Ph.D. Thesis Review

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Title: Truncated Conical Shells as Absorbers of Impact Force.
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Elastic-plastic deformation of shell structures is commonly used way to absorb kinetic energy of impact of bodies. Energy absorbers together with controlled force distribution across the vehicles are important ingredients of crash safe vehicles design. Both experimental and numerical approaches are used to investigate mechanical response of simple-shaped shell structures under impact loading, that provides designers with basic data needed to perform basic decisions and dimensionless of real energy absorbing systems. The thesis are focused on mechanical response of shallow conical shell based structure response onto impact loading with impacting masses or velocities varying as well as the geometric parameters of energy absorbing part. Author performed systematic study including large number of explicit dynamic finite element calculations. Further he processed FEM analyses results and transformed it into parameters commonly used to express the performance of absorbers. Formulation of shallow shell shaped impact energy absorbers properties based on the sensitivity of their performance on design parameters can be understood as the most important objectives of the thesis.

Meeting the objectives of the dissertation Author formulated the partial objectives of the dissertation as:

- To evaluate series of various numerical models for cones of different base angle and thickness values in order to simulate the axial impact of various impact velocities and impact masses by using the Abaqus/Explicit finite element software. Chapter 5 deals with the detailed model description and validation, including mesh density sensitivity analysis and validation of simplified „quarter“ part model. Also the material modeling is performed carefully, and I found it, despite the strain rate sensitivity had been based on literary resources, credible.
- To perform analysis on the structures modeled as energy absorbers with variable impact velocities, impact masses and geometrical parameters such as the absorber thickness and base conical angle. The numerical simulation results will also be used to develop an understanding of the detailed behavior of structures under impact loading depending on the various parameters. In chapter 6 150 finite element analyses performed by author is presented in form of graphs documenting the relations between various parameters. Author focused his work to evaluate the influence of particular parameters onto crash safety performance parameters. Quasi-static and dynamic analyses are discussed separately. The chapter provides reader with quite deep insight into this complex topic. Author has managed to communicate large amounts of information in a very efficient way.

- To process the data from the numerical results with respect to different result parameters to investigate the effectiveness of structures under impact loading to be used as energy absorbers. In Chapter 7 author presents the results in a compact form finishing the transformation process of „big data“ obtained by FEM calculations on data directly applicable in the design of shock absorbers.

- To generate an opinion on the usability of the structure as an energy absorber by taking into consideration of both commonly used structures.

I note that the objectives of the dissertation were fulfilled.

Author's insight on the „state of the art“. The author has an adequate knowledge of the problem of shock absorbers in the means of transport, as well as in mechanics of solids, he is familiar with finite elements analysis. In the dissertation he has commented on relevant articles dealing with both experimental and numerical/analytical research of shell structures serving as impact energy absorbers. He realized that there is often no link between understanding the conversion of kinetic energy to dissipated deformation energy at the global level of absorber performance parameters with a detailed solution of the mechanical response of the absorber

The theoretical contributions of thesis. The author has filtered and ordered data resulting from lage scale numerical study of shallow conical shell shaped impact energy absorbers such a way, that it enables better understanding the process of the impact, it enables discovering and explanations of some behaviors, that may help to focus further investigations of similar structures.

The thesis contribution for practice. Quantified relations between impact absorber design parameters and it's performance parameters (Chapter 7), and, namely the design guidelines formulate d in Conclusion of the thesis can motivate designers to use this kind of structures.

Suitability of the methods used. The methodology used in the thesis is considered appropriate. The most important was the search for appropriate, new ideas bringing and explainig insight into data obtained from large set of finite element analyses. The author has performed this work with great honesty and diligence, and the result was achieved.

The formal level of dissertation. The formal level of dissertation is standard. The work has a logical structure, the chapters titles are accurate. The author does not violate citation ethics. The work is written in good English with a minimum of misspellings. Charts and pictures are printed at the appropriate size, with the appropriate captions. The curves in some graphs (e.g. 6.19) are hardly distinguishable, I recommend to use symbols or colors instead line types only. There are some incosistencies e.g. in paragraph 2, page 27 *Mean Crushing Force* is defined, as

$$F_m = \frac{\int_0^{d_{max}} F \mathrm{d}x}{d_{max}},$$

that means one number per whole impact. In Chapter 6 the *Mean Crushing Force* is understood as moving average defined as

$$F_m(d) = \frac{\int_0^d F \mathrm{d}x}{d}.$$

It seems that author arbitrarily confuses terms *Force* and *Reaction force* (Fig. 6.4, 6.5, 6.6, 6.17 ...). In Fig. 6.10, 6.12 the x-axis title should be *Thickness*.

Conclusion Despite some of the above-mentioned shortcomings, I can say, that the author of the thesis performed excellent work and proved his ability to perform research and to achieve scientific results. **I recommend the thesis for presentation with the aim of receiving the Degree of Ph.D.**

7. 2. 2019
Miroslav Španiel

Question

1. You have proven quarter model carefully. However, is the symmetry in original state generally respected in collapse modes? What about the case if you have included some imperfection?

2. On Figure 6.49 I read. Mass is $m = 1000\,\mathrm{kg}$, velocity $v = 5\,\mathrm{m\,s^{-1}}$ that implies kinetic energy $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 1000 \times 5^2 = 12\,500\,\mathrm{J}$. How more than $30\,\mathrm{kJ}$, according to the graph, can be absorbed?