

Compliant Parts Simulation Procedure

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ABSTRACT

The development of virtual techniques becomes more and more important for the automotive industry to allow an acceleration of the vehicle development and the reduction of hardware prototypes. By analyzing the main problem points arising on the first hardware builds it came out, that compliant parts are most critical, since their digital representation does not coincide with the reality, so that many changes are made after first hardware validation.

Already some years ago GM has started to work together with the Fraunhofer-Chalmers Centre in Gothenburg, Sweden, on the development of the software **Industrial Path Solutions (IPS)**. At one side the enhancements of the software itself build up the basis for investigations of cables, hoses etc, at the other side in particular for this kind of simulation the industry itself has to invest a lot effort for the effective application of the software.

To allow the effective usage of compliant part software load cases were defined. These had been classified regarding their requirements on the software and thus a status had been determined for each class, which indicates the feasibility. On the basis of issues with compliant parts the above procedure will be explained and demonstrated to show the benefit of such software for the automotive industry.

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INTRODUCTION

Product quality is one of the most important characteristics for the success of a company. Only a customer who is satisfied with the quality will buy a new product from the same company again. Product quality is the key for a good image and the best advertisement for the company.

As decisive factor GM has identified the importance of the quality and works hard on its daily improvement. In all departments of vehicle development engineers are searching for new ways of discovering problems in an early stage. The enhancement of the virtual methods helps a lot to satisfy this demand.

The reference to the reality is the basis for the implementation of a virtual method. To meet this requirement a lot of knowledge, mathematics, software programming, etc. is necessary. In 2004 GM started an internal project to investigate potential software tools for the interactive simulation of compliant parts. The reason for that was the demand on reducing hardware prototype phases. Since until then compliant parts could only be validated on hardware, virtual investigations of these parts and operations build up a prerequisite for the elimination of prototypes. With suitable software it is possible to detect problems like clearance problems, length compensation as well as critical forces and

stresses in a vehicle project early in the vehicle development process.

The software to simulate compliant parts is still under development. In parallel, the integration in the vehicle development process is ongoing. For this task the software must fulfill a lot of requirements.

Another task for integrating the software lies in defining a correct set of load cases. Therefore the vehicle is analyzed and load cases are defined. The load cases are allocated in different load case classes. For obtaining realistic results load cases have to be specified with correct parameters for loads and materials, so that load cases mirror the requirements of real applications. The paper gives an overview how GM has integrated the compliant part simulation software into the vehicle development process and for which load cases the software is used. The paper gives furthermore insight into the engineers work with the software, which is demonstrated on four concrete examples.

REQUIREMENTS AND FEATURES

This section should not only give an overview about the requirements on the software, but also about the work at industry to be able to apply the software beneficially. Also exemplarily the actual status of the software tool IPS will be

given, which requirements are already fulfilled and which points are still open.

Software requirements

When the project was started, the first step was to summarize the requirements on such software. Already from the beginning it was supposed to perform investigations on compliant parts interactively during a virtual tryout directly in DMU in contrary to a simulation with large pre- and post-processing.

Beside this demand on real-time the requirements are classified in requirements on the models of compliant parts and requirements on the functionality to act on compliant parts. The reason for that lies in the different nature of these requirements. The first group deals with the theory that had to be developed for handling of cables or hoses, whereas the second group has to do with requirements regarding the graphical user interface. For the latter we have restricted the content to items, where new development is necessary for compliant parts. Of course there are additional features of an interface like distance and angle measures or section planes that are useful in this context. See [Table 1](#) and [Table 2](#) for the listed requirements, which will be described below.

Table 1. Model requirements for compliant part software

No.	Model Requirements
M1	Segment routings between clip points
M2	Intermediate clips
M3	Branching points
M4	Free end points
M5	Preformed hoses
M6	Multilayered hoses
M7	Non-circular cross-sections
M8	Inelastic behavior
M9	Temperature/Pressure Dependency
M10	Surfaces
M11	Large displacements of surfaces
M12	Buckling

Whereas the first model requirement M1 simply means the poor basic routing, the items M2-M4 define the necessary modeling for wiring harnesses. The usage of intermediate clip points M2 would allow investigating the optimal position of the clip on the cable and also the application of different clip types with less restriction on degrees of freedom. So some clips could be modeled as pins, which allow rotation along one axis only, or as guiding point, where rotation is possible in all directions only the position of the middle line is fixed at that location.

The modeling of branching points M3 has high demands on the mathematical model, but is very helpful for engineers to predict the locations of branching points. Furthermore, the free end points M4 are in particular suitable for manufacturing engineering, since parking positions of cables and hoses during assembly, f. e. marriage, could be simulated.

To be able to analyze hoses M5 and M6 are required. M5 allows setting the stress-free state of a hose to a non-straight middle line, which is often the case for cooling hoses. The multilayered hoses M6 generally introduce a collision handling between an inner hose or cable and an outer hose. Besides the usage of this feature at hoses one could also think about a wiring harness segment in a grommet there.

M7 allows the modeling of other parts that could be described through a middle line and constant cross-section, f. e. weather strips or safety belts.

