Acoustic assessment of an electric water pump using ANSYS Workbench and Multiphysics simulation

Feasibility study of a complete acoustic workflow

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This technical article describes an acoustic emissions study conducted on an electric water circulation pump used for supplementary cooling or heating functions in vehicles, by the Modeling & Simulation Pumps Department of Pierburg Pump Technology. This case study was used to demonstrate the feasibility of using a complete acoustic workflow, from the analysis of the main exciting loads to the acoustic output, which made it possible to quantify the relative contributions of the different loads to the final acoustic emission.

This article describes a study conducted by the Modeling & Simulation Pumps Department of Pierburg Pump Technology to investigate the acoustic emissions of an electrical water circulation pump.

The electronically commutated water circulation pump (WUP), shown in Fig. 1, is mainly used for supplementary cooling or heating functions such as:

- the removal of residual heat after the vehicle engine has been turned off (in connection with a radiator fan);
- to quickly warm up the interior of the vehicle, as part of the auxiliary heating systems;
- to support mechanical water circulation pumps in critical operating conditions (stop and go);
- to cool batteries and drives in electric vehicles.

Characterized by its small size and compactness, this pump can be easily mounted in different positions under the engine hood.

Fig. 1 - Electrical water circulation pump (WUP).

However, if the pump is installed close to the cabin, its sound emissions can be amplified and become an annoying noise for passengers.

For this reason, the possibility of having one or more tools to analyze the complexity of an acoustic problem, from its root cause(s) to its occurrence, is a considerable advantage – both to prevent a potential problem and to apply corrective modifications during the design phase.

This study investigated the sound generated by a WUP pump using multiphysics simulations in ANSYS Workbench. The case study was logically decomposed into its essential physical parts and analyzed using the single-physics blocks in ANSYS.

Then, the sub-models were linked to take into account the causality and interaction among the physics, and to finally study the component's vibro-acoustics.

Background

Vibro-acoustic phenomena are inherently a multiphysical issue: the structural vibration of a body generates pressure waves that propagate in the surrounding medium (e.g. air) generating sound. The vibration of the structure, in turn, is caused by exciting loads which can have different origins (fluid-dynamics, mechanical, electro-magnetic, etc.).

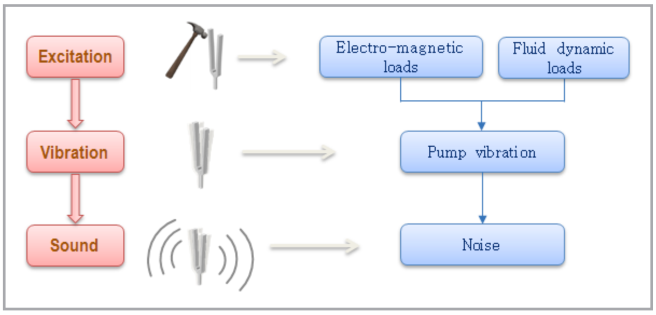

Fig. 2 - Schematic workflow of the acoustic phenomena and their application to the WUP pump.

In the Pierburg case study – the water circulation pump WUP - a brushless DC motor with electronic commutation drives the pump impeller. The fluid-dynamic pressure distribution acts on the wet surfaces of the pump housing and the impeller. Therefore, the general structure of the pump is excited by a combination of electromagnetic, fluid dynamic and mechanical loads, which cause its vibrations.

The vibration of the pump structure produces a series of pressure waves, which propagate through the surrounding medium and can be perceived as sound. Furthermore, the ultimate acoustic perception is influenced by the position of the receiving apparatus with respect to the source, and the characteristics of the surrounding environment. Fig. 2 shows the general logical scheme of vibro-acoustic phenomena and their application to our case study.

Multi-physics simulations

The test case was analyzed by deconstructing the problem into its basic physical elements and their interactions. Similarly, simulations were performed starting from single-physical blocks (e.g. CFD, electromagnetism) and then connected with causal connections within ANSYS Workbench.

Before going into the details of the modeling activity blocks, there is a brief description of the pump.

