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Comparison of Different Data Acquisition Techniques for Shape Optimization Problems

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Abstract**—**Non-linear FEM calculations are indispensable when important technical information like operating performance of a rubber component is desired. For example rubber bumpers built into air-spring structures may undergo large deformations under load, which in itself shows non-linear behavior. The changing contact range between the parts and the incompressibility of the rubber increases this non-linear behavior further. The material characterization of an elastomeric component is also a demanding engineering task.

The shape optimization problem of rubber parts led to the study of FEM based calculation processes. This type of problems was posed and investigated by several authors. In this paper the time demand of certain calculation methods are studied and the possibilities of time reduction is presented.

Keywords**—**Rubber bumper, data acquisition, finite element analysis, support vector regression.

I. Introduction

COMPANIES can only be competitive if they are able to provide time and cost efficient and innovative products. It is an engineering task to develop better solutions. The results of their design are different plan variants. In order to proceed the final control calculation and the manufacturing documentation optimization step is necessary. The finite element analysis is one of the best tools which make the possibility for producing these plan variants and simulating the mechanical response of the investigated structure. For the cost and time efficient work and development the software and hardware are available. In rubber technology cost and time efficiency requirements are also in focus.

Engineering rubber parts have to meet several kinds of requirements as a result of their function. One of these is that they must have a predefined load-displacement curve under load while the material characteristics remain the same. Achieving this aim is a problem of optimization.

The rubber bumpers built into the air-springs of vehicles (Fig. 1) perform several important functions, such as working together with the air-spring as a secondary spring, thus modifying the characteristic when pressed together. When the vehicle is in a stationary position and settles to the ground, the static weight of the chassis and the body rests on the bumper. If the fiber-reinforced bellows of the air-spring wears through while the bus is running, the vehicle can safely reach the nearest garage at a limited speed bouncing on the bumper, so no additional damage will occur. It prevents metal-on-metal collision at large dynamic impulses, and absorbs the impulse. These rubber bumpers are subject to compressive stress, for which the characteristics show a progressive feature.

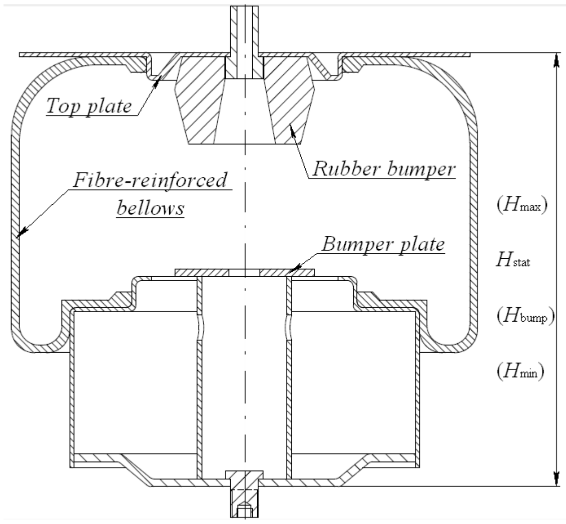

Fig. 1 The air-spring structure with the rubber bumper

The literature does not devote much room to the shape optimization of the rubber bumpers of air-springs. The stiffness of rubber mounts in three directions on the basis of parameter examinations is optimized in [1]. Optimization based on sensitivity analysis using a special purpose finite element code is performed in [2] for material properties and shape, where stiffness was also taken into consideration. Determining the shape had the aim of minimizing the volume of the rubber part. For the purpose of minimizing the cross-sectional area and the maximum stress of the rubber mount and for that of maximizing the life cycle, shape optimization using an Ogden-type material model and commercial finite element software is applied in [3]. Several objective functions in a system where the optimization had several stages are handled. A back-propagation neural network (BPN) is used to find the connection between the input and output data and then a micro-genetic algorithm (MGA) is used for global optimization. A large number of finite element running results are used as learning points. The differential evolution (DE) algorithm produced excellent results for different applications in engineering. The optimization process is performed by

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Fortran routines coupled with finite element analysis code Abaqus in [4]. Shape optimization was used to design a rubber bushing model using DE algorithm to meet target stiffness curve obtained by finite element method. A Pascal code based DE was developed for shape optimization [5]. A formulation of the non-parametric shape optimization problem of a rubber bushing in order to fit the static load-displacement curve with the desired one was presented in [6]. In [7] an [8] extensive studies on shape optimization of a rubber bumper are performed, see also in Fig. 1. The procedure is based on the finite element method and the support vector regression (SVR) model. A finite element code developed by the authors and based on a three-field functional is used for the rapid and appropriately accurate calculation of the characteristics of rubber bumpers. A rubber shape is evaluated by the work difference and the area between the desired and the actual load-displacement curves. The objective of shape optimization was to find the geometry where the work difference is under a specified limit. The tool of optimization was the SVR method, which provides the regression function for the work difference. The minimization process of the work difference function leads to the optimum design parameters. The work difference is the area (filled with grey) between the desired load-displacement curve and the curve obtained by finite element computation for a specific rubber bumper shape, see in Fig. 2.

