Process Automation for the Construction of a Finite Element Model of a Diesel Powertrain

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The design of an industrial product involves the contribution of two main groups of technicians: those who propose design solutions and those who analyze their performances from the points of view of various physical disciplines. Their jointed efforts are aimed at finding a trade-off between several, and sometimes conflicting, needs. Such a process is often very time-consuming, being heavily influenced by the implementation of the procedures for the analyses. This process could be improved by reducing the time spent to perform repetitive actions such as the built-up of the mathematical models, so leaving the analyst more time for carefully assessing the results and propose modifications to the designs.
According to this view, the present paper describes the structure and functioning of an Isight process for the automatic construction and complete assembly of the Finite Element (FE) model of a diesel engine and transmission, to be used for a powertrain bending modal analysis. Inputs are principally the CAD models of the main components; output is the FE model ready for the analysis. The measurable result of this process is the reduction of the time requested by the model built-up phase: three to four hours for the automatic process against a one and a half week for an analyst who performs the same job manually. From this, some other advantages derive, described in the paper.

Keywords: Noise, Vibration, Isight, Simlab, Powertrain Bending, Finite Elements, Modal Analysis

1. Introduction

The design of a powertrain is a task that involves the contribution of several disciplines, each of which having its peculiar parameters to handle, like fuel consumption, torque, power, durability, noise harshness and intensity, vibrations, etc… Some of these describe the performance of the powertrain, some others tell about the comfort and pleasantness of driving. To the latter category belong the noise and vibration parameters, which in recent years have gained more and more importance in determining the success of a vehicle on the market.

To this aim, the study of the dynamic behavior of the powertrain is fundamental to predicting some phenomena like the in-vehicle noise, the dynamic stresses (related to durability) and so forth. Methods exist to conduct this study either experimentally or analytically, or by a mixed approach.

In all cases, the concept is that the overall modes of vibration of the powertrain must correspond to frequencies higher than those covered by the excitation coming from the functioning of the engine. Here are some examples drawn from literature about this practice: the design of a transversal V6 powertrain with the objective of maximizing its vibration frequencies and pull them outside the range of influence of the exciting forces (Iqbal, 2005); the optimization of the engine mounts for a longitudinal V6 powertrain, with the aim of reducing the vibration of the vehicle in idle and road conditions (Anab, 2005); the prediction of the in-vehicle noise due to vibrations, by means of a hybrid Transfer Path Analysis (PTA) (Kim, 2008); three practical examples of application of analytical and experimental tools to the design of a powertrain (Juang, 2006).

This paper is focused on the analytical approach. An Isight process had been developed by the authors, within a collaboration between GM Powertrain Europe Srl and Exemplar Srl. The process assembles some common CAE software, providing a tool capable of building a complete FE model of the powertrain, ready for a modal analysis. Such process substitutes the hand-work of an analyst for building up the FE model, with a remarkable savings in terms of time. Thanks to this, the analyst is relieved of a great amount of repetitive work, which does not add to the comprehension of the physics of the problem. As a consequence, the analyst is given more possibilities to exercise his/her engineering skills, which results in a better exploration of the design solutions.

The paper follows this scheme: description of the concept of the manual (current) procedure, description of the automatic process and discussion of what the passage to the automatic process had brought in the design practice.

2. The Powertrain Bending Analysis Procedure

The name Powertrain usually indicates the assembly formed by all the parts of the vehicle that generate the torque; in this paper, however, the same name refers only to the pair constituted by the engine and the transmission gearbox. These two parts are bolted together and subsequently hung to the frame of the vehicle by means of brackets. Between each bracket and the frame there is a component, here indicated as *mount*, designed to uncouple dynamically the powertrain from the vehicle, this component being a rubber ring, a hydraulic device or any other solutions of the like. Whatever this component may be, the result is that the powertrain almost “floats” on the mounts during the vibration as if it were unconstrained. However, the separation is never complete and part of the vibration of the powertrain is conveyed to the vehicle through the structure of the latter, resulting in noise (structure-borne) and vibrations.