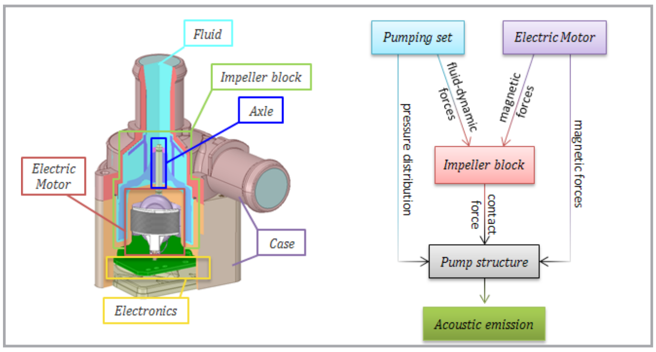

Fig. 3 - Sketch of the WUP pump and breakdown of the physical segments leading to the acoustic emissions.

Geometry and problem analysis

The main parts of the analyzed pump are sketched on the left side of Fig. 3. The electric motor is driven by electronic commutation. An external rotor is an integral part of the impeller, which rotates around a fixed shaft (axle). The fluid fills the impeller and the rotor cavity. All components are enclosed inside a plastic housing. The right side of Fig. 3 outlines the breakdown of the physical segments that characterize the origin of the acoustic emission. The fluid pumping set implies a certain pressure distribution on the wet walls of the rotor and the impeller, as well as on the pump structure (outer casing). In the meantime, electromagnetic forces act between the rotor block and the stator, which is connected to the pump structure. Therefore, the rotor-impeller block is subject to both fluid-dynamic and electro-magnetic forces. Due to a small axial and radial space between the axle and the housing, this component can beat the pump structure and transmit some contact forces to it. However, only the axial gap is considered in this study since it impacts the most in terms of loads. The vibration of the pump is caused by the above-mentioned loads on the structure and is responsible for the emission of noise into the surrounding environment.

Fluid-dynamics analysis

The first block of simulation is the computational fluid dynamics (CFD), analyzed with ANSYS Fluent. The CFD domain of the centrifugal pump is shown in Fig. 4. We studied the specific working point at a rotation speed of 3000 rpm using a transient simulation to study the temporal trend of the main fluid-dynamics parameters. One of the simulation outputs was the pressure distribution on the surfaces in contact with the pump housing over

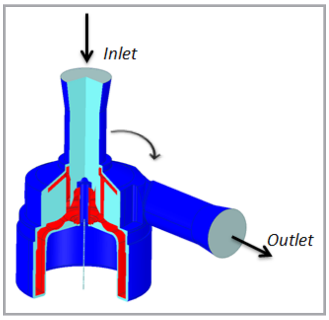

Fig. 4 - Computational domain of the fluid-dynamics simulation.

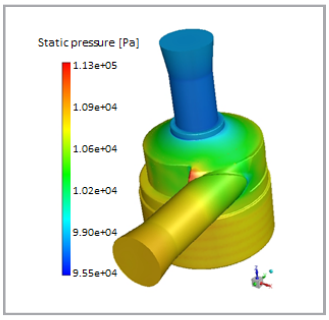

Fig. 5 - Pressure distribution on the fluid walls in contact with the pump housing at a specific time step.

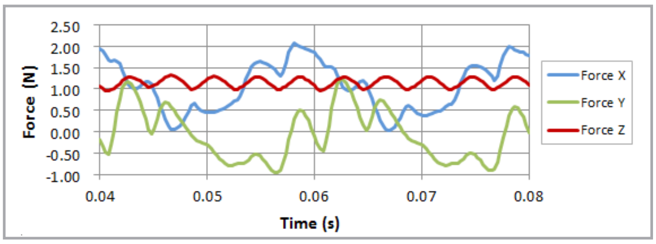

Fig. 6 - Total force acting on the rotor-impeller block due to fluid-dynamic pressure.

time, shown in blue in Fig. 4. The result at a specific time step of the transient simulation is reported in Fig. 5.

