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Adams Marc Co-Simulation of a Washing Machine

By **Seung-Oh Kim, Samsung Electronics and Hemanth Kolera, MSC Software**

Samsung Electronics is one of the world's largest electronics manufacturers and has a presence in over 80 countries and employs around 308,745 people. As of June 2018, Samsung Electronics' market cap stood at US$325.9 billion. The 2018 Which? Awards recently announced Samsung Electronics as the leading Large Appliance brand for its range of home appliances. For Front-Load and Top-Load Washers, JD Power & Associates ranked Samsung #1 in Customer Satisfaction in 2019.

A washing machine is an essential component of our day-to-day activities. Advances in washing machine design have included increases in capacity and spin speed. The industry-wide machine weight and cost reduction initiatives conflict with these design initiatives.

Reducing vibrations in washing machines is a challenge. During spin cycles, significant imbalanced centrifugal forces are generated, which then result in vibration and shaking. Elimination of such vibrations is critical to the design of silent washing machines and the best possible user experience.

A modern washing machine is a complex multi-body system comprising a drum, suspended to a tub with bearings in one or both ends. Operation of the washing machine is actively controlled based on sensors that gauge operating parameters such as water levels, temperatures, loads and tub motion. The rotary motion of the drum creates a flow of detergent and water which cleans the load and also extracts the water during the drying phase of the cycle. The tub is suspended inside a housing using a suspension system, designed to limit the propagation of vibrations from the tub to the housing and from the housing to the floor.

Modeling and analysis of the washing machine dynamics is a considerable challenge as the washing machine comprises of several highly nonlinear elements such as friction dampers, rubber feet, rubber bushings etc.

Samsung has devoted resources to develop methods that can model and predict washer dynamics. The model-based insights are then used to develop technology that can reduce vibrations in the washing machine. Samsung's roadmap for washing dynamics analysis starts with first developing credible models that

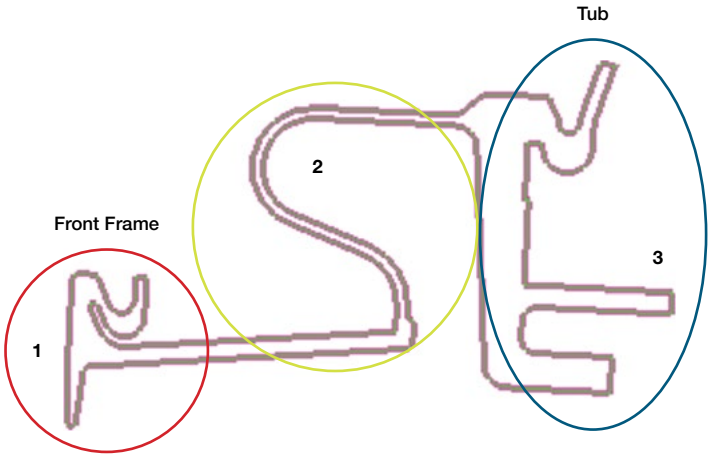


Figure 1

can accurately capture the fundamental physics. This involves accurate modeling of the spring, damper and diaphragm characteristics and material properties of the elastomers. At the next level, analysis is used to optimize the design for noise and vibration. The ultimate goal is to mimic the actual laundry exercise.

Front loading washing machines have a large grey gasket or diaphragm seal around the door. This gasket is what keeps the water from flowing out of the washer when in use. One side of the diaphragm is connected to the frame and the other side to the tub. Besides leak proofing, the gasket provides vibration insulation between the frame and the tub and also prevents the washing machine from jamming (See Fig.1). A cross-sectional view of the washer is shown. Section 1, provides the seal between the door and the glass. There is no contact between section 3 of the diaphragm and the rotating drum. The gasket design has to ensure that there is no contact or wear in the middle section 2 of the gasket.

The washing loads are transmitted from the gasket to the springs damper, suspension system and then to the main frame.