Purpose of the Noise, Vibration and Harshness (NVH) analyst is to estimate the dynamic behavior of the powertrain and provide indications about how to modify it in order to reduce undesired effects. The judgment on the design is formulated by comparing the frequency range of the exciting forces, generated by the engine during its functioning, to the natural frequencies with which the design responds. As for the exciting forces, these are separated into *engine orders* by means of a Fourier Transform, which results into a number of distinct terms; for a four-stroke in-line engine, the engine order that excites the powertrain the most is the second, since the first is naturally compensated for this particular engine architecture and the orders above the second have a negligible intensity. The natural dynamic response is estimated via a modal analysis of the powertrain, considered as a free body in the space. The fundamental mode shapes expected at the lowest frequencies are the vertical bending, the horizontal bending and the torsion about the longitudinal axis. In all these cases, the deflection involves primarily the deformation of the parts at the interface between engine and gearbox, while both engine and gearbox remain substantially without deformation. As a consequence, this is the region of the assembly where modifications can be suggested (for example: to add bolts, to add a bending brace). The powertrain design is considered “good” when the upper limit of the frequency range covered by the second order excitation is lower than the fundamental frequency of the powertrain.

2.1 Description of the Procedure

The standard procedure implemented in GM requires the construction of the FE model for the Powertrain Bending analysis in the following manner:

- Starting from the CAD models of the main components of the powertrain, the analyst builds the FE model, complete with bolts.
- The inertial properties of the FE model are assessed and compared to those obtained experimentally on a prototype of the powertrain or on an existing powertrain already in production similar to the one object of the analysis.
- The engine and the transmission gearbox are checked in order to verify that they represent the masses of the two parts with an acceptable precision.

When these steps are over, a modal analysis is launched on a linear analysis code, such as Nastran or Optistruct, where the first few natural frequencies and modes are requested. By looking at the mode shapes, the three main modes, namely the vertical bending, the horizontal bending and the torsion about the longitudinal axis are detected. From this result, the design is judged in the following manner: if the fundamental frequency is higher than the upper limit of the range of frequencies covered by the second engine order, the design is acceptable; on the contrary, the design needs modifications, which will be analyzed by means of the same procedure.

2.2 Motivation for Developing an Automatic Process

All the above steps are very much standardized, namely they are applied always in the same way to any design. At the same time, the FE model build phase is usually very demanding in terms of time: a skilled analyst may need from five to ten working days to complete it. Most of this time is spent in making the bolts, for there is no tool to create them in the way prescribed by GM.

The standard nature of this procedure, coupled with the everlasting need for making the design process faster (and therefore cheaper), led to the conclusion that the procedure could be turned into some automatic process. To this aim, Isight as a process automation manager and Simlab as a FE builder were proposed and then built up together into a single ready-to-use and robust tool.

3. The Automatic Process

The Isight process is constituted by a series of steps that cover the three points listed in paragraph 2.1. Prior to applying it, the analyst has to collect the necessary data, namely: the CAD models of the parts, given as parasolid files; the list of materials assigned to each, given through text files; the ranges of bolt holes diameters encountered on each and every interface between the connecting parts, given again through text files; the information about the inertial characteristics of the real engine and gearbox.
The process works according to the flow-chart depicted in Figure 1.

