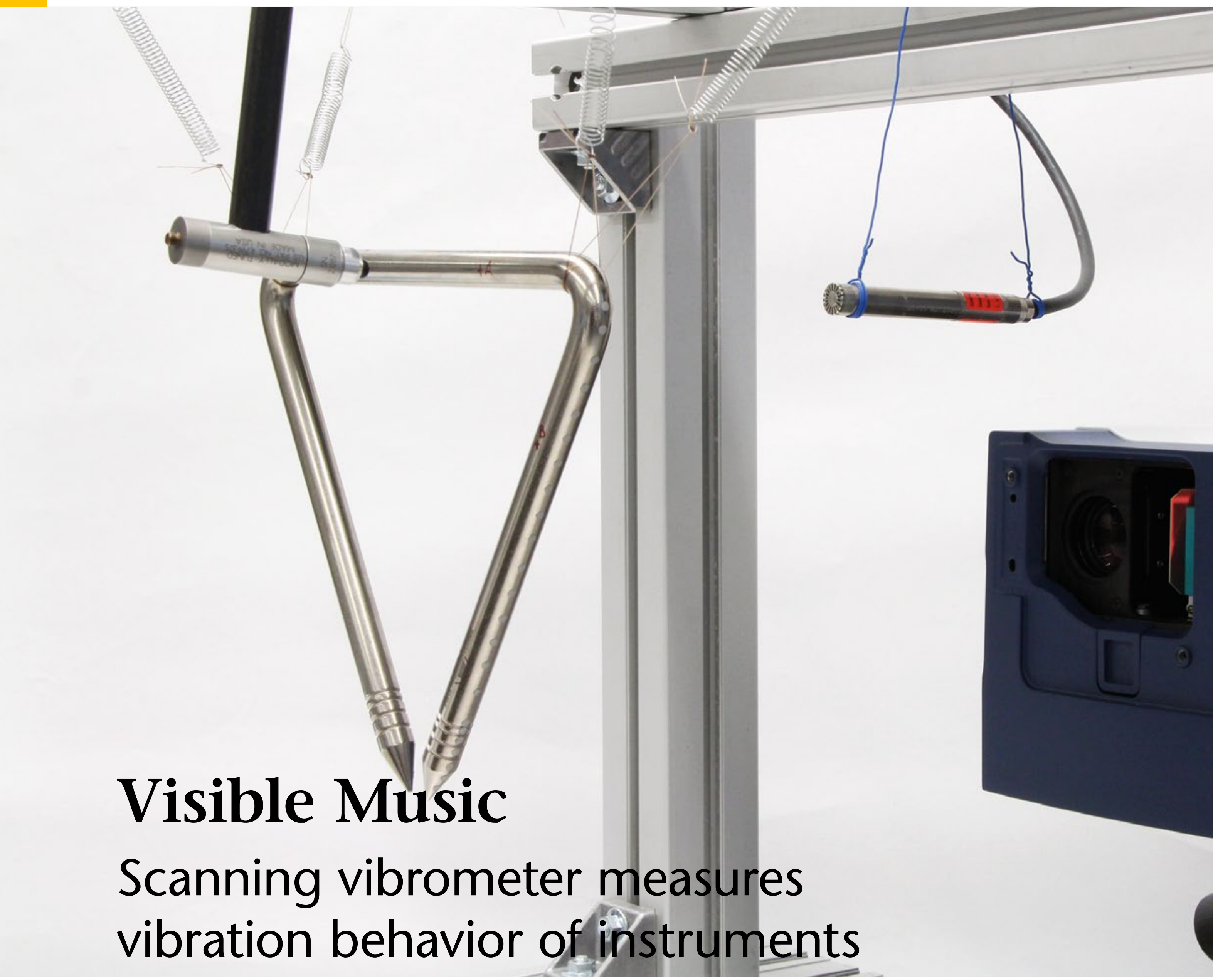

Visible Music

Scanning vibrometer measures vibration behavior of instruments

The history of musical instruments dates back nearly as long as the humanity itself. During the last centuries, the development of the quality as well as of the play of musical instruments has been pushed empirically and experimentally by instrument makers and players. This development can hardly be surpassed. Therefore, at first sight, the scientific study of instruments does not seem to allow any further significant improvement. It is, however, very important to gain an understanding for these complex systems and to provide numerical models to illustrate the behavior of sound.

