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Ford Motor Company Accelerates Design for Manufacturability of Conical Joints Using Abaqus for 3DS CATIA and Isight

Developing high-quality bolted joints is an integral part of vehicle chassis design. While less understood than the design of connecting members, such as a toe-link that connects the sub frame to the knuckle, robust joints are critical to improving handling and longevity of vehicle performance. Joints that are loose tend to exacerbate quality issues such as alignment, and ultimately the durability of the joined components. A properly designed joint is more efficient and can support larger loads with smaller size fasteners without loosening.

Engineers at Ford Motor Company were tasked to deliver a robust cantilevered conical joint design for the rear suspension system of a midsize passenger car (see Figure 1). To minimize time and cost while meeting functional targets, the team developed an automated Design of Experiments (DOE) process using Abaqus for 3DS CATIA (AFC) for structural analysis and Isight for process automation and optimization.

"Our team chose AFC in order to deploy standard stress modeling and simulation practices in the form of templates to a broader group of engineers within the design organization," says Satyendra Savanur, chassis CAE engineer at Ford.

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>
> **Satyendra Savanur,**
> *Chassis CAE Engineer,*
> *Ford Motor Company*

"Linking Isight with AFC enabled us to develop a powerful and automated design analysis methodology. We used response surface model, one of the approximation models, for finding optimal parameters to size the joint."

Analyzing conical joint performance

A bolted joint is the most common type of attachment method used in the suspension of a car. In this application, a conical joint is used for connecting the toe-link to the rear knuckle with a cantilevered type connection. The two mating parts of the conical joint—the bushing inner sleeve and the knuckle—each have unique manufacturing tolerances of the cone angle.

To develop a robust conical joint between a steel inner sleeve and an aluminum knuckle the following aspects were considered:

- manufacturing tolerances of each component
- contact area between the cone and seat
- angle of the cone
- torque loss after the service load is removed.

To perform virtual tests of their design, the Ford engineers used AFC to create the finite element model of the knuckle and the bushing inner sleeve with the geometry input and material properties from their model created in 3DS CATIA. AFC maintains associativity with the 3DS CATIA model to ensure that the Abaqus model updates are robust when the CAD model is changed within the usable range of design variables.

During the physical assembly process, a forged steel inner cone is forced against an aluminum knuckle seat. Due to the different manufacturing processes used to make each part, the angular tolerances of the conical design features are different on the inner sleeve and the knuckle mating surface.

"Because of the potential angular mismatch, there are variations in contact area when the two surfaces mate together and the joint is fully torqued," says Savanur. Local yielding can occur in the mating materials, leading to changes in contact area and pressure distribution during assembly of the joint. When the service load is applied, further changes to the contact area and contact pressure can occur.

"It is therefore important to simulate both the joint assembly and the loading and unloading of service loads on the joint during the analysis," he says. "Our objective was to deliver a robust conical joint design for the entire range of conical mismatch between the cone and the knuckle."

Figure 1. Close-up view, before assembly, of the toe-link (black) and the rear knuckle (silver) using a conical joint.

For a robust contact analysis and even contact pressure distribution, the mesh of the inner sleeve was constructed to align with the mesh of the knuckle seat. To facilitate mesh alignment in the contact area, a separate "domain" of the knuckle seat (shown in turquoise in Figure 2) was created to simplify meshing. This part was connected to the rest of the knuckle body with a tied contact in Abaqus.

To simulate the bolt assembly process, a virtual bolt between the inner sleeve and the knuckle joint seat was created. External service loads were applied on the sleeve center. Nonlinear stress-strain curves for aluminum and steel were imported into AFC to facilitate the nonlinear analysis. Contact pairs and bolt tension were all created inside AFC. Output of contact area (CAREA) and contact force magnitude (CFNM) were possible using AFC for postprocessing. Finally, the Abaqus analysis file was output and submitted to the high-performance computing (HPC) cluster for running the analyses.

Managing the DOE process

Ford's need to evaluate a large number of designs with different combinations of parameters prompted the engineers to create an automated DOE process. In this process, CAD geometry updates and FEA model updates are completed in the same loop thus allowing a completely automated DOE approach.

At Ford, 3DS CATIA startup is customized with an external product management system. Scripting is used to strip away the linkages to the product management system before initializing the 3DS CATIA interface.

