

Virtual Analysis of Compliant Parts

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ABSTRACT

Automotive OEMS are continuously working on improvements of their vehicle development processes, to improve quality, reduce lead time and cost. In particular the enhancement of virtual methods is crucial for manufacturing engineering to enable the elimination of physical prototype builds and thus to reduce development cost and time. By analyzing the main issues in reduction of physical builds, compliant parts were identified as being most critical, since their digital representation does not coincide with the reality, so that many changes needed to be made after first hardware validation.

As input for compliant part analysis software the material properties have to be specified to allow simplified handling of these parts as homogeneous objects. This is a completely new task for automotive industry, since this data was not needed before and is thus unknown. In detail, for a realistic analysis of the real behavior of compliant parts the bending stiffness or equivalently the Young's modulus, together with the density and Poisson's ratio are needed.

A validation showed, that a lot of cables could be modeled quite well using a linear elasticity approach with the described properties. Since the sensitivity of the cables regarding the shape is really low regarding these material properties, the simple measurement setup is already sufficient for a lot of applications mainly from the design and packaging area and is already used globally. Further activities to improve the accuracy of material properties for nonstandard cables and hoses are ongoing.

INTRODUCTION

In the time of increasing competition and related pricing pressure the replacement of physical prototypes by virtual prototypes is a common method of choice. While the representation of rigid parts in virtual prototypes is satisfactory, large deviations occur with nominal data for flexible parts like cables, hoses and interior parts.

As a consequence most product and assembly validations are executed during the hardware phase at a quite late point in the development process leading to high change efforts and cost. A prior virtual analysis of those problems would allow an accelerated validation phase, reduction of test hardware and a fundamental decrease in engineering changes.

To achieve this, an interactive simulation tool for all flexible materials is desired, where different approaches can be investigated. Besides the software aspect the material and geometry properties of flexible parts play a significant role in obtaining accurate simulation results. Since the majority of problems arise for wiring harnesses, the modeling of the related structure stood at the beginning of the in-house activities at Adam Opel GmbH - General Motors Company.

This paper contains an overview of different numerical approaches for cable simulation, the measurement details for wiring harnesses with a sensitivity analysis and the application status of the software together with some examples.

MATHEMATICAL BACKGROUND

For the effective usage of compliant part software the supposed approach should support interactive investigations of cables to allow the application of the software during virtual tryouts, which are performed regularly at specific gates in the vehicle development process for the validation of the assembly process. Additionally, general nonlinear theory

should be applied to avoid restrictions in cable routing and allow the usage of the software for all wiring harnesses inside the vehicle and plant. Another desired feature lies in the accurate modeling of free hanging branching points, because the misrouting of branches causes a lot of issues during hardware validation.

To allow the application of the software inside GM, a software environment and user interface should be available. In contrary to (1) GM is not aiming to include the wiring harness analysis capability into a virtual reality system. Instead, a desktop solution providing this capability to every engineer is preferred with a graphical user interface allowing fast and easy handling of flexible parts.

When the activities were started to investigate concepts for cable simulation in 2004, only a few research groups over the world had studied this topic. (2) applied for patent with an algorithm for single cable segments with boundary conditions up to 180° variation. Their concept included a software development kit, which was designed to be integrated into virtual reality user interfaces.

Another approach from the virtual reality community comes from (3) and (4). Also developed to be integrated in interactive simulation environments, their numerical approach is based on an extension of the multibody dynamics theory including collision handling and friction.

An immersive virtual reality approach was investigated by (5) including collision handling with the focus on the user expert creativity and intuition, whereas (6) introduces a dual mechanical model based on the finite element method, where a free form surface model of the flexible part is combined with a rigid bar network.

Additionally, there had been some work on the topic of real-time interaction of cables and hoses by (7) and (8), both with the main focus on the routing functionality with 3D handling and neglecting material properties.

Finally, (9) includes cable simulation based on beam theory in their software Industrial Path Solutions (IPS). Their approach is based on the general nonlinear theory and is therefore open to extensions concerning branching points and inelastic behavior. Due to the availability of a user interface this approach was evaluated to fit best the GM requirements.

MODELING ASPECTS

The pure software development is not sufficient for the effective application of compliant part software. As an input material properties have to be specified, which are in general not available until now. The reason for that lies mainly in the complexity of composite materials like hoses and wiring

harnesses and the unavailability of simulation techniques for those parts.

TASK

From a mathematical point of view, the computation of the shape of a cable is based on the minimization of the internal energy of the complete system. Surprisingly, this leads to an interesting effect, that by neglecting the gravity the results are independent of the density and the bending stiffness. This yields that the middle lines are theoretically equal for differently thick cables in absence of gravity.

Due to this fact one can think that the determination of the exact material parameters is not worth to investigate. Indeed for comparisons of different wiring harness scenario a rough approximation could lead to sufficient results for optimizing a routing. However, when forces, moments or stresses should be analyzed, the determined results are linear dependent on the input material parameters and should therefore be calculated carefully.

The physical behavior of wiring harnesses depends not only on the number and types of cables inside but also on the insulation and the type of clips or other fixation points. Furthermore the position of cables is not known in advance and varies from one wiring harness to the other due to the manufacturing process by hand. However, the inclusion of single wires with all respective aspects like friction and position in simulation directly would destroy the opportunity of interactive simulation because of the complexity of that task.