The initial topic of this research project is the investigation of two triangle instruments. At first sight, the instruments differ in form, see Figure 1, and for the listener their sound is also clearly dissimilar. The aim of the study is to investigate the influence of special geometrical properties of a high-quality triangle on the radiated sound, primarily to gain experience in numerical modeling and experimental analysis of musical instruments.

EXPERIMENTAL SET-UP AND MEASUREMENT PROCEDURE

The experimental analysis is divided into two parts. The experimental modal analysis, using a Polytec PSV-400 Scanning Laser Doppler Vibrometer, provides the eigenfrequencies and mode shapes of the structure. The measurement is then repeated using a microphone to obtain information related to the transmission behavior from the structural vibration to what the listener hears. For music, the triangle is suspended by one string and excited by a small metal stick. In the experiment the triangle has to be suspended at two points to avoid a twist and large motion during the measurement, see Figure 2. Because of the softness of the suspension, the triangle can be decoupled from the experimental rig. Furthermore, this suspension facilitates the comparison between measurement and numerical analysis, as the structure can be assumed as free. Similar to when played, the excitation in the experiment is performed by an impact hammer. The sound does not differ significantly from when excited with the metal stick. Figure 3 shows the mounting of the impact hammer, ensuring that every strike is at the same place, in the same direction and with approximately the same energy. In the experiment, the excitation of the triangle is performed in two directions. The first is in the triangle plane (Figure 2 green) and the other is orthogonal to this (Figure 2 blue). In contrast to alternative measuring methods with ▶

Figure 1: Special geometrical properties of the high-quality triangle instrument.

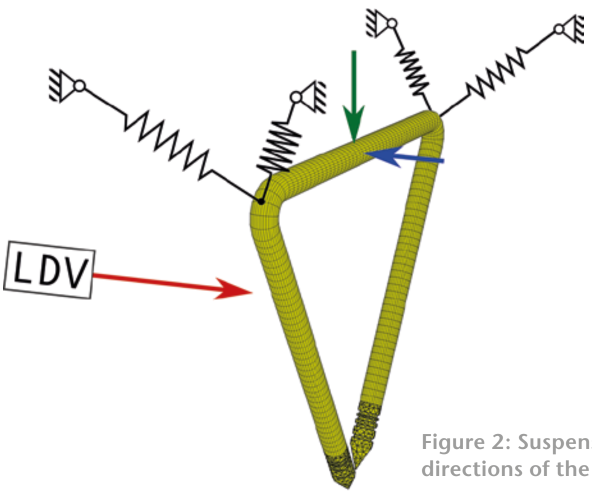

Figure 2: Suspension and excitation directions of the triangle.

accelerometers, the contactless measurement using laser Doppler vibrometry has some advantages. Firstly, vibration properties of the structure are not influenced by additional masses. Secondly, the optical approach of the PSV-400 greatly simplifies the setup of the scan grid. To achieve good signal quality, dots of retroreflective tape are applied to the chrome-plated surface of the triangle to ensure a strong backscattered light level.

The microphone is placed at a distance of 40 cm from the triangle. The distance is limited by the spatial dimensions of the test rig, and yet it must be far enough away to measure outside the acoustic near-field. The suspension geometry and structural excitation remain unchanged.
To analyze the influence of the high-quality triangle's special geometric features in the numerical simulation, it's important to know the real material properties. These parameters are obtained by an indication procedure. The criterion for having chosen the right parameters is the agreement of the eigenfrequencies between measurement and simulation.

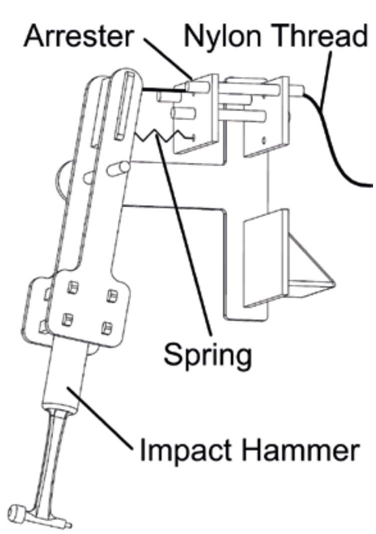

Figure 3: Mounting of the impact hammer.