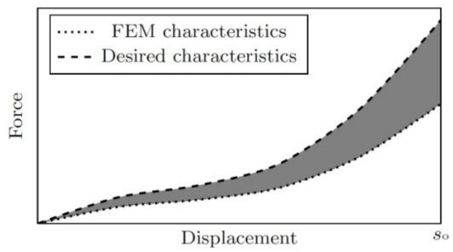

Fig. 2 The derivation of the work difference

Studying the different approaches and methods, it is clear that a large amount of numerical data is required for the accurate solution of the shape optimization problems, e.g. for rubber parts. The basic tool for data acquisition in this area is the finite element analysis using a special purpose FEM code or commercial finite element software as a solver. Both solutions have their advantages and disadvantages considering for instance the memory and time demand of the calculation or the time and the complexity of preliminary calculations before running the computing algorithm.

The running time of the solver can be significant in practice, though in the above mentioned optimization problems the proportion of the time interval is needed for this step in the total calculation time is generally low.

Analyzing the total time of FEM based calculation processes some possibilities of time reduction can be found in the pre-processing and the post-processing phase.

In this paper three calculation methods applied by the authors in shape optimization of rubber bumpers used in air-spring structures are presented and compared from point of view of the total time demand.

II. Comparison of the Time Demand of Different Finite Element Solvers

Rubber bumpers may undergo large deformations under load, which in itself shows non-linear behavior. The changing contact range between the parts and the incompressibility of the rubber increase the non-linear behavior further. For rubbers the material models are generally given by the strain energy density function. A successful finite element simulation of rubber parts hinges on the selection of an appropriate strain energy function and on the accurate determination of material constants. The two-parameter Mooney-Rivlin material model is applied to describe the material behavior. According to the ISO 7743 [9] laboratory measurements including compression tests are used to determine the numerical material parameters for the finite element analysis. The problem illustrated in Fig. 1 was solved with a special purpose code and with a commercial finite element software as well. Each approach must provide the same results. The displacement response of the rubber bumper provided by the finite element software can be seen in Fig. 3.

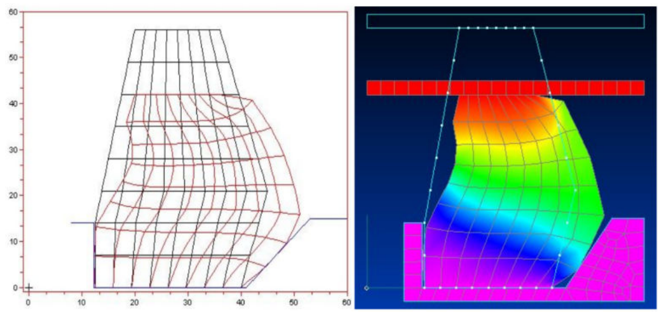

Fig. 3 The displacement response of the rubber bumper with the usage of the code and the finite element software

III. Strategies for the Data Acquisition Process

In the above mentioned rubber shape optimization problem the large deformation and the working condition involve contact making the task more complex. The basic steps of the finite element calculation including contact are illustrated in Fig. 4. It is well known that finite element analysis consists of three separated modules.

The first is the pre-processing which involves the construction of the geometry, the development of an appropriate finite element mesh, the assignment of suitable material properties and the application of boundary conditions in the form of loads and constraints.

The second is the solving step (processing) which involves the stiffness generation and the solution of equations and results in the evaluation of nodal variables. This is a black box operation. Here, the governing equations are assembled into matrix form and are solved numerically.

The third is the post-processing which deals with the representation of results. Once the solution is verified, the quantities of interest can be examined.

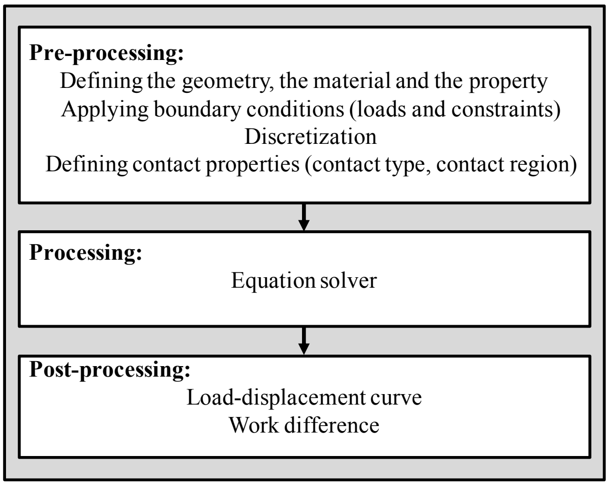

Fig. 4 Basic steps of the finite element calculation

The three steps were investigated from point of view of the total time demand and the possibility of time reduction. The first aspect of the analysis was the way of data transmission between the three main phases. As a result of this consideration the following strategies were defined (Fig. 5):

- Manual Data Acquisition (MDA);
- Partially-programmed Data Acquisition (PPDA);
- Fully-programmed Data Acquisition (FPDA).

