Structure-Borne Noise Transmission Behaviour of Hydraulic Hoses

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Abstract

Within a project at the Institute for Machine Tools of the University of Stuttgart numerous investigations were carried out in order to identify the basic mechanisms of the structure-borne noise transmission through high pressure hydraulic hoses. The influence of the different constructive and operational parameters on the noise transmission was shown for longitudinal, bending and torsional excitations.

This paper describes also the development of a finite element model of the hydraulic hose. The experimentally gained knowledge about the dynamic behaviour of the hose was used in the development phase of the FE model. To validate this model, the results of the conducted modal analysis can be applied. The basic guidelines of the model verification will be introduced.

KEYWORDS: vibration, fem, hydraulic hose

1. Introduction

Reduction of noise emissions of hydraulic systems has become essential during the recent years and nowadays has turned into inseparable part of the development process. A detailed knowledge about the vibrational behaviour of hydraulic hoses is very important in order to describe and simulate the dynamic behaviour of a complete hydraulic system.

2. Experimental investigations on the structure-borne noise transmission through hydraulic hoses

In order to describe the structure-borne noise transmission behaviour of high-pressure hydraulic hoses, numerous measurements were conducted on a custom made test rig /1/. The influence of the hose type, the fitting type and the crimping type of the fitting (constructive parameters) as well as the operating pressure, the pressure pulsation amplitude and the pressure pulsation frequency (operating parameters) was investigated. The longitudinal, bending and torsional excitation types were used in order to examine the different wave transmission types separately.

The hose consists basically of inner tube, reinforcement, cover and fitting. The reinforcement affects most significantly the structure-borne noise transmission through the hose.

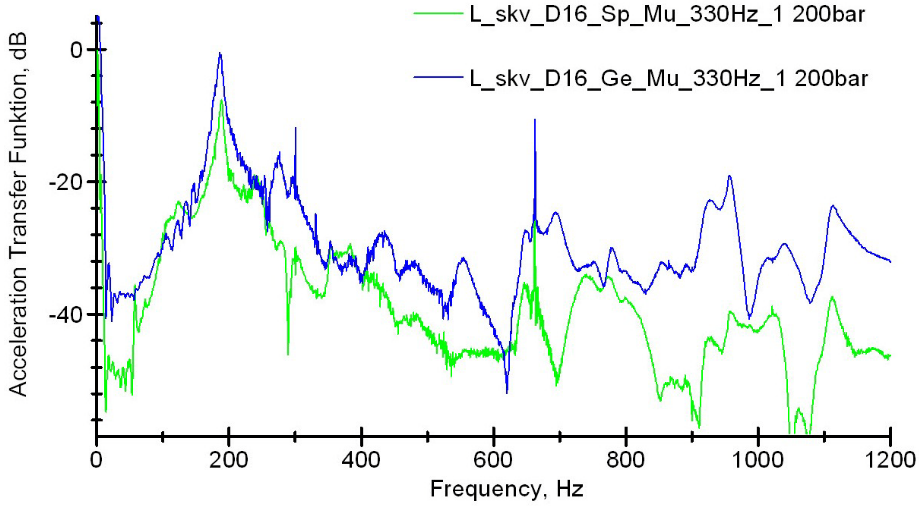

Figure 1: Influence of the hose type (green: spiral hose, blue: braided hose) on the vibration transmission in longitudinal excitation

The transfer functions of the acceleration along the hose for both reinforcement types, braided and spiral, are shown in **Figure 1**. The braided hose, compared to the spiral, displays a considerably higher vibrational transmission through the whole frequency range. In bending excitation the braided hose has similar behaviour. In torsional excitation, however, a higher structure-borne noise transmission of the spiral hose was observed. This might be due to the pre-strained spirally wound fibers of the reinforcement /2/.

Both the crimping type and the fitting type have an influence on the vibrational transmission through a hydraulic hose to further parts of the hydraulic system. A lower structure-borne noise transmission is detected in longitudinal excitation for the no-skive fitting in the upper frequency range above 500 Hz. This behaviour is observed both in bending and in torsional excitation.

While in longitudinal excitation the hose with SAE-Flange shows a slightly higher damping than the one with swivel female fitting, in bending and torsional excitation exactly the opposite is observed. Because of this non definite behaviour, no clear statement on the different excitation types can be drawn.

Moreover, the vibrational transmission behaviour was analysed in dependence on the varying operating parameters. The influence of the pressure pulsation frequency and amplitude on the structure-borne noise transmission through the hydraulic hose was observed only at the excitation frequency and its harmonic /1/.

3. Simulation

The efforts to minimize the noise emission and impact of hydraulic systems become more and more important with respect to simulation of the dynamic vibrational behaviour of such systems in the early development phase. The complete hydraulic system simulation should also take into account the vibrational characteristic of a hydraulic hose. Therefore a correct finite element model of the high pressure hydraulic hose should be developed using the experimentally gained data.