Adams-Marc Co-Simulation

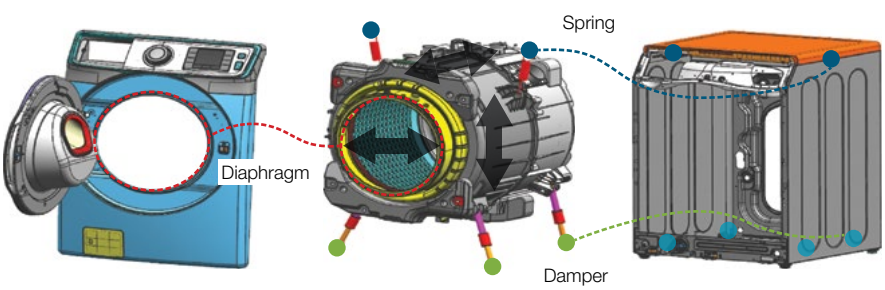
We used an Adams-Marc co-simulation capability to include geometrically and materially nonlinear structural behavior in multibody dynamics (MBD) simulation. Any Adams model and any Marc model can be used in co-simulation with this tool. Post-processing is done separately, Adams results in Adams, and Marc results in the Marc postprocessor.

A co-simulation between an MBD solution like Adams and a Non-linear FEA model such as Marc provides several benefits. The non-linear FEA can accurately describe non-linear behavior of flexible components, including plastic deformation, non-linear material, large deformation of the components, buckling, self-contact etc., while the MBD model can accurately model the system, providing realistic boundary conditions for the non-linear components. A co-simulated model would simulate much faster than a complete model in non-linear FEA without compromising on the accuracy. Current diaphragm simulation approaches at Samsung that did not leverage co-simulation between Adams and Marc did not capture the actual systems dynamics and had limited value to the design process.

The Adams models of the washing machine dynamics include models for the spring, the damper and the diaphragm. The spring is modeled as a preloaded spring element with tensile force, while the damper is modeled as a two-stage non-linear damper element. The diaphragm is modeled as a bushing element, and the primary stiffness is calculated based on the Marc analysis (Figure 2).

The Marc model captures the nonlinear material properties of the rubber diaphragm using empirical models. Various constants

