ACOUSTIC PROPERTIES OF DIFFERENT RUBBER-BUFFERS

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ABSTRACT

The institute has built a test rig for the investigation of acoustic properties of rubber-buffers. Different rubber-buffers are excited by a harmonic force in the frequency range of 40Hz to 1kHz and the damping and isolation properties are analyzed. The rubber-buffers are compared regarding their dynamic properties and some conflicts of goals are pointed out.
A numerical model describes the dynamic behavior of the test rig with the rubber-buffer and gives a clear understanding of the dynamic behavior. Furthermore, a comparison between the simulative and experimental results is done.

INTRODUCTION

Parts made of rubber are used in many applications of mechanical engineering. Different tasks have to be fulfilled. Rubber-buffers ensure the elastic behavior of assemblies, damp and isolate vibrations. Rubber shows a complex material behavior. Therefore, it is necessary to characterize the rubber-parts or the rubber-material for example by a frequency response analysis. In general, the rubber-part is excited by an input signal and the output signal is measured to quantify the dynamic properties. In this case an acceleration-based method is used to determine the dynamic properties of different rubber-buffers.

Several other investigators also have investigated the dynamic properties of rubber-parts and samples.

Cramer [1] has used the complex modulus in dependence of frequency and temperature to describe the damping and stiffness properties.

Lee et. al. [2] have used a 6-degrees-of-freedom-oscillator to describe the transmission behavior of marine-diesel-engine-bushings. Specific velocities as well as the amplification are computed.
The dynamic behavior of prestressed rubber-parts have been modeled via constitutive equations and have been implemented into a material model by Retka [4].

Hyperelastic material models have been implemented into a Finite-Elements-model by Boulanger et. al [6], which describes the wave propagation properties.

Lohse [3] determines the interactions in suspension mounts and their influence on the dynamic behavior of a front wheel.

Willenborg et. al [5] have used a rubber-buffer-rod-structure to quantify different dynamic properties in the case of a pulse-shaped force.

All mentioned publications have not investigated in frequency response analysis based on acceleration-signals. Furthermore, no numerical frequency response analysis by Finite Elements has been done by the mentioned authors. The advance of this paper is the comparison of different geometries and hardnesses of rubber-buffers concerning their amplification.

Another very important focus of this publication is the detailed modeling of the designed test rig by Finite Elements.

The paper is structured as follows: The next section contains the test rig description together with the design of the rubber-buffers. The third section shows the measurement data of different rubber-buffers. The fourth section describes the simulation model in detail and highlights some special aspects. Section five compares experimental and simulative data, discusses the results and points out limitations. At the end conclusion are given.

SPECIMENS AND TEST RIG

Two different specimen geometries are investigated, see Figure 1. All rubber-buffers are made of carbon-black-filled natural rubber. The cylindrical geometry is available in two different hardnesses of 38 and 68. The waisted geometry has been investigated only concerning the soft rubber. Overall, three different specimen types are analysed.

The rubber-buffers consist of three different parts. There are two steel plates with an internal thread, which is needed for the mounting to the test rig. The rubber compound is connected to the steel plates by a vulcanization process.

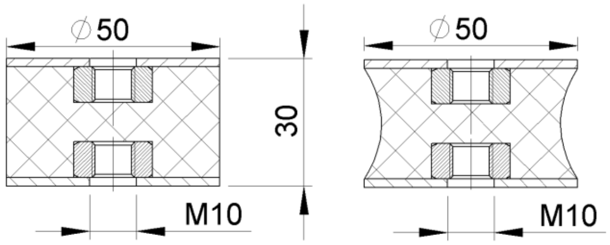

Figure 1: Geomtry of cylindrical and waisted rubber-buffer

In general, the test rig consists of five parts, see Figure 2. The sample holder consists of three parts and is a welding assembly. The base plate is welded to a rectangular tube, which is connected to the input shaft by weldings. By spot-welding wave reflections at the contact between the tube and the input shaft can be minimized. The sample holder is much stiffer than the rubber-buffers. Therefore, the excitation force is nearly independent from the sample stiffness, which is very important to ensure comparable relations of input and output signal for different hardnesses and geometries.