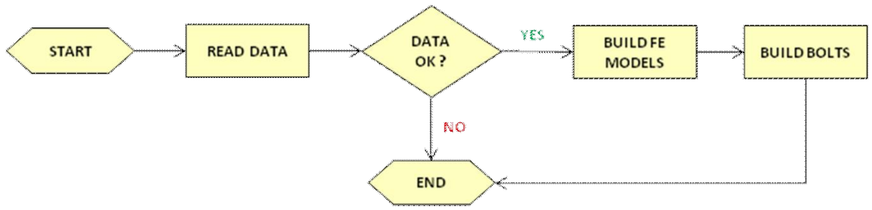

Figure 1. Flow-chart of the Automatic Process

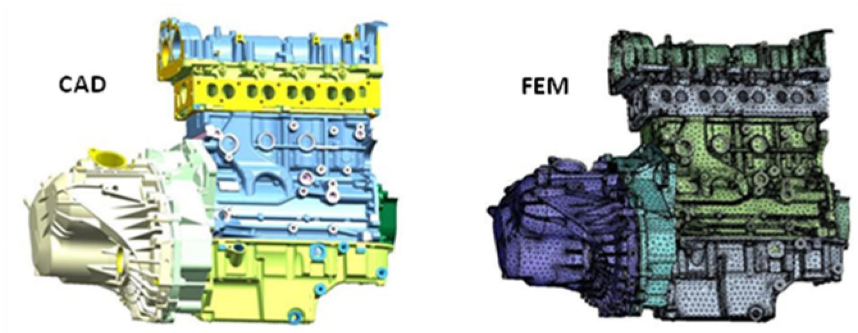

Figure 2. Input CAD and output FE model for the Automatic Process

The first step consists in reading the input data, which are immediately searched for any mistake that would stop the process. If the check is passed, the process calls Simlab and builds the FE models of the single components, followed by the bolts connecting them to each other. This done, the mass of the model is verified as done in the manual application of the procedure.
Figure 2 shows the original CAD models and the final FE model produced by the automatic process for a four-cylinders turbo diesel powertrain.

3.1 Problems Encountered in the Development of the Process

The development time for this process had been around one year. The core was built in two months, to which another two months followed during which tests were performed. From the tests is was evident that the creation of the bolts was wrong, because the latest version of Simlab available on the market the moment when the process was developed did not contain any function capable of producing a result compliant with the GM procedure. Therefore, the rest of the time was spent in developing and testing such a function in Simlab and include it in the forthcoming release 9. The function is pretty robust and can define correctly the bolts even when the CAD models of the holes contain imperfections, which often lead to imperfection in the FE models.

3.2 Deployment of the Process and Future Developments

This Automatic Process was designed in order to become a standard tool throughout GM. To this aim, the access to the process through Fiper was tested, with positive results. The most appreciated feature of Fiper is that the process files can be stored on a single server, to which every analyst can access via an internet page. This way guarantees the standard application of the process and every modification to it would be instantaneously available to every user in the world; on the other side, however, any failure occurring on the server or any trouble in connecting to it would make it impossible for all the analysts to access to the process promptly. As a consequence, the correct deployment of the process is still debated, leaving some room for the possibility to send out the original process files to each single analysis group within GM.

For the future there are plans to improve the process with some new features, related to details in the content of the FE models, but the Isight structure should remain substantially unchanged. However, the experience gathered so far with Isight led to planning the automatization of some other processes in GM, either in the NVH department and possibly in others. In all of these cases the purpose is the same as for the Powertrain Bending process: to reduce the time spent to perform repetitive operations, enabling the analysts to work more on the concepts and to explore more possibilities in the definition of the design.

4. Some Considerations on the Automatic Process

Since the validation phase, consisting in repeating old analyses of several powertrains by means of the process and checking the results, the automatic process revealed its beneficial characteristics. First of all, the time cost for the analyst shrunk from the original five days (best estimate) to around two – three hours. These times are measured starting from the moment when all the input data have been gathered and ending with the completion of the model built-up phase; the time needed to collect the data is the same in the two cases. One objection to the use of a process like the one described in this paper may be that, due to the automatization, the analyst misses the chance to get the feeling of the physical behavior of the powertrain. In other words, since he does not work on the models directly, he does not know them in detail and may be unable to understand the problems that may arise with the design. However, this does not occur, in that the process relieves the analyst of the tedious part of his job, leaving him/her more time for the analysis of the results, followed by engineering considerations and new solution proposals.

Another big advantage brought in by the speed of the automatic process is that many more design solutions can be evaluated in a given time. During the first phase of a design, when the overall sizes and shapes are liable to be changed deeply, such a possibility is surely welcome. In fact, this is the moment when the various teams, representing the various disciplines, strive to have their own targets and requirements met, which are very often in conflict with one another. What comes out from this phase is more or less the final design and any subsequent change is very unlikely to provide any relevant improvement to the design if the initial solution contains some big flaw. To explore a large number of possibilities in a short time during the initial phase means to assess more completely the possibilities at stake, thereby leading to a more compliant solution. This is what the automatic process is meant for.

5. References

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