Figure 2



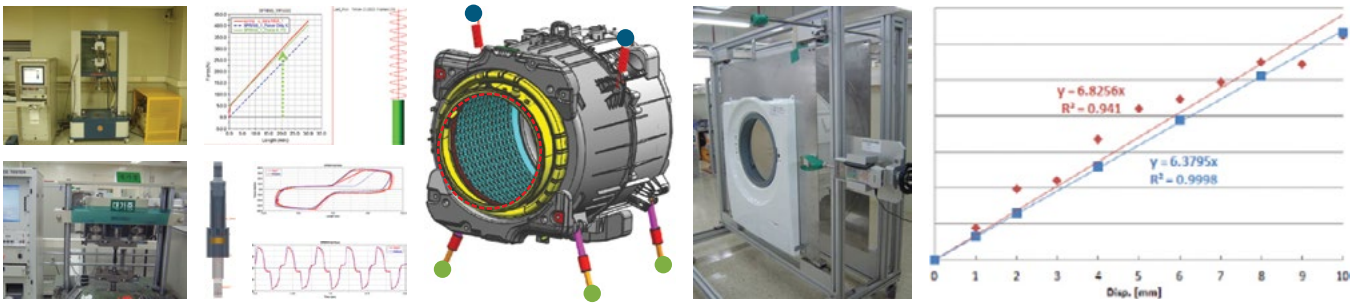


Figure 3

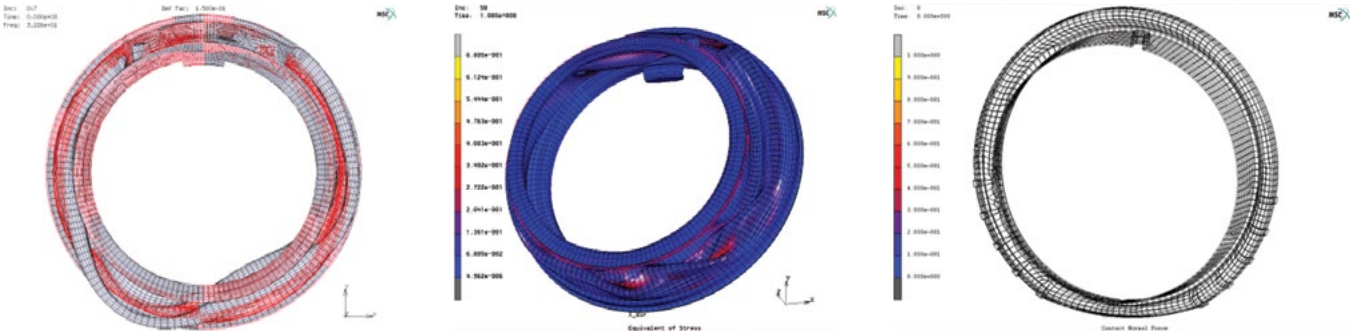
in the empirical model are calculated using material test results. The workflow for capturing the nonlinear material properties is as shown (Figure 3).

Material data is gathered using tests such a simple tension, planar tension, Eg. Biaxial Tension and Shear. The gathered data is processed to extract various model coefficients required to characterize non-linear material models such as Mooney, Ogden etc. The data fitting can be prioritized to capture the dominant strain and strain levels. The characterized material models are then used to run various analysis types in Marc as shown in Figure 4. Linear harmonic analysis can be executed in Marc to gauge the natural frequencies and the diaphragm and estimate the level of vibration. Non-linear static analysis can be used to predict the equivalent stiffness and any contact. The primary stiffness calculated from the Marc model feeds into a rigid Adams Multibody dynamics model which can predict the dynamic acceleration/ displacement and the load transfer to the frame. Besides computing the loads on the washer frame, an Adams-March co-simulation can be executed to run transient dynamics simulation to evaluate deformation, contact and buckling.

The coupling between Adams and Marc (v18.1) is established using MSC CoSim v1.6. The MSC CoSim engine has been developed in order to provide a co-simulation interface for the direct coupling of different solvers/disciplines within a Multiphysics framework. The .ADM and .ACF files from Adams and the .DAT file from Marc are imported into the CoSim interface.

The Adams analysis conditions included an unbalanced laundry load of 500g which was used to trigger the vibrations. Maximum motor RPM was set to 1300. Two Marc cases were evaluated, on two different diaphragm geometries, with and without side ribs.

Figure 4

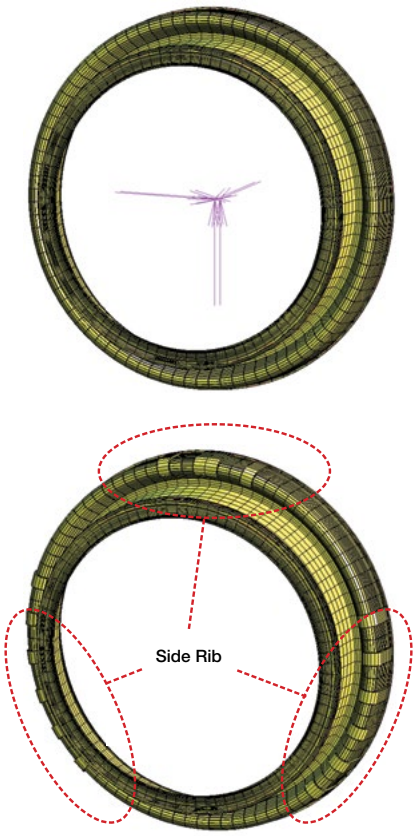


Step 1:
Rubber Material Test
(Simple Tension, Planar Tension, Eq. Biaxial Tension & Simple Shear)

Step 2:
Data Reduction
(Cycle Selection, Polynomial Fitting, shift)