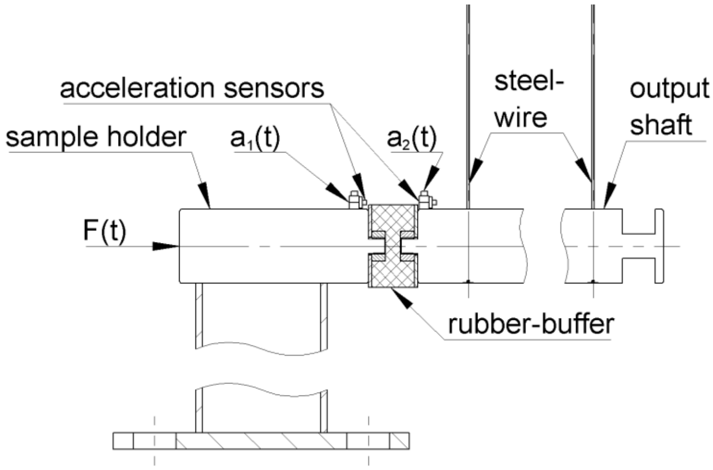

Figure 2: sketch of rubber-buffer-test-rig

The rubber-buffer has two internal threads and is mounted to the test rig by the external thread of the sample holder and the output shaft. This way of mounting the rubber-buffer is needed, because a full-surface contact is very important for the wave propagation and measurement results.

The output shaft is supported by two steel-wires, which compensates lateral forces and resulting bending moments concerning the rubber-buffer. As a result, prestress-effects caused by bending are minimized. To avoid wave propagation from the test rig fundament through the steel-wire to the rubber-buffer the suspension of the steel-wire is decoupled from the fundament by soft elastomer-plates.

In the front and in the back of the rubber-buffer two acceleration sensors a_1 and a_2 are placed to measure the system response in dependence of the frequency.

MEASURED DATA

In general, three different measurement points represent the measurement chain. All sensors are ICP-sensors. The input signal is a force signal, which is varied from 40Hz to 1000Hz in the case of the soft waisted rubber-buffer and from 55Hz to 1000Hz for all other samples. All sensors are connected to the same amplifier and AD-Card to avoid hardware-based time shift problems. A measurement data program records the data with a sampling rate of 80KHz for each measurement channel.

The next step is to define the characteristic values.The transfer behavior of a dynamic system can be defined by the amplification V in the frequency domain:

$$V(f) = \frac{a_{2max}(f)}{a_{1max}(f)} \tag{1}$$

where a_{2max} is the acceleration in the back of the rubber-buffer and a_{1max} the acceleration in front of the rubber-buffer.

Another important dynamic property of a system is the mechanical impedance, which is the resistance of an elastic body against mechanical loads:

$$z(f) = \frac{F_{max}(f)}{v_{2max}(f)} \tag{2}$$

where F_{max} is the amplitude of the force signal and v_{2max} the amplitude of the velocity at measurement point a_2.

After removing zero-offset and filtering, the data the different dynamic properties can be analysed.

Figure 3 shows the amplification of three different specimens in dependence of the frequency. The waisted soft rubber-buffer shows the smallest eigenfrequency of about $f \approx 55$Hz with an amplification of about $V \approx 5.6$. The reason for the smallest eigenfrequency of all investigated buffers is the smallest stiffness.The cylindrical soft rubber-buffer has an eigenfrequency of about $f \approx 85$Hz and an amplification of about $V \approx 5.7$. Comparing the soft waisted and soft cylindrical rubber-buffer it can be determined, that the amplification and the damping value are nearly the same, because they are both made of soft natural rubber with a hardness of 38. The hard cylindrical rubber-buffer shows the largest eigenfrequency of about $f \approx 185$Hz with an amplification of about $V \approx 6.7$. The smaller damping properties of the hard cylindrical rubber-buffer compared to the other two specimens are a result of the large rubber hardness of 68.