RESULTS AND CONCLUSIONS

Fundamentally, acoustic instruments radiate sound that represents a superposition of many harmonic oscillations of different frequencies. These frequencies correspond to the natural frequencies of the structure.
A typical sound usually comprises one fundamental tone along with harmonic overtones. The sense for a beautiful tone is highly dependent on the musical experience and talents of the listener. There are objective criteria which can be found to explain consonance or dissonance of two frequencies, or harmonic correlation of all occurring frequencies. However, the triangle is a percussion instrument that can be played without regard to the tonality. Therefore, the series of frequencies should not exhibit one fundamental tone. That is why the criterion of harmoniousness cannot be applied. The sound of the triangle is highly dependent on the direction of excitation. The microphone measurement shows that it is not possible to ensure that only one direction is excited. Therefore, it is not identifiable which natural frequencies belong to which excitation direction. The advantage of the PSV-400 is that the direction of measurement can be set in only one direction. Here, the eigenfrequencies can be assigned to the corresponding excitation direction.

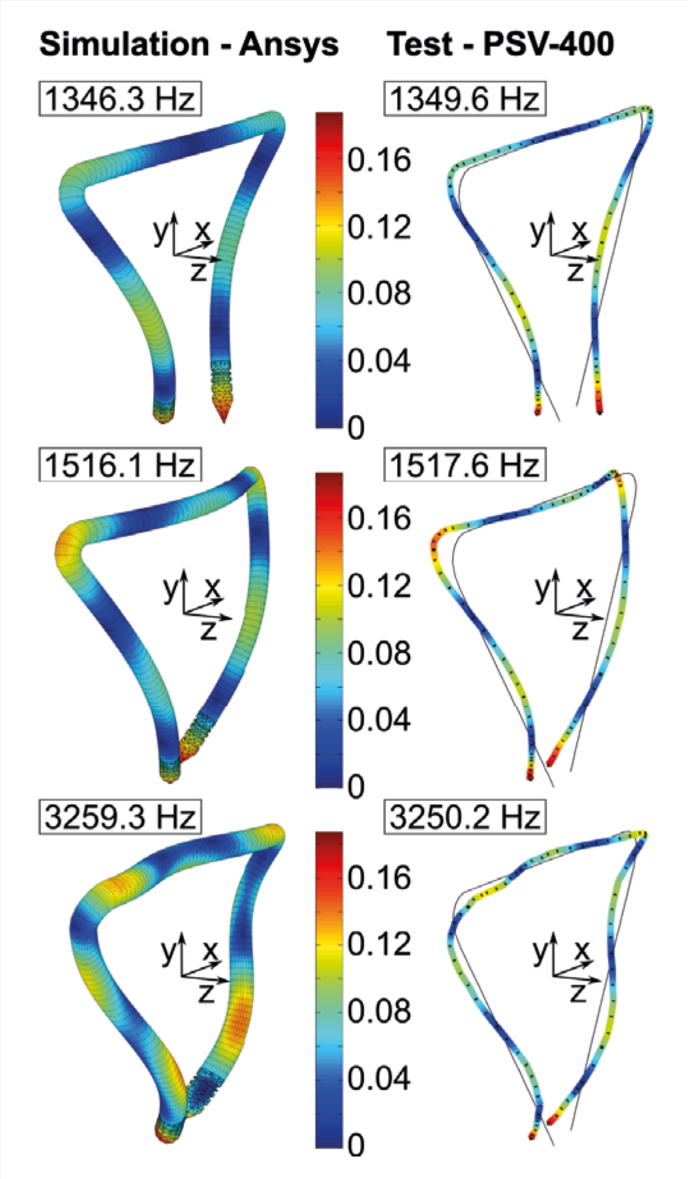

Figure 4: Comparison of mode shapes between simulation and experimental test.

From these results and the criterion for consonance it can be seen why the higher-quality triangle instrument sounds better. The first five eigenfrequencies are responsible for that. For a good sound it is necessary that the corresponding tones are not dissonant to each other. The next step will be to optimize the triangle's shape such that the sound quality is optimized. ■

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