3.1. Building the finite element model of the hose

The finite element model was built in the ANSYS FE-Program, using the ANSYS Parametric Design Language (APDL). The created parameterised batch file enables the creation of many model variants in concordance with different geometries and boundary conditions. The input parameters (diameters, lengths, etc.) are entered using dialog boxes. The modelling process begins “from bottom up”. The points and the lines define areas, which are meshed and extruded into volumes. A cross section of the model is shown in **Figure 2**. The chosen finite elements are described further on.

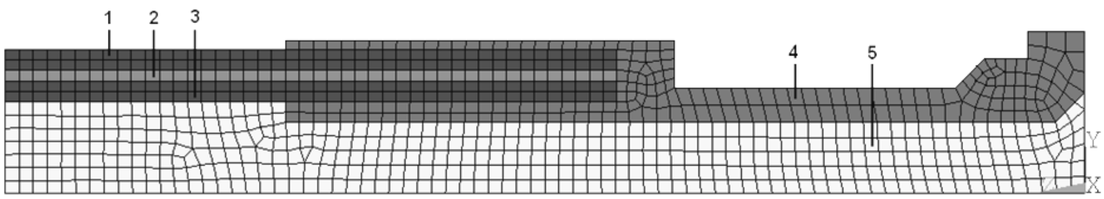

Figure 2: Model cross section: 1-cover, 2-reinforcement, 3-inner tube, 4-fitting, 5-fluid

3.1.1. Element types and material properties

All element types should have the same degrees of freedom (DOFs) in order to be compatible to each other. Also in dynamic analysis, where the wave propagation is of interest, midside-node elements are not recommended because of the non-uniform mass distribution /3/.

For the steel fitting a standard structural 3-D solid element SOLID185 was used. It has eight nodes and three DOFs at each node: translation in the nodal x, y and z directions.

For the inner tube and the cover of the hose the SOLID185 element is used, too. The Tube and cover material is synthetic rubber. For better performance they should be modelled using the option for nearly incompressible material behaviour. A Poisson's ratio of 0,49 was used.

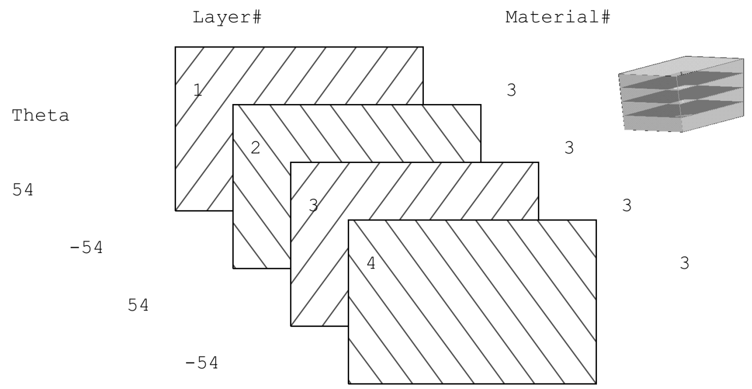

Figure 3: Layered element of the reinforcement

The most important part for the simulation of the hose is the modelling of the reinforcement. It has a layered structure, which significantly affects both the mechanical and vibrational transmission behaviour of the hose. A layered structural solid shell element SOLSH190 is suitable for such types of problems. A separate section in the element was defined for every reinforcement layer. Different orientations (see **Figure 3**) and material properties can also be defined layer-wise. This allows the modelling of the complete reinforcement considering its orthotropic character. An example element of the reinforcement is shown in a Figure 3.

For the first simulation step the elastic modulus data were based on the calculated data gained from the experimental modal analysis and the results on the stress-strain behaviour /1//4/. **Figure 4** shows the experimentally obtained material data. The Poisson's ratio in the fibres direction was set to 0,27.

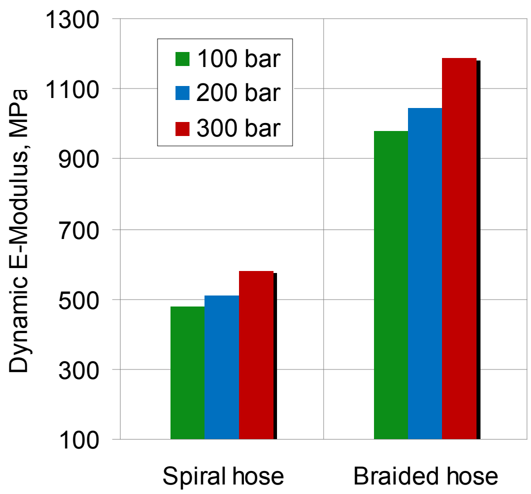

Figure 4: Dynamic E-modulus of a spiral and braided hose

The fluid medium is modelled by FLUID30 element. It has four degrees of freedom, translations in x, y, z and pressure. The coupling between the fluid and the structure is taken into account through fluid-structure interface (FSI) option. This option should be switched on for the fluid elements at the fluid boundary. The speed of sound in the fluid is experimentally measured and also taken into account.