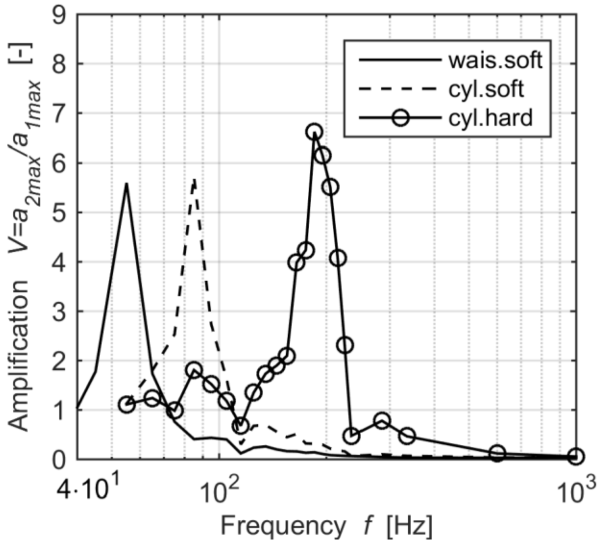

Figure 3: Amplification of different specimens

Figure 4 shows the mechanical impedances of the rubber-buffer-test-rig for different mounting situations. As told before, the rubber-buffer stiffness is much smaller than the stiffness of the sample holder, where the load $F(t)$ is introduced. Therefore, the same force value causes almost the same acceleration value at measurement point a_1, which is very important for rubber-buffer characterization purposes. The mounting situation of the soft waisted rubber-buffer shows the largest mechanical impedance of all samples over nearly the whole frequency range. Just at $f \approx 55$Hz and $f \approx 65$Hz the cylindrical hard rubber-buffer has a larger mechanical impedance. Except the two mentioned measurement points the cylindrical hard rubber-buffer shows the smallest mechanical impedance over the whole frequency range.

At $f \approx 1000$Hz the waisted soft and cylindrical soft rubber-buffer show the same mechanical impedance.

It can concluded that the mounting situation has a tremendous influence on the measured mechanical impedance, see Fig. 4. If the stiffness of the sample holder would be smaller or equal to the stiffness of the rubber-buffer, the acceleration at measurement point a_1 is influenced by stiffness of the rubber-buffer.

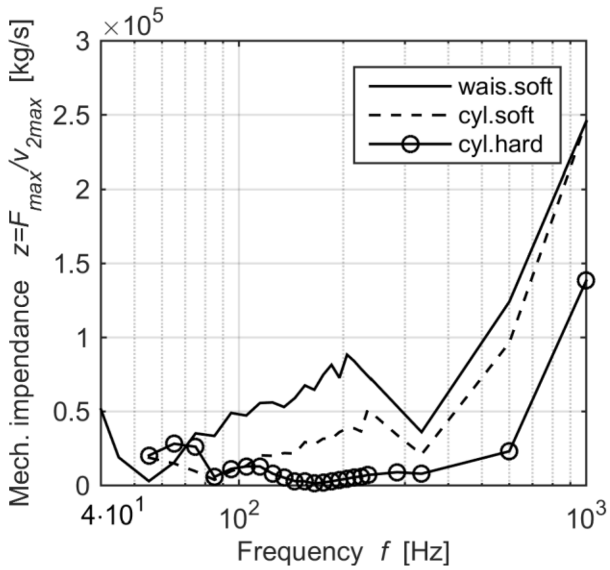

Figure 4: Mechanical impedance of different specimens

SIMULATION MODEL

Figure 5 shows the Finite-Elements simulation model of the rubber-buffer test rig with the cylindrical buffer geometry. Every part is represented by its exact geometry as shown in Figure 2. The whole model consists of solid elements and is meshed by Tetraeder-Elements with a linear initial function. Rigid elements are used to couple the accelerations sensors to the sample holder and output shaft. Furthermore, the representation of the welding is also done by rigid elements. All rigid elements have six degrees of freedom. The force is also introduced to the structure by rigid elements. The middle of the base-plate scew holes is connected to the boundary nodes by rigid elements and fixed totally.