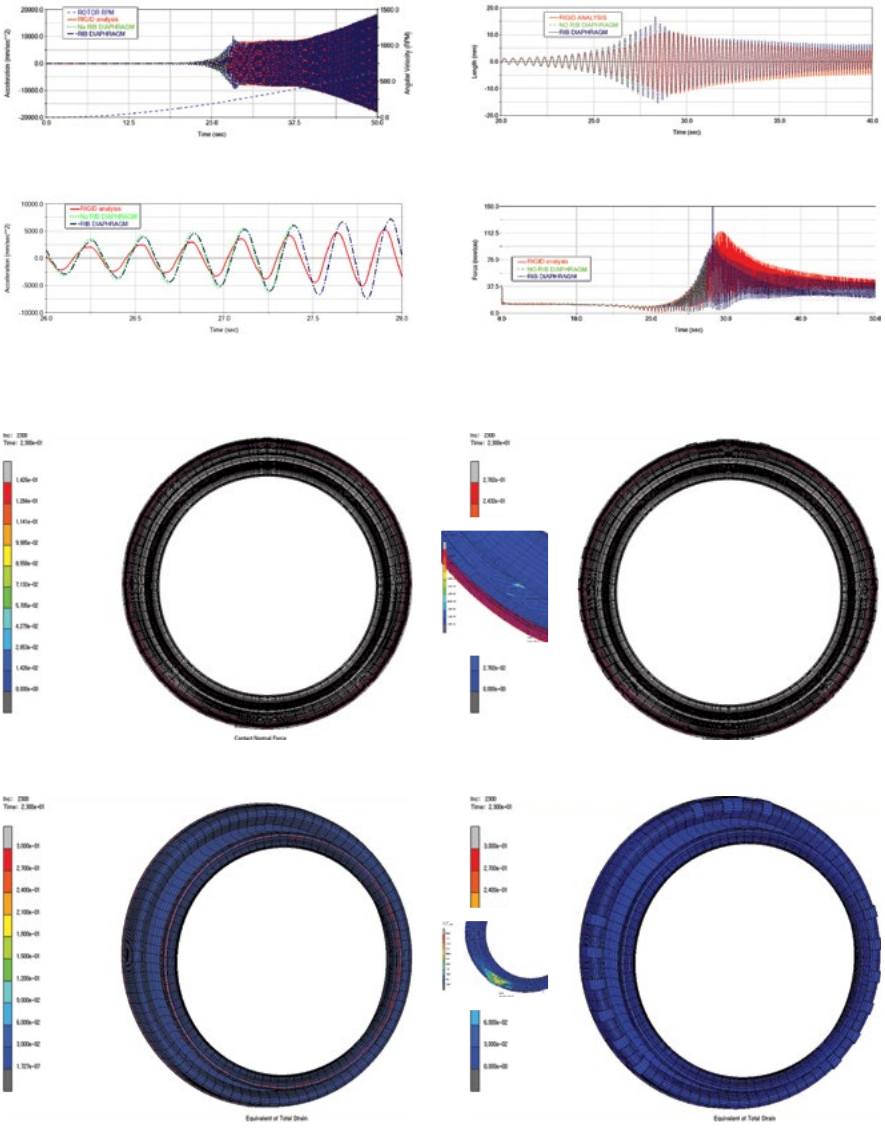
Step 3:
Curve Fitting
(Mooney, Ogden …)

Step 4:
Check Dominant Strain
(Select Strain Level)



Co-Simulation has helped Samsung gather design insight at both the system and component level.

Figure 5



It can be seen from the co-simulated results (Figure 5) that the tub acceleration/ displacement increases, while the frame front force decreases compared with the bushing model.

Design decisions can be made based on direct comparisons of simulated metrics such as total strain and contact normal forces for the two gasket designs.

Exploration of the washing machine dynamics via co-simulation has helped Samsung gather design insight at both the system and component level. The next steps in Samsung's co-simulation journey involves more in-depth simulation-based exploration for vibration reduction and robust design using the most optimized set of Co-sim analysis conditions.