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# Structural Dynamics of Bones

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Technical Papers



## Determining Mechanical Properties of the Human Hipbone Through Vibration Measurements

**Non-contact laser Doppler vibrometry is a powerful tool to aid in the study of biomechanics. Recent experiments to determine the dynamic properties of a pelvic bone relied on deflection measurements from a 3-D scanning laser vibrometer. Excellent results were attained using this measurement technology, even with objects that are geometrically intricate and complex.**

### Introduction

Engineers routinely use experimental modal analysis to analyze the vibration characteristics of mechanical components. These deflection measurements are often used for reference purposes to verify simulation models. Recently, Finite Element Methods (FEM) have been used in biomechanics to investigate and model components for medical applications. For example, to assist with bone surgery, various approaches to generate realistic bone models from Computer Tomography (CT) data are being evaluated. Here as well, experiments are needed for verification purposes. The quality of the verification and resulting model significantly depends on the measurement method and the technology used.

In contrast to engineering sciences, the focus of interest in biomechanics is predominantly on biological materials. Due to the complex changes that take place with extracted biological material (drying out, decomposition), there is only a short period of time to make a relevant measurement. For this reason, an optimized measurement method is required which guarantees the examination of fresh preparations.

### Test Setup

Initial tests to develop an optimized measurement process were carried out on a treated pelvic bone. Initially, a suitable suspension device was constructed for the bone to be examined. While doing so, attention had to be paid to the experiments being carried out in “free suspension”. With the aid of rubber ropes, the bone is suspended in a test frame in such as way that the resonant frequencies of the rigid body suspended by the ropes are less than 10 Hz. Above 100 Hz, the object under investigation can be considered to be freely mounted. The non-reactive connection of the electrodynamic shaker to the object under investigation and its vibration-isolated suspension needs to be carried out just as carefully.

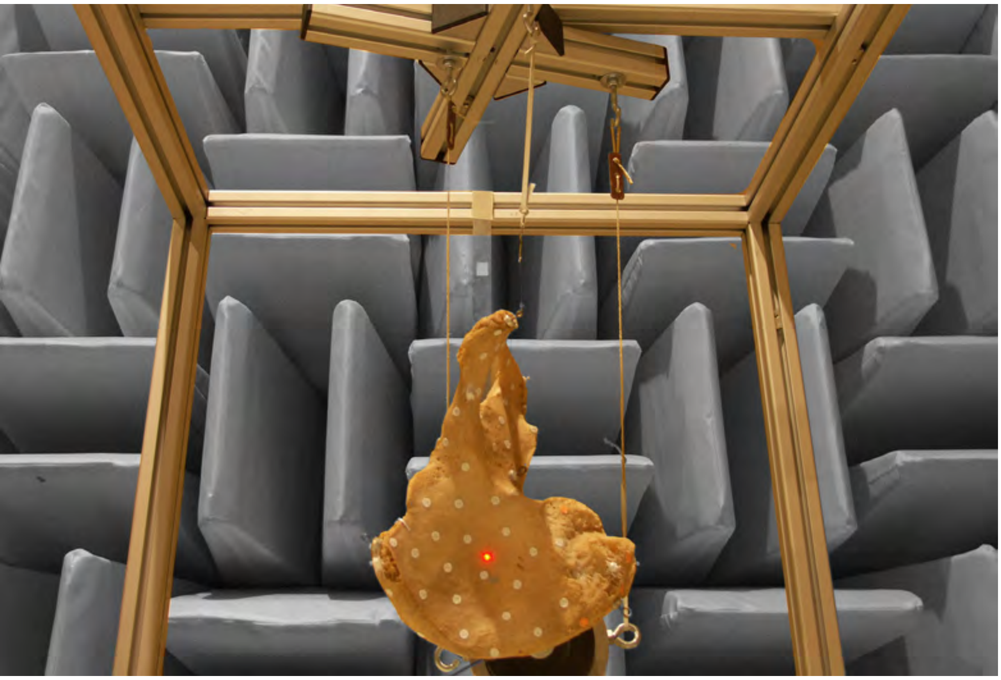

Figure 1: Suspension of the hip bone on rubber bands (red spot: focus point of the laser beam).