The element size is 2,5mm at most. As a result, the FE-model of all parts has almost 190000 elements together.

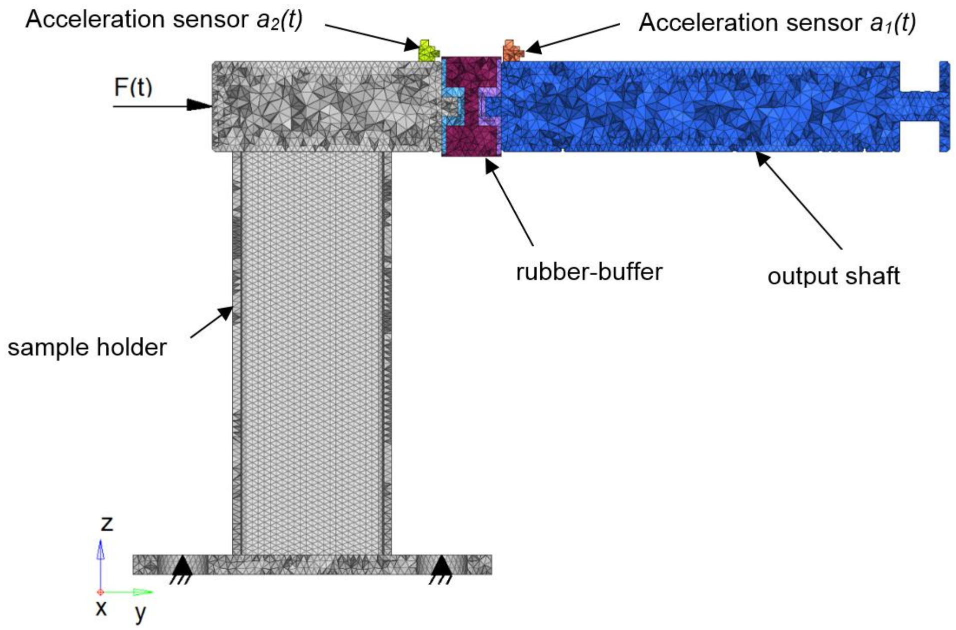

Figure 5: Sectional view on FE-model

COMPARISON OF EXPERIMENTAL AND SIMULATION RESULTS

In the following section the experimental data will be compared to the simulation to ensure a good accordance as well as to point out limitations and possible improvements of the model.
The damping is implemented as structural damping for all elements and is based on the maximal value of the amplification for each specimen:

$$D = \frac{1}{2V_{max}} \tag{3}$$

Figure 6 shows the experimental and simulative data of the soft waisted rubber-buffer. It can be observed that the simulation data shows a very good accordance concerning the Eigenfrequency. The simulation has an Eigenfrequency at $f \approx 56$Hz and the experimental data at $f \approx 55$Hz. The maximal values of the amplification have a deviation of 11%.