The time-variant of the total force acting on the rotor-impeller block (red surfaces depicted in Fig. 4) was also extrapolated from the Fluent simulation; the corresponding result is shown in Fig. 6. In addition, the average fluid-dynamic torque required was used as a reference value for the electromagnetic simulation.

Electromagnetic simulation

The electromagnetic simulation of the single-phase brushless (BLDC) motor was performed with Maxwell 3D with the aim of calculating the vertical forces on the rotor. A sketch of the computational domain for the electromagnetic calculations is shown in Fig. 7.

The main input of the simulation was the excitation current to the winding. A sinusoidal current form was chosen to simplify the problem and due to the lack of additional information. In addition, the minimum root mean square (RMS) value of the excitation current capable of generating the desired torque was chosen. Two main outputs were extracted from the simulation: the stator forces on the rotor (reported in Fig, 8) and the total loads (forces, torque) on the stator, which is connected to the pump housing.

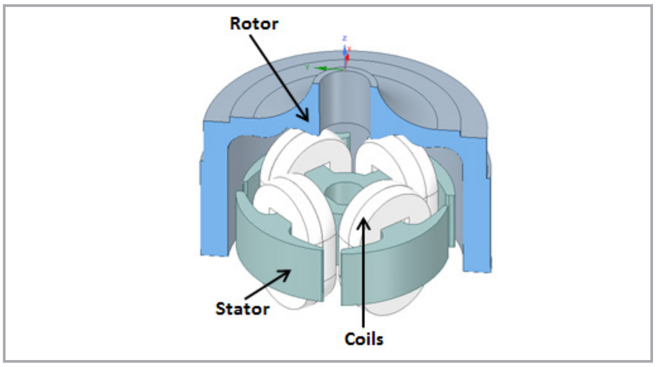

Fig. 7 - Computational domain of ANSYS Maxwell 3D electromagnetic simulation.

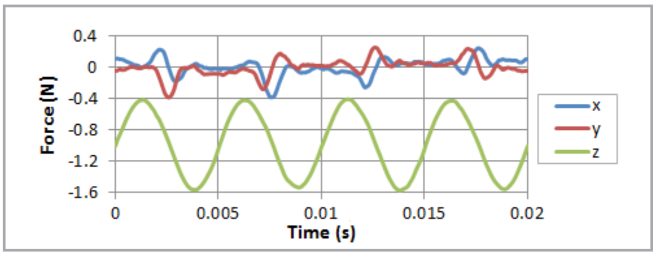

Fig. 8 - Time trend of the force components on the rotor during one rotation.

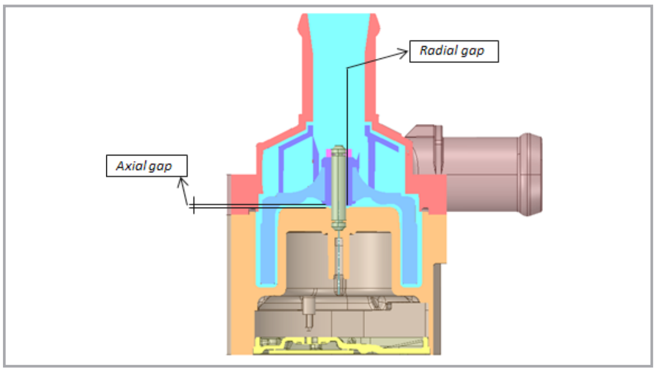

Fig. 9 - Axial and radial gaps between the rotating block and the shaft fixed to the housing.

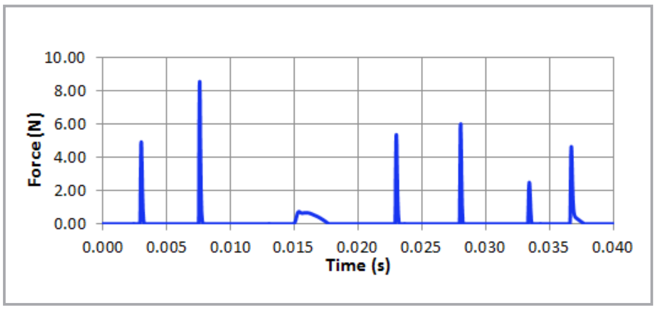

Fig. 10 - Contact force due to the impeller block beating against the pump structure.