Design parameters are then fed into 3DS CATIA with an external Excel file, a common method used to update a design table within 3DS CATIA. The input parameters from the Excel file are mapped to the DOE task of the Isight manager. This enabled automatic updates of the Excel sheet for each loop. Since Excel is synchronized with the design table, this results in automatic updates of the CAD geometry inside 3DS CATIA. Within AFC, geometry and FE mesh are associated, so the resulting mesh is updated to the changed CAD data.

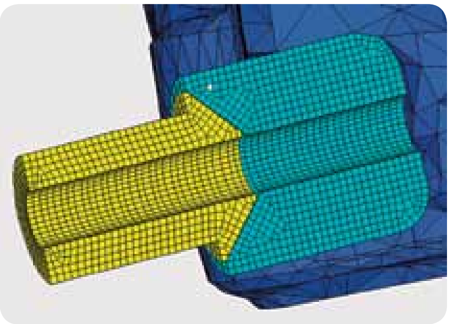

Figure 2. CAE mesh details of the conical joint.

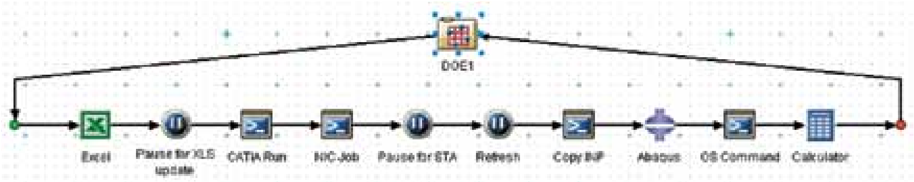

Figure 3. Integrated DOE automation loop using Isight.

"By developing a single integrated process, we were able to drive automatic updates of the geometry and mesh at the same time," says Savanur. To manage and control the DOE process, Isight was used as the process automation manager. The resulting automation loop is completely integrated to run 3DS CATIA and AFC for CAD updates, create the Abaqus FE models, and submit job submission for analysis and post-process results.

The Abaqus component inside the Isight loop was used to extract outputs, including CAREA and CFNM for each run of the DOE (see Figure 3). The input parameters from the Excel file are then mapped to these output parameters to create an Isight approximation model.

"In our case, we used the response surface model method of approximation," says Savanur. This approximate model of conical joint behavior can then be used to show how input affects output and quickly optimize the conical joint.

"This is the first application of an integrated DOE automation loop to morph geometry using 3DS CATIA with Abaqus at Ford," says Savanur.

Isight enables more efficient processes

The set-up and validation of the 3DS CATIA and AFC scripts, HPC job submission batch file, and the Windows batch command file took time and resources to develop, but were well worth it as they are reusable for subsequent projects with minor changes.

"Developing a comparable 3DS CATIA model with an associated Excel design table, and linked to an associated AFC model would take approximately three days to construct," says Savanur. "Modifying and debugging the previously developed scripts to run with these new models would take another day. Using Isight, it took about 3.5 hours for the process to complete 35 analysis runs."

"Typically, the manual CAE process consumes two days just to complete one run. Of course, this timing can be reduced if the project is critical, but this is the typical day-to-day turnaround time balancing several projects per engineer," says Joe Peters, chassis CAE supervisor at Ford.

Time inefficiencies typically occur in the transfer of data back and forth between CAE and CAD organizations, as people have multiple assignments and do not immediately stop their current work when new design iterations are requested; this is analogous to CPU time verses wall clock time.

"It is estimated it would have taken approximately 70 days to complete all 35 runs, while maintaining other day-to-day work; whereas, our new process eliminates the inefficiencies that were part of the manual CAD/CAE procedures," says Savanur. "By creating an integrated and automated closed-loop DOE process using Isight, we completed this task in about four days. This was the only way to help achieve the program objectives of cost and timing with a lean CAE organization."

"Using the automated DOE process, we were able to drastically cut down the time required to develop a robust conical joint with minimal resources," says Peters. "The largest amount of time savings was realized in the automated process of creating a CAE model from CAD. This is a testament to the fact that a small CAE team using new innovative technology helped Ford to achieve program objectives."

By using AFC and creating an integrated closed-loop DOE process with the help of Isight, Ford was able to deliver a robust conical joint design. This joint exhibits good contact area and retains clamp load after load removal, within the specified manufacturing tolerances.

For More Information

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