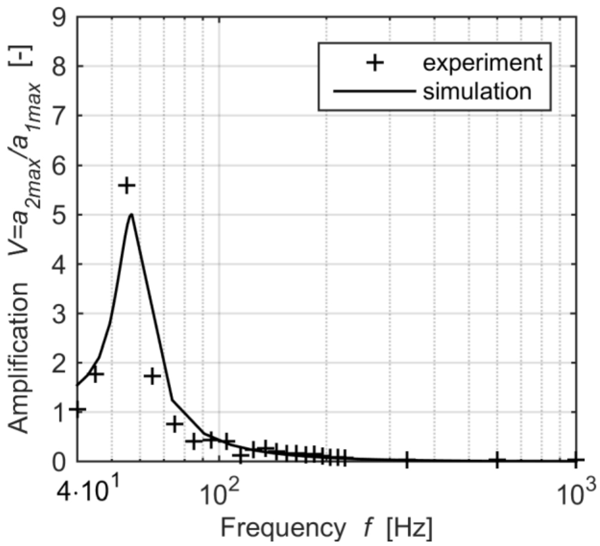

Figure 6: Simulated and measured amplification of the soft waisted rubber-buffer

In Figure 8 the simulated and experimentally determined amplification of the hard cylindrical rubber-buffer is shown. A good accordance concerning the Eigenfrequency and maximal value of the amplification can be seen. With regard to the maximal value of the amplification there is a deviation of 7%.

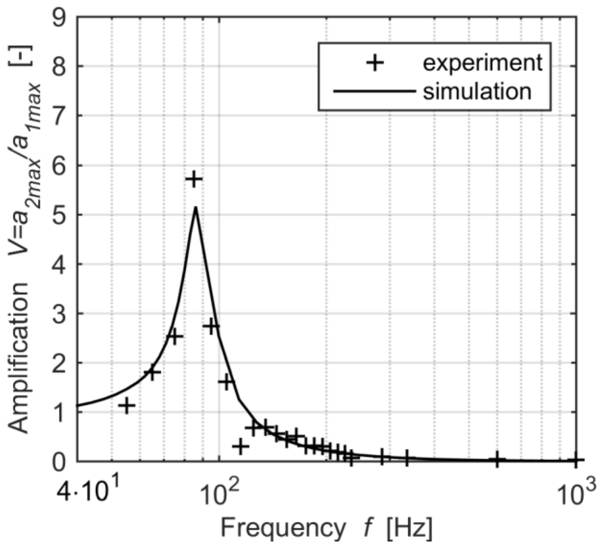

Figure 7: Simulated and measured amplification of the soft cylindrical rubber-buffer

The last comparison between simulation and experiment is done with regard to the soft cylindrical rubber-buffer, see Figure 7. The Eigenfrequencies of the simulation and the experiments are nearly the same. A deviation of 11% is observable concerning the maximal value of the amplification.

It can be concluded, that the simulation of the rubber-buffer-test-rig is able to describe the dynamic behavior regarding the frequency response analysis in an appropriate way.

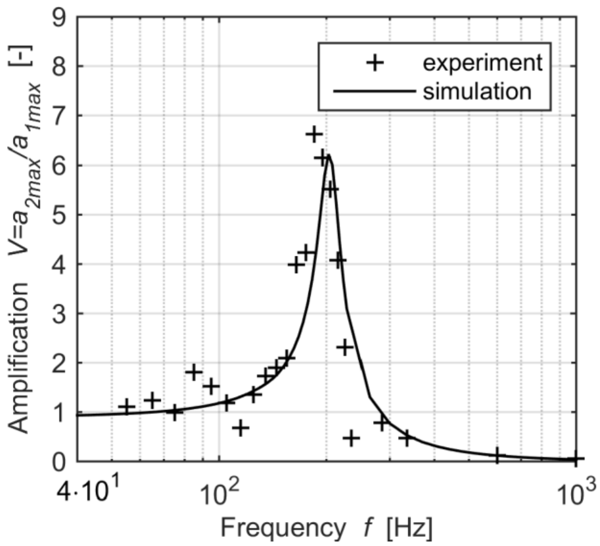

Figure 8: Simulated and measured amplification of the hard cylindrical rubber-buffer

CONCLUSION

On the experimental side, the rubber-buffer-test-rig is able to investigate the dynamic properties of different rubber-buffers with an internal thread. The investigations will be extended to rubber-buffer with an external thread.

The parameter identification can be improved by using the method of least-squares to find the best value for the damping. This should lead to even better results concerning the accordance between simulation and experiment. However, there is a good accordance concerning the measurement and simulation.

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