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Experiments and Modeling for Quantifying Noise Sources in Hydraulic Pumps

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Abstract

The objectives of the current research are to quantify noise transmissions from the internal sources in hydraulic gear pumps and basic hydraulic systems. This is accomplished through both experimental and modeling-based approaches that build upon the prior work and test facilities at the Maha Fluid Power Research Center. The experimental techniques developed as part of this work are useful for determining key features of noise generation and propagation, and are also applied in order to improve model techniques and for model validation. Better understanding of key features of noise allows for development of new quieter pumps and motors.

Introduction

As a key component in power transfer, displacement machines are subject to high loads and oscillatory forces. They are also typically the largest source of noise in hydraulic systems and a key aspect of future design improvements. External gear machines (EGMs) have major advantages in many types of fluid power applications to fulfill the role of delivering fluid. Primarily, they are very robust and durable. They are also inexpensive to manufacture due to their small number of parts and simple principle of operation. The displacing action in an EGM is achieved by the meshing of two gears, which causes a change of the volume inside every tooth space volume (TSV) in each gear as the gears mesh.

There are many different designs for external gear pumps. The chosen reference pump is among the most successful designs for high pressure (up to 300bar) applications. The pump body is typically composed of two or three pieces which enclose the gears and have machined ports for connecting the pump to a hydraulic system. An example reference external gear pumps is shown in Figure 1a.

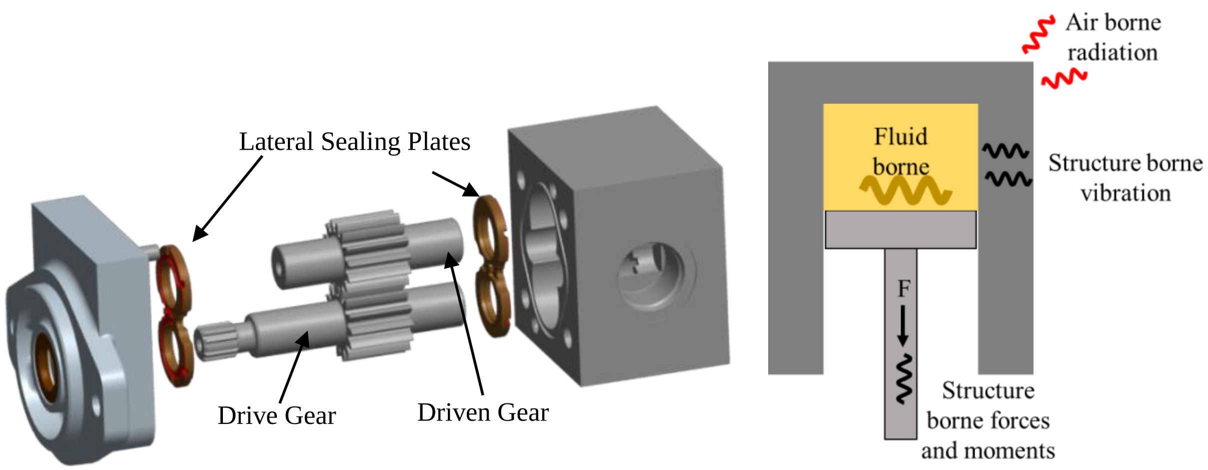

Figure 1: a) Example EGM. b) Noise sources in a displacement machine.

An essential part of understanding external gear pump operation from a standpoint of noise generation is the modeling of the internal phenomena. A significant issue in the performance of displacement machines is flow pulsations created by the finite number of displacement chambers. This creates oscillations in the system at the frequency of shaft oscillation as well as integer multiples of the shaft frequency times the number of pumping chambers. These flow oscillations cause a fluid pressure ripple called fluid-borne noise (FBN) as shown in Figure 1b. Difficulty in modeling the sources of FBN comes mainly from the complexity of simultaneously modeling pump phenomena such as fluctuating fluid pressures on internal surfaces, pressure peaks, cavitation, contact forces, and bearing performance. At Maha lab of Purdue University, modeling the operation of gear pumps and axial piston pumps has advanced through the development of multi-domain simulation models that combine different simulation approaches. The simulations aim to carefully analyze the complex fluid, structure, and thermal interactions characterizing the flow and the lubricating gap behavior in these machines with Vacca (2011) focusing on EGMs. Pressures and loads inside the pump result in forces and vibration transmission through the solid structures called structure-borne noise (SBN). Finally, the vibration of the system surfaces radiates to the surroundings in air-borne noise (ABN). For all different designs of hydrostatic units there is not a clear correlation between all internal features of operation and the ABN. Because of this, additional research is required to better understand the sound generation and propagation from the internal sources of noise in the displacement machine. This is accomplished through experimental and simulation-based efforts as described in the following sections.

Theory

The pump model for the external gear pump takes into account the different connections between the TSV and other system volumes as well as the changing of net volume in the meshing zone. The pressure inside the volume as a function of fluid properties, geometric volume variation and the net mass transfer with the adjacent volumes can be given by the pressure build up equation from Vacca (2011). The mass flows between volumes are modeled by the orifice equation based on the equivalent connection between volumes. The equations put into practice in the structural-acoustic model are published by Opperwall (2012). To summarize, the structural response is described by Hooke's Law and the primary governing equation for the steady-state acoustic pressure is the second-order Helmholtz equation.

The acoustic theory for interpreting experimental results is heavily based on Fourier frequency analysis. The efforts use the fast Fourier transform (FFT) as well as power spectral density (PSD) efforts to interpret the measured results.

$$A_{iBN} = \left|\frac{fft(x_i)}{NFFT_i}\right|$$

$$P_{iBN} = A_{iBN}A^*{}_{iBN}$$

Frequency analysis is particularly useful due to the highly oscillatory performance of hydraulic pumps and motors.