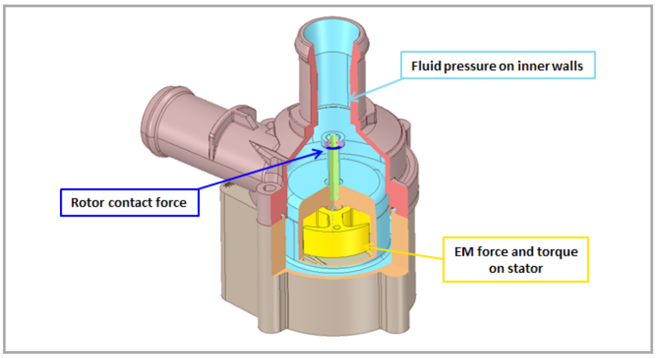

Fig. 11 - Main loads acting on the pump structure.

Multi-body simulation

The third block of analysis focused on the dynamics of the impeller-rotor block, to study the contact force of the block on the pump structure. In fact, there are axial and radial spaces between the rotating part and the shaft fixed to the housing, as shown in Fig. 9. As already mentioned, only axial dynamics were taken into consideration in this study.
The contact problem was studied using the Multibody software MSC ADAMS, in which the input of the calculation was the sum of the fluid-dynamic and electromagnetic forces (only of the vertical components), previously obtained with the CFD and Maxwell calculations.

The outputs of the Multibody calculations were the kinematics of the impeller block and the contact force of the block on the pump structure due to the impact between the two parts, shown in Fig. 10.

Multi-physics and vibro-acoustic analysis

All the loads acting on the pump structure, calculated in the previous steps, were used as input for the structural simulations,

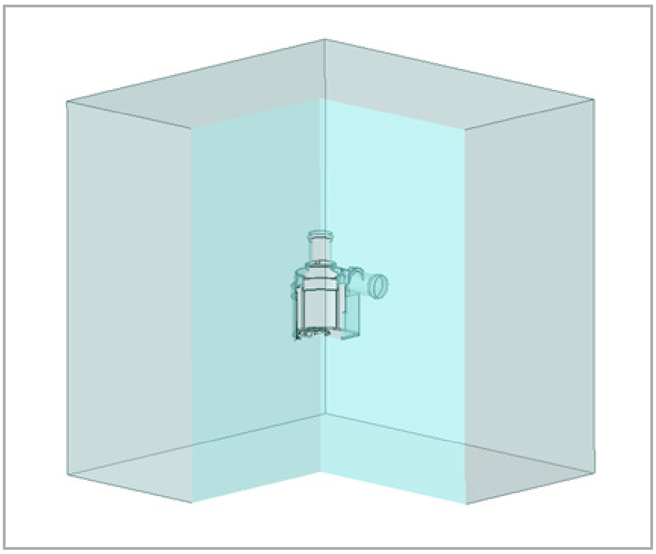

Fig. 12 - Acoustic domain (air) around the pump.

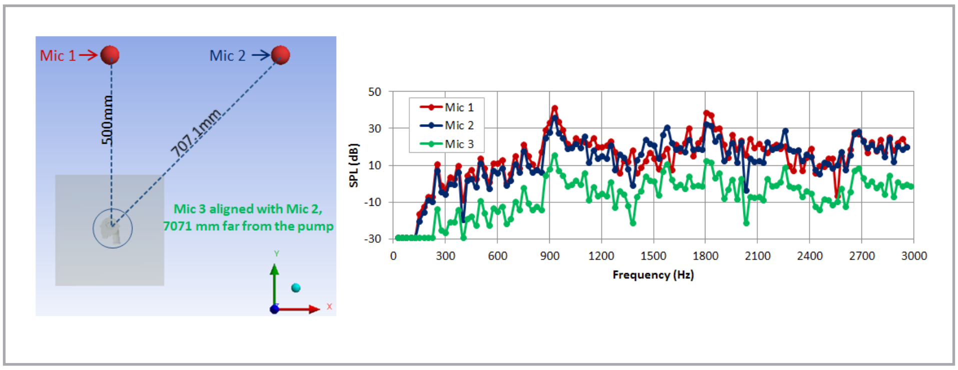

Fig. 13 - Sound pressure level of the virtual microphones for the acoustic simulation.