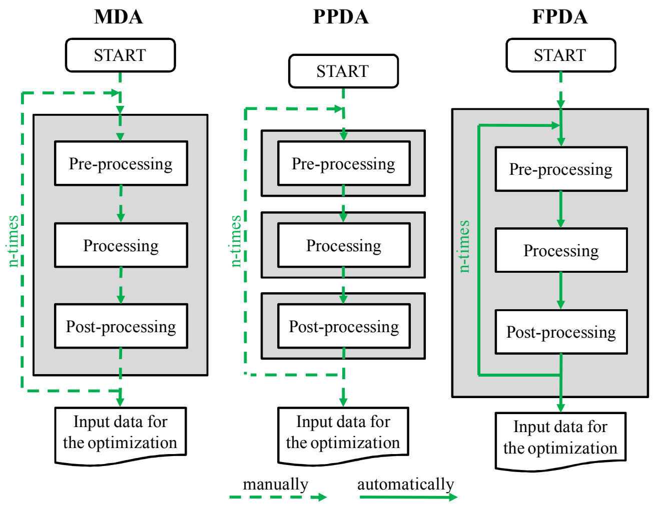

Fig. 5 Classification of calculation

The time demand of the steps in the case of the different strategies is denoted and the relationship is given by (Fig. 6):

$$t_{MDA}^{global} = n(t_{MDA}^{pre} + t_{MDA}^{sol} + t_{MDA}^{post}) \quad (1)$$

$$t_{PPDA}^{global} = n(t_{PPDA}^{pre} + t_{PPDA}^{sol} + t_{PPDA}^{post}) \quad (2)$$

$$t_{FPDA}^{global} = n(t_{FPDA}^{pre} + t_{FPDA}^{sol} + t_{FPDA}^{post}) \quad (3)$$

where t_{MDA}^{global}, t_{PPDA}^{global} and t_{FPDA}^{global} are the global time demand in case of the MDA, PPDA and FPDA, respectively, the superscripts ^{pre}, ^{sol} and ^{post} are the pre-processing, (processing) solving and post-processing modules, respectively, and n is the number of the so called learning points for the optimization process. Comparing the time intervals introduced we have that

$$t_{MDA}^{pre} \gg t_{PPDA}^{pre} \gg t_{FPDA}^{pre} \quad (4)$$

$$t_{MDA}^{sol} = t_{FPDA}^{sol} \approx t_{PPDA}^{sol} \quad (5)$$

$$t_{MDA}^{post} \approx t_{PPDA}^{post} \gg t_{FPDA}^{post} \quad (6)$$

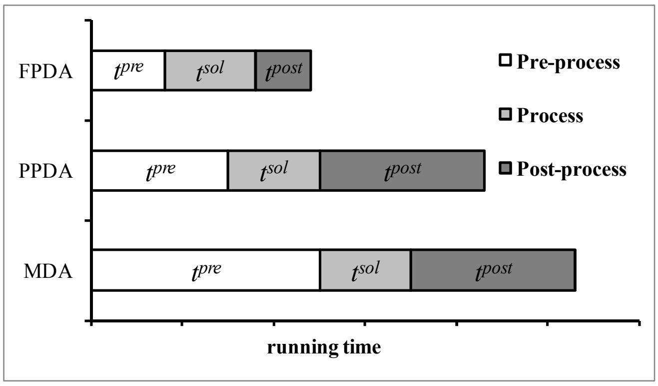

Fig. 6 Time demand of the investigated methods

In the Manual Data Acquisition (MDA) method the model has to be described directly and every single geometry and related finite element settings has to be defined manually and independently in the pre-processing phase. The load-displacement curve of the rubber bumper has to be determined manually after running the solver. Note, that further calculations are necessary for the determination of the input data of the optimization process. Using MDA method the whole calculation process can be controlled.

The Partially-programmed Data Acquisition (PPDA) is carried out with three individual software. In the PPDA approach the geometrical data belonging to the model and the finite element settings are provided by a special purpose code and the analysis and the post-processing are also carried out by software developed by the authors, but the data transmission is manual. Using special purpose code as a pre-processor significant time reduction can be reached (Fig. 6).

The Fully-programmed Data Acquisition (FPDA) method contains automated calculations (pre-processing, processing and post-processing) and automated data transmission.

IV. Conclusion

In this paper finite element calculation based optimization methods were investigated from the point of view of time demand. It was stated that the time demand of the pre-processing phase and the post-processing phase can be significant, but the most time-consuming part of the process is the data transmission between the three main blocks. Thus the reduction of time demand of shape optimization processes is possible with the automation of data transmission besides the programming of the pre-processing and post-processing part.

The total time of calculation process in the case of FPDA is significantly less than in the other cases, that is, the development of an automated calculation process answered the time reduction problem of shape optimization.

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