A model-based approach for the NVH performance improvement of Soft Close Actuators for automotive applications

Caterina NATALI[1], Giacomo MANFREDINI[2], Vincenzo SCARFONE[2], Fabrizio BECATTINI[2], Giorgio DALPIAZ[1], Emiliano MUCCHI[1]

[1]University of Ferrara, Department of Engineering, Via Saragat, 1, Ferrara – 44122, Italy
ntlcrn@unife.it
[2] MAGNA CLOSURES S.p.A., Via Francia, 101, Guasticce (LI) – 57017, Italy

Abstract

The aim of this paper is to describe a numerical vibro-acoustic methodology, experimentally assessed, for the estimation of the overall vibratory and acoustic level of a Soft Close Actuator (SCA), for automotive applications. The process is carried out in order to develop a digital twin enable to represent the Noise, Vibration and Harshness (NVH) behaviour of the real mechanism. The vibro-acoustic model is the combination of three sub-models: a multibody (MB) model, a structural finite-element (SFE) model and an acoustical boundary-element (ABE) model. The MB model is used to obtain the reaction forces on the case of the actuator during working conditions. Reaction forces are employed as an input for the further SFE dynamic model to evaluate the dynamic response of the SCA's case, which is the only meshed part. The dynamic response is exploited to set-up an ABE model which allows to estimate the noise generation in terms of acoustic properties. The numerical simulation results are validated using experimental data acquired on a real SCA. The developed model is a powerful tool for the improvement of NVH performance of the analysed actuator.

1 Introduction

Soft Close Actuators are external motorized actuators installed on side doors of high-end car. Their function is to automatically close the car latch if the side car door is not completely or correctly closed. This particular actuator is composed by a DC electric motor, a number of plastic gear pairs and a Bowden cable. The presence of the electric motor and gear pairs determines excitation of the mechanism causing its noise and vibration signature. Uncomfortable levels of noise may be produced by the SCA during its operational life, which could not be tolerate on high-end car applications. Since it may be difficult to estimate the acoustic emission during the design process, which is finalized at performing the required cinch operation, noise levels may exceed acoustic tolerance limits. The overall acoustic pressure level, in fact, will depend both on the choice of the SCA components, i.e., gears and electric motor, and on the properties of the case. Assuming that the design of the internal components is fixed (i.e., the choice of the motor and the gears material and geometry is imposed), one may propose many designs for the housing in order to obtain the lowest noise generation possible while achieving the required cinch operation in the required timing. This goal can be accomplished by performing an extensive campaign of experimental testing, which means to proceed with a trial-and-error process testing a number of SCA with different housing design, acquiring the acoustic pressure levels for each one of them. This process is highly time-consuming and requires a large number of resources. A faster way to optimize the design consists in generating a digital twin of the actuator, i.e., a digital replication of the physical entity [1] allowing to test different SCA configurations without creating a physical prototype of the actuator for each test. In this case, the experimental tests must be carried out only to validate the baseline model: design modifications, then, may be numerically evaluated by changing its input parameters. Within this framework, this paper describes the generation of a digital twin of a real SCA mechanism, employed in high-end car applications, aiming at evaluating the overall acoustics in operational conditions. The proposed digital twin is a combination of a multibody (MB) model, a structural finite-element (SFE) model and an acoustical boundary-element (ABE) model. In the following, after a brief description of the experimental setup, the models are presented and experimentally assessed.

2 Experimental setup and results

The SCA mechanism used for the tests is shown in Fig. 1. The Bowden cable couples the SCA with the Side Door Latch, integrated in the particular test rig created to reproduce the side door car setup. The performed experimental tests may be divided in two categories: experimental modal analysis (EMA) and operative analysis. The EMA has been carried out by using 34 excitation points and 2 response points distributed on the surfaces of the case, by using the roving hammer based method. Additionally, 3 excitation points and 1 measure point have been distributed on the plate, at which the SCA is fixed. The excitations have been applied with an impact hammer model PCB 086E80, while the responses have been measured by piezoelectric monoaxial lightweight accelerometers model PCB 352C22/NC. The results of this analysis are used to validate the SFE model. The operative analysis has been realized in cinching and homing conditions by applying a voltage to the motor with PWM control. Acceleration on the case has been measured by using two piezoelectric monoaxial accelerometers model PCB 352C22/NC (Acc1 and Acc2 in Fig. 1) and the acoustic pressure has been measured with one microphone model PCB 378B02 in front of the SCA, at a distance of 30 cm from the corresponding surface (Mic1 in Figure 1). Tests have been conducted for one working condition by imposing a voltage of 11 V with PWM control, to the motor.