using the Harmonic Response block of ANSYS Workbench. Fig. 11 shows these loads: the distribution of the fluid-dynamic pressure on the walls (light blue), the electromagnetic loads on the stator (yellow), and the contact force due to the impact of the impeller block (dark blue).

The structural harmonic response was calculated to find the vibration of the pump (deformation, velocity and acceleration).

Finally, the acoustic emission due to the pump vibration was studied in ANSYS Harmonic Acoustics. The acoustic domain (Fig. 12) included only the medium for the propagation of sound waves (air), while the volume occupied by the pump is empty.

The speed of the pump's outer skin was transferred to the air domain as an input for the acoustic simulation. A free field condition was simulated at the boundaries of the acoustic domain.

One of the main post-processing outputs of the acoustic simulation was the sound pressure level (SPL) of the virtual microphones, which can also be positioned outside the acoustic domain. An example of the results obtained is shown in Fig. 13. The microphone output was then post-processed with external software to create an audio file in order to achieve a proper acoustic assessment.

About Pierburg

A dedicated player in the process of transformation and an active part of societal change: for more than 100 years, Pierburg has been a driver of progress in the field of mobility – over and over again. As specialists for increasing efficiency, CO2 reduction, and lowering of emissions, the four Pierburg Business Units are solution providers, agents of change, and architects of sustainable mobility with a clear commitment to climate protection and cleaner air.

Fig. 14 shows the summary of the simulation workflow, which was the practical application of the theoretical breakdown shown in Fig. 3. This block diagram shows the segments of the single physics, the simulation tools used and their connections.

Conclusions

The WUP case study was a successful example of demonstrating the feasibility of a complete acoustic workflow, from the analysis of the main exciting loads to the acoustic output. This approach made it possible to quantify the relative contribution of the different loads to the final acoustic emission. The ANSYS Workbench environment made this activity efficient due to the possibility of establishing direct links between the different physics, which facilitated the transfer of data and results.

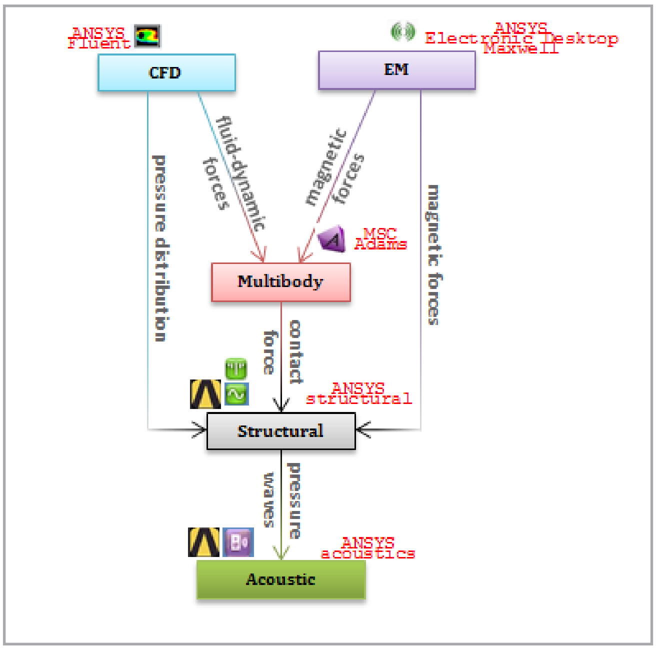

Fig. 14 - Simulation workflow developed for the WUP acoustic test case.

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