STRUCTURE OF WIRING HARNESSSES

A wire consists normally of a copper part covered with a mantle of PVC or another polymer. The nominal cross-section areas range from 0.35 to 25 mm² with no restrictions in combining them to bundles with diameters of 2-3 mm up to approx. 30 mm. The bundles of wires were held together by different types of insulation, see [Tab. 2](#) for the most typical examples.

Whereas the tapes compress the wires, which stiffen the harness, the bundle inside of conduits has free space to move, so that these differences must be taken into account. Furthermore, the diameter and geometry of the convoluted conduits is known in advance in contrast to the tapes, where the wires inside the bundle define the diameter. The twisted cloth tube is used for heat and friction protection and leads also to different properties in comparison to tapes and conduits in particular for the diameter because of its thickness.

MEASUREMENTS

As input parameters for the simulation the Young's modulus E , the density ρ and the Poisson's ratio ν are required. But instead of Young's modulus and density the equivalent parameters bending stiffness EI and mass per unit length ρA are considered, which have the relationship

$$\rho = \frac{\rho A}{\pi r^2}, E = \frac{4EI}{\pi r^4},$$

where a circular cross section is assumed with area $A = \pi r^2$ and moment of inertia $I = \pi r^4/4$ with radius r .

To obtain accurate values for that, measurements are performed described in the following.

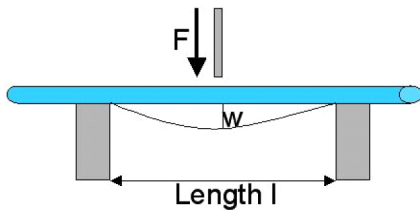


Fig. 1. Bending stiffness measurements

Fig. 1 shows the configuration of the measurements to obtain bending stiffness values. The mathematical theory assumes two links of the bar at both beddings; hence the displacement in the middle is given as

$$EIw = \frac{Fl^3}{48},$$

where F denotes the applied force, w the displacement in the middle and where the bending stiffness EI can be computed. The outcome of the measurements consists not of a single value of force F , length l and displacement w but encloses a curve of values signaling the values over time in a force versus displacement diagram shown in Fig. 2.

The fitting of the straight line representing the elastic phase is considering an initial nonlinear phase. The gradient of this curve was then taken as bending stiffness. The measurements for density and diameter were carried out with an accurate scale of precision 0.1 g and a sliding caliper of precision 0.1 mm.

With this measurement technique behind a process was defined, which yields the material properties for standard cables and hoses in preparation for the simulation. As consequence the software for compliant part analysis could be applied productively at GM. In the following some investigations regarding the sensitivity of input parameters on the simulation results are considered.

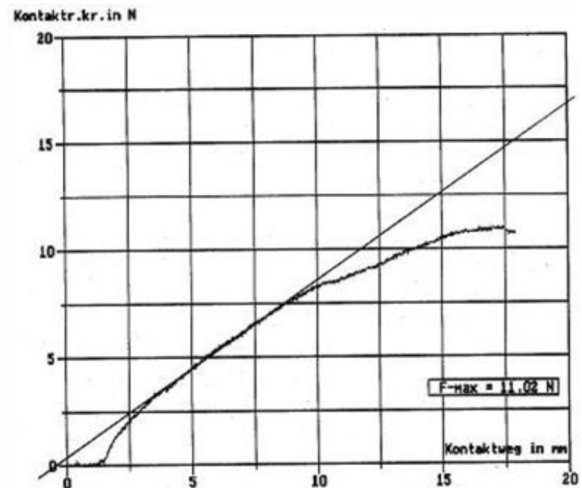


Fig. 2. Measurement results curve, the x-axis contains the displacement w in the middle and the y-axis the applied force F in N

SENSITIVITY ANALYSIS

For the sensitivity analysis four different cable shapes were simulated, see Fig. 3 and the input parameters were changed in regular distances for Young's modulus and density, the four different shapes and the resulting diagrams in double-logarithmic scale can be found in Fig. 10 and Fig. 11.

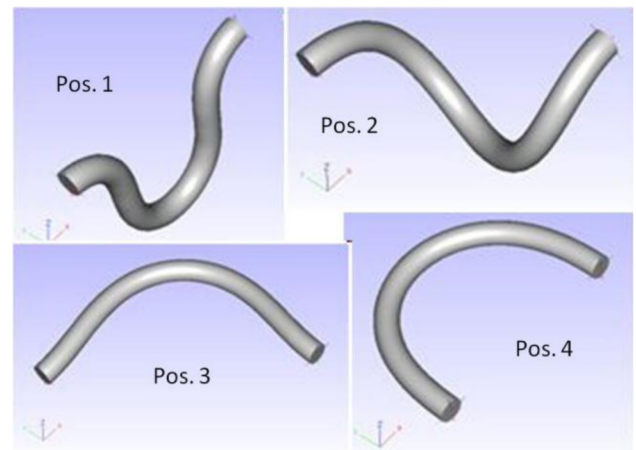


Fig. 3. Simulated cable shapes

Both diagrams show a linear dependency of the input parameters on the maximum deviation. But much more interesting is the fact that for typical values, i.e. $\sim 10^6 - 10^8$ N/mm² for Young's modulus and $\sim 10^3 - 10^4$ kg/m² for the density the deviations do not exceed values of $\sim 10^{-2}$ mm, so that the error due to fitting analysis could be neglected for shape prediction. If forces, moments or stresses should be investigated, the defined process to obtain the material properties leads to a deviation of 30% in the input