Methods

The model combines the lumped-parameter predictions of pump operation to predict the pressure and force oscillations on the solid structures shown in Figure 2. The structure responds according to its resonant frequencies as predicted by a finite element modal analysis.

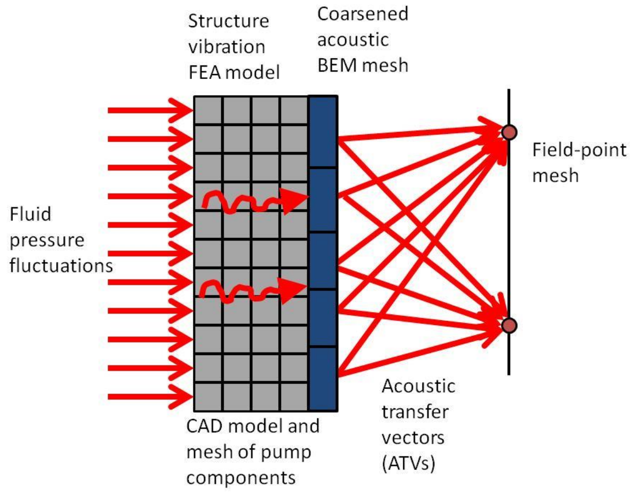

Figure 2: Vibro-acoustic model methodology.

The forces applied on the structure propagate through the solids and then a boundary element mesh (BEM) controls the interface from the solids and the radiation to surrounding points using acoustic transfer vectors. In this way the total noise contribution of the pump noise sources can be quantified in the model. Likewise, in the experimental efforts, the noise sources and transmission can be measured using pressure sensors, surface-mounted accelerometers, and microphones in order to experimentally quantify the FBN, SBN, and ABN as it transmits through the system. The experimental efforts seek to quantify both the sources of noise as well as the transmission through the system in order to be used for model validation as well as for developing new strategies for designing quieter units.

Results and Discussion

The goal of the combined simulation and experimental investigation is to go beyond the ISO standards for sound power and simple noise measurements by developing new experimental methods and analyses in order to determine the underlying phenomena behind the noise propagation through the system with the goal of driving improvements both in modeling and in design of new quieter displacement machines. This goal also includes validating the vibro-acoustic model. The validated predicted and measured FBN is shown for the outlet pressure ripple in Figure 3a.

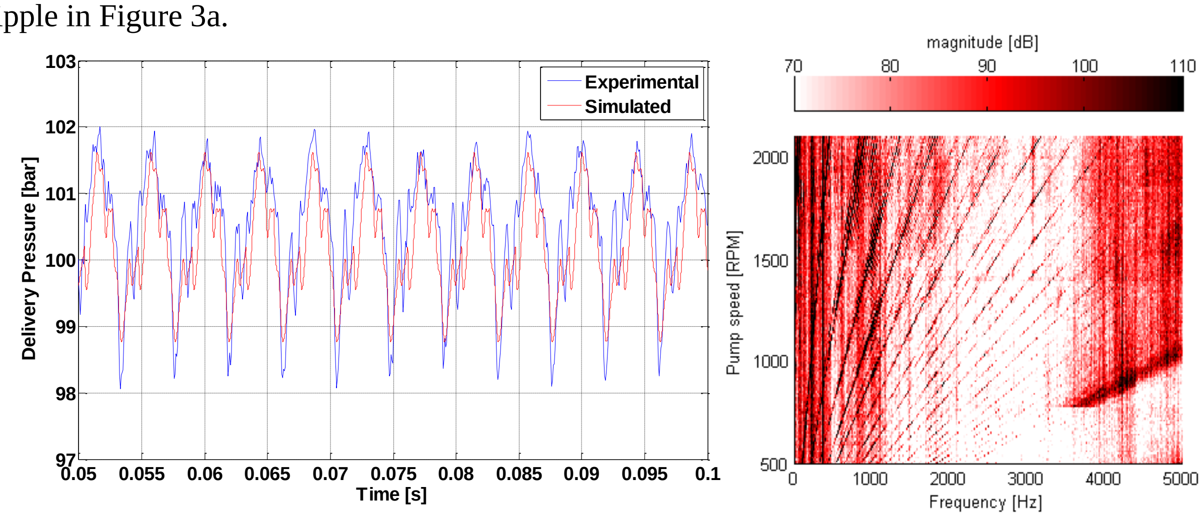

Figure 3: a) Experimental validation of delivery pressure ripple model. b) Power spectral density of measured air-borne noise

Measuring noise sources and transmission in the domains of the fluid, structure, and air can give deeper insight since they share many of the same frequency characteristics. The change in frequency content as the sound propagates through the system can then be better understood by looking at a wide range of operating conditions for the measured ABN as shown in Figure 3b, as well as a variety of other methods.

Conclusion

In conclusion, a numerical model of the sources of FBN in external gear pumps was improved and investigated. The impact of FBN and SBN noise sources on the radiated ABN was investigated under a variety of loading conditions. Greater understanding of the noise generation and propagation was achieved through experimental studies and development and analysis of a model for noise generation.

References

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Opperwall, T., Vacca, A., 2013, A combined FEM/BEM model and experimental investigation into the effects of fluid-borne noise sources on the air-borne noise generated by hydraulic pumps and motors, IMechE Proceedings of the Institution of Mechanical Engineers, Part C, Journal of Mechanical Engineering Science, April 22, 2013.