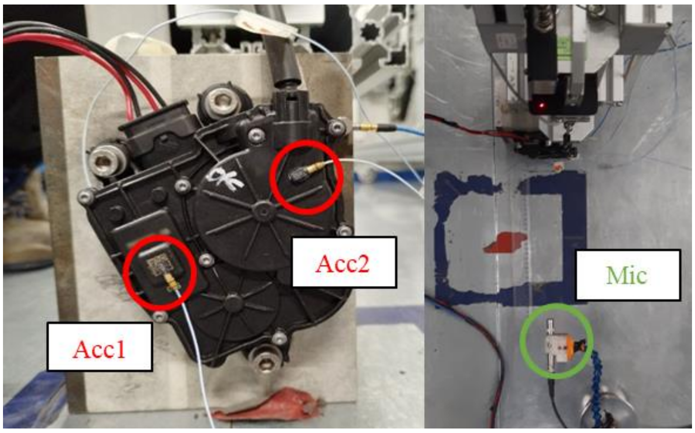

Figure 1: Experimental setup

Experimental results have shown that both the acceleration and acoustic pressure signals are dominated by the frequencies of the electric motor, namely the frequencies of the cogging torque, which is one of the main causes of torque ripple, noise and vibrations in electric motors [2]. On the other hand, the frequencies related to the gears meshing are not visible. It has also been noticed that highest energy content of both the vibration and acoustic signals is in the frequency range around 1000 Hz and 3500 Hz. This result allows lowering the computational burden for the SFE and ABE model by reducing the frequency range of the analysis to this reduced interval.

3 Description of the models and experimental validation

The developed digital twin is a combination of three sub-models: a MB model, a SFE model and an ABE model of a SCA employed in automotive applications. The output of the combined MB/SFE/AFE model is the overall acoustic pressure due to specified working conditions and actuator design. The MB model allows to estimate the reaction forces on the case of the actuator. As from the experimental results it has been noticed that the vibration response it dominated by the excitation due to the electric motor, the plastic gears and their meshing have been neglected in the MB model, which has been developed in MSC Adams\View [3]. Consequently, only the forces due to due contact between the motor and the actuator cases are considered. The torque oscillations of the motor due to the cogging torque have been imposed as function of the motor speed, in the form of Fourier series. In order to model the contact between the motor and the actuator case, bushing elements have been introduced, which stiffness values have been estimated by means of FE computation. Frequency-dependent reaction forces are the input of the dynamic model. In the SFE model developed only the case is meshed. All the internal components are substituted by concentrated masses connected to the bearing housings by rigid elements. The SFE model was developed by using Simcenter 3D as the pre/post processor and Simcenter Nastran as the solver [4]. It has been validated by performing a numerical modal analysis (Nastran SOL 103) on the frequency range of interest and comparing the obtained natural frequencies and mode shapes with the results assessed by the experimental modal analysis (EMA). The examined frequency interval is the one with the highest acoustic emission as determined by experimental measurements. The results obtained with SOL 103 are reported in Tab. 1.

	Natural Frequency [Hz]		
	EMA	Numerical	MAC
Mode 1	1749	1735	0.66
Mode 2	2421	2457	0.56
Mode 3	3729	3639	0.52

Table 1: Comparison between the first three natural frequencies obtained experimentally (EMA) and numerically (SOL 103).

Then, the same validated mesh is used to carry out a dynamic analysis where the input forces are the ones obtained by the MB model and applied on the actuator case. In this case the modal frequency response solution (SOL 111 in Nastran) is used. Furthermore, frequency-dependent modal damping is introduced, which values are estimated by the EMA. To validate the results, numerical acceleration results are compared with experimental results obtained during the operative analysis by the accelerometers Acc1 and Acc2. The output of the SFE the model is exploited as input for the ABE model, which employs the indirect boundary element method (BEM) to evaluate the overall acoustic pressure at specified locations due to the vibration of the case. The ABE model is developed using MSC ActranVI [5]. One point has been located in the same position as the microphone in order to estimate the acoustic pressure to be compared with experiments.

4 Concluding remarks

In this work, a combined MB/SFE/ABE model for vibro-acoustic analysis has been presented. The model is exploited to generate the NVH digital twin of a real SCA employed for automotive applications. The MB model simulates the dynamic behaviour of the component inside the case; the SFE model allows to predict its vibration; the ABE model determines the overall acoustic pressure level at microphone point. Results have been experimentally assessed, and a good accordance is found between the numerical and the experimental data. In fact, the SFE model of the case accurately identifies the first three natural frequencies in the highest acoustic emission interval (Tab. 1). Furthermore, the dynamic SFE model is capable of capturing the accelerations due to the electric motor excitation and so the ABE model in terms of acoustic pressure level. The validation process allows to assert the combined MB/SFE/AFE model as a digital twin of the gearbox which may be used as a powerful tool to guide the designer in the choice of the optimal solution for the noise generation problem.

References

[1] A. El Saddik. “Digital Twins: The Convergence of Multimedia Technologies”. In: IEEE MultiMedia 25 (Apr. 2018), pp. 87–92.
[2] Zhu, Z. Q., and David Howe. "Influence of design parameters on cogging torque in permanent magnet machines." IEEE Transactions on energy conversion 15.4 (2000): 407-412.
[3] MSC Software. Adams/View. Version 2017.2
[4] Siemens PLM Software Inc. Simcenter 3D. Version 2022.1.
[5] MSC Software. ActranVI. Version 2021.