Figure 2: Test setup with a 3D scanning laser vibrometer.

## Calibration and Measurement

The 3D Scanning Laser Vibrometer (PSV-400-3D) is used to measure the vibration response of the hip bone (Figure 1, 2). By using three scanning heads oriented at three known angles, the vibration response can be measured in all three spatial directions (X, Y and Z) at the same time. When aligning the scanning heads with each other, the measured alignment points should allow the largest possible volume to be spanned. In addition, for the best measurement results, a distribution of the measurement points across the depth of the object is needed.

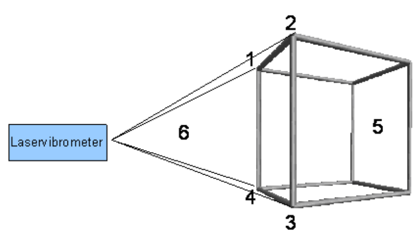


Figure 3: Position of the alignment points on the test frame.

Based on these criteria, six alignment points were defined (Figure 3 ). To accurately measure objects within the test frame, the following steps must be carried out:

- Define the measurement grid and measurement coordinate system
- Carry out a geometry scan
- Assign the focus values

To make the measurements on the bones being studied, the coordinate system of the FE model is used. For this purpose, before carrying out the CT scan, markers are stuck to certain points on the bone and are used as alignment points, thus allowing precise transmission of the position of the individual measurement points to the FE model. To determine the optimal measurement points, the results of the FEM modal analysis are used as a first approximation, shedding light on the bone area with the greatest displacement. Using a vibration exciter (shaker) to continuously excite the bone, the force introduced into the structure at the coupling point and the simultaneous response (vibrational velocity) at the defined measurement point were measured. Two areas of the preserved bone were measured (Figure 5). The transmission functions were measured and superimposed on each other in Figure 4, whereby five resonances are seen.

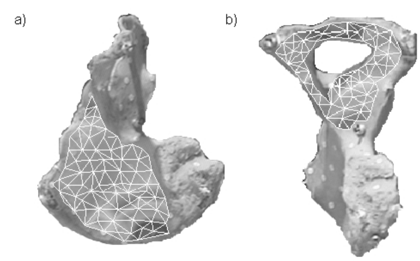


Figure 4: Measurement areas of the treated bone studied: a.) Measurement grid 1, b.) Measurement grid 2.

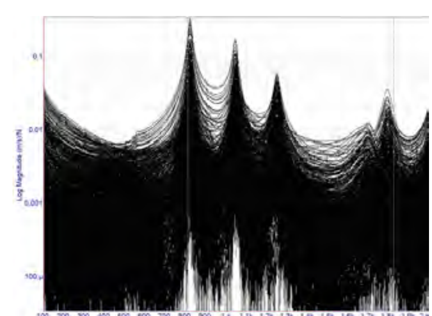

Figure 5: Superimposed view of the measured transmission functions.

## Conclusions and Outlook

Based on the results of work carried out so far, there are five mode shapes in the frequency range from 100 Hz to 2000 Hz that can help align the numerical models with real experimental results. Both the test method and the measurement process were optimized to reduce time and effort, fulfilling the necessary requirement of keeping biological samples fresh and close to their in-situ dynamic characteristics.

The 3D scanning laser vibrometer, which was used for the first time to determine the modal parameters of a pelvic bone, enables the measurement of the spatial vibration modes with an accuracy and resolution that has not been available until now.

Compared to previous methods, measurements using the 3D laser vibrometer represent a substantial improvement in the dynamic analysis and modeling of human pelvic bones.

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