Since the isotropic approach for wiring harnesses denotes a strong simplification of a complex system, the linear elastic approach may not be accurate enough for a reliable investigation of some kinds of compliant parts. Therefore it is required to handle inelastic behavior M8. Similarly, also the temperature and/or pressure could have significant impact on the behavior of a cable or hose, which leads to the requirement no. M9.

The last 3 requirements deal with surfaces, f. e. headliners or carpets, which are also in focus of the project. The application of compliant part software includes in this case the validation of assembly processes, where the fixation points are considered and potential deformations of the objects are evaluated, so that nonlinear theory with buckling is essential.

Table 2. Functionality requirements for compliant part software

No.	Functionality Requirements
F1	Force/moment/stress computation
F2	Length optimization
F3	Warning messages at limits
F4	Add/remove clip points/branches
F5	Input of motion data
F6	Synchronization of motion data
F7	Interactive manipulation
F8	Collision detection
F9	Collision handling
F10	Swept volume computation
F11	Automatic path planning
F12	Dynamical investigations

As output of the software it is desired to obtain the forces, moments and stresses of compliant parts for the evaluation of different routings or sequences, so this is the functionality requirement with the highest priority. The numbers F2 and F3 are based on that, so that it is possible to investigate different lengths of compliant parts in an easy way and to set limits on output parameters.

Whereas F4 describes a basic feature for the handling of clips and branches, F5 to F7 denotes different possibilities of motion. At one side the import of predefined motion data in a specific format is possible, so that simulation results could be transferred to the compliant part software. This could also be extended with F6, where a synchronization of motion data is helpful to be able to assign different motion files to different objects. At the other side interactive manipulation for the direct investigation without precise knowledge of the motion could be chosen for unspecified motion. As format for motion data we have chosen XMO-files, since they can also be imported to Teamcenter Visualization.

The collision detection and collision handling, items F8 and F9, lead to a more realistic behavior of compliant parts. Item F10 simplifies the presentation of the outcome of an investigation through showing the complete space a compliant part could take.

The last two items are the most difficult to implement. Automatic path planning of compliant parts denotes actually three different features. The first feature should be able to automatically find a path of a compliant part from a start- to an end-position without colliding with the environment. The second feature should compute a path for rigid parts, but with a compliant constraint, i.e. import for service engineering to disassemble parts without opening a closed loop. The last feature deals also with rigid parts, but the path should be computed under consideration of compliant parts in the environment.

Moreover, the most investigations can be performed on the basis of a quasi-static model, but for some applications dynamical modeling F12 is required, i.e. to consider noise and vibrations.

Industry Tasks

Beside these requirements on the software itself a lot of additional activities of a company are required to be able to apply compliant part software beneficially. First of all the material properties of compliant parts are playing a significant role in the outcome of compliant part investigations. So a process has to be defined, how to obtain accurate values for density, Young's modulus etc.

But not only input parameters are required. For the evaluation of investigations boundary values are meaningful, f. e. tensile strength values or conditions on bending radius. Some of these are already available as static criteria; some of these have to be measured.

Also important for an industry user is the process for simulation. Although the situation in the virtual environment is displayed similarly to the hardware and interactive

manipulation is enabled, the handling of compliant and rigid parts and the complete process of investigation differ significantly. Whereas in hardware only one variant could be analyzed at once, in the compliant part software one could summarize all interesting variants and work with swept volumes instead. Also tolerances could be handled in the same way.

The testing and validation of the software build the basis for the productive usage of compliant part software, since only a validation is able to show, how the simulation results have to be interpreted. Therefore all different kinds of load cases should be validated and compared to reality to gain experiences with the software. These could then influence the simulation process.

Actual Status

When the project for the simulation of compliant parts was started, an intensive investigation of available tools and theories was performed, see (1). GM/Opel decided to work with Industrial Path Solutions (IPS) of the Fraunhofer-Chalmers Centre, see (2). Whereas this status is given with respect to IPS, the most strategies described in this paper could easily be adapted to other approaches.

Referring to [Table 1](#) the items M1-M5 and M7 are fulfilled in the IPS software. This means it is possible to model segments between clips, clips in the middle of a cable, branching points and free end points as well as hoses with middle-lines which are non-straight. Even if these modeling aspects are planned to be enhanced in future releases of the software, they allow meaningful investigations for wiring harnesses and hoses already today. The additional requirements M6 as well as M8-M12 will add surfaces and multi-layered hoses to the number of compliant parts, which could be analyzed.

The functional requirements F1-F10 are completely available in the software, so that detailed investigations could be performed with realistic behavior due to collision handling, with motions that coincide with the motion on the street and with user friendly tools for length optimization and boundary conditions. Furthermore, the swept volume could be given to designers to route cables and hoses with care of engine/chassis motion.

The last two items in [Table 2](#) are technically an ambitious challenge. The automatic path planning as described above would allow the computation of complex assembly paths with compliant parts, whereas dynamic investigations could be beneficial in noise and vibration departments. Although both features will not support a large number of load cases, the business value legitimates the needed effort.

The actual status on GM internal investigations in this project contains an outstanding process to obtain the material properties, guidelines for the usage of compliant part software and a defined process for the productive simulation of suitable load cases. Some of the experiences will be explained on typical examples later in this paper.