3.1.2. Loads and boundary conditions

The experimental modal analysis of the hydraulic hose is carried out without fluid flow and with closed fitting ends. The fittings in the FE model were also closed. The nodes on the end face of the right plug have zero displacements in all three directions. The other end of the hose is free. A three dimensional FE model of the hydraulic hose is shown in **Figure 5**.

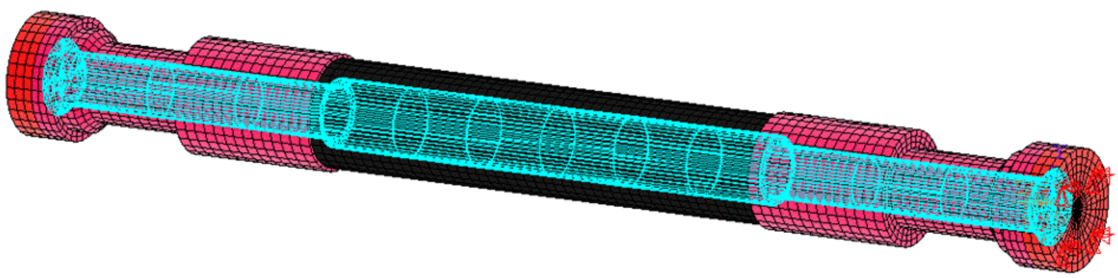

Figure 5: 3D FE model with constraints and pressure loads

A static pressure is applied at the inner structure face of the hydraulic hose as a surface load. The applied pressure levels correspond to the experimental test conditions. A static analysis was performed in order to pre-stress the hose structure model with the set loads and to prepare it for the following modal simulation step.

3.2. Model verification basic guidelines

Every simulation model has to be verified by comparison to the real object in order to obtain reliable simulation results. In the current study the FE model of the hydraulic hose should be compared to the modal properties obtained by the experimental modal analysis. An objective function is needed for the update process. The formula is as follows:

$$\min\left\{\sum_{i=1}^{N}\left(f_{i\exp}-f_{i_{FEM}}\right)+\sum_{j=1}^{M}\left(\psi_{j\exp}-\psi_{j_{FEM}}\right)\right\} \tag{1}$$

Here f is the i-th natural frequency, ψ the j-th mode shape, obtained experimentally and respectively by FEM. The update of the FE model begins with the identification of the model parameters that have significant influence on the results. The already known parameters such as geometries and some material properties have to be entered in the system. The initial values of the unknown parameters were estimated based on “a priori” knowledge. The second step of the model update is to run a modal analysis. Because of the unsymmetrical matrix, resulting from the fluid-structure interface, an unsymmetrical solve method was used. As already mentioned, the modal analysis calculation can be run only after the performed static pre-stress analysis. The results (natural frequencies and mode shapes) should be compared to the experimental modal data using the target function.

Figure 6 shows the computed fourth mode shape of the hose at 38,53 Hz, which was obtained by the first simulative FEM calculation with the initial model parameters.

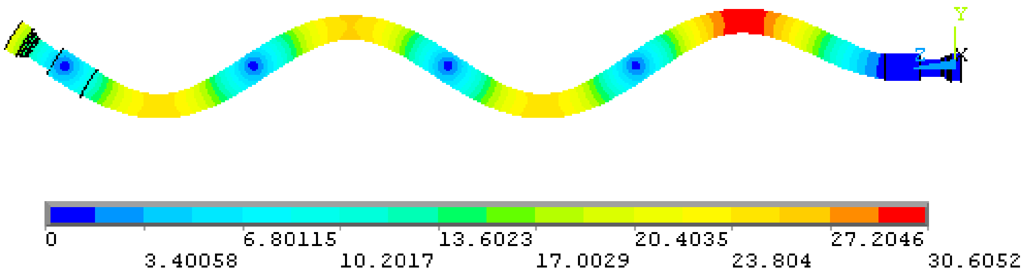

Figure 6: Fourth mode shape (Displacements, mm)

The frequency of this mode shape matches the experimentally one, which has a value of 39,23 Hz, with very good agreement. This is not the case for the other eigenvalues, they do not converge. The results from the initial simulation step showed that in order to reflect the reality of the complex hose structure, a further parameter optimization is needed. In order to continue the optimization process, a new reliable set of model parameters have to be generated using statistical or stochastic methods. Then a new simulation step can be executed. This update process of the FE model must be continued until an acceptable deviation within certain boundaries is reached.

4. Conclusion

Numerous experimental investigations have been conducted which aimed at describing and identifying the mechanisms of the structure-borne noise transmission through the high-pressure hydraulic hoses. A finite element model of the high pressure hydraulic hose was built using the gained knowledge in the first project phase. The reinforcement, the most complex structure of the hose, was modelled using a layered element. This should allow a parameterized simulative investigation of the hose vibrational behaviour. The methodology of the FE model update was also described. The first simulation showed that the right way towards a more comprehensive model was chosen. The updated model of the hydraulic hose should be transferred and adapted to existing model of hydraulic systems in order to enable the simulation of the dynamic vibrational behaviour of the complete hydraulic system.

5. Acknowledgement

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6. References

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