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Editorial

Special Issue "Applications of Finite Element Modeling for Mechanical and Mechatronic Systems"

Marek Krawczuk [1,†] and Magdalena Palacz [2,*,†]

[1] Department of Mechatronics and High Voltage Engineering, Faculty of Electrical and Control Engineering, Gdańsk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland; marek.krawczuk@pg.edu.pl
[2] Department of Production Engineering, Faculty of Organisation and Management, Silesian University of Technology, Roosevelta 26, 41-806 Zabrze, Poland
* Correspondence: magdalena.palacz@polsl.pl; Tel.: +48-32-237-7393
† M. Krawczuk and M. Palacz contributed equally to this work.

Abstract: Modern engineering practice requires advanced numerical modeling because, among other things, it reduces the costs associated with prototyping or predicting the occurrence of potentially dangerous situations during operation in certain defined conditions. Different methods have so far been used to implement the real structure into the numerical version. The most popular have been variations of the finite element method (FEM). The aim of this Special Issue has been to familiarize the reader with the latest applications of the FEM for the modeling and analysis of diverse mechanical problems. Authors are encouraged to provide a concise description of the specific application or a potential application of the Special Issue.

Keywords: finite element method; numerical modeling; mechanical parameters; damage detection

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Modern mechatronic systems first appeared about 50 years ago. A mechatronic system is currently defined as a structure implementing tasks from the area of four subsystems related to sensors (collect data about the operation of the system), control (a system processing data collected from sensors and regulating the operation of the executive system, whose task is to control the device), executive system (regulating the operation of the actuators) and a linking system (transmitting data between the above-mentioned subsystems). The design and state analysis of such complex systems is undoubtedly a demanding challenge for engineers and designers, as it requires the use of expertise from various engineering areas.

The main problem that engineers encounter is the use of well-known analytical mathematical methods, which are inadequate for more complex systems and can lead to erroneous results. For this reason, modern engineering in principle already depends on numerical modelling. This makes it possible not only to reduce the cost of prototyping designed mechatronic systems, but also to predict potentially dangerous situations resulting from operation. Among the various methods of numerical modelling which can be used in modern engineering, the most common is the finite element method due to its universal nature and the relatively simple way of preparing the model. Despite the fact that the method appeared commercially in the 1950s, its popularity is still increasing and the mathematical core is constantly being improved. It is used in the modelling of almost all areas of science and technology. In this book it was possible to gather examples of the applications of the finite element method in many areas of technology, carried out by various research centres. One general statement may be derived here—FEM is a viable tool.

In the group of papers devoted to the analysis of complex mechatronic systems, it is necessary to notice studies from the area of automotive and aerospace industry, in particular [1–6]. Among papers devoted especially to the analysis of complex mechatronic systems the following ones can be listed. The first listed [1] presents a methodology for conducting a study of the behaviour of a disabled driver during a crash by the use of FEM. Interesting conclusions have been derived, the reader is encouraged to follow them. In the [2] a direction for crash model development in Multi Body Systems programs to consider a varied 3D body space zones stiffness related to the structure of the car body and the internal car elements instead of modeling the car body as a solid with an average stiffness has been indicated. Such an approach would provide an alternative improvement to Finite Element Method (FEM) conventional modeling. Following [3] presented a methodology of optimising the weight of a bell crank, sourced from a Louis Christen Road Racing F1 Sidecar by developing a 3D model in ABAQUS (one of leading worldwide known commercial FEM based software). The model has been verified through the experimental measurements of dynamic characteristics. After that the model was used for topology optimisation procedure and then converted back to a 3D model and then fabricated to produce a physical prototype for design verification and validation by means of FE analysis and laboratory experiments and then compared with the original part. The proposed procedure is applicable and effective in topology optimization to obtain a lightweight (approximately 3% weight saving) and structurally strong design. The authors of [4] have used FEM for the structural analysis of the front single-sided swing-arm of a new three-wheel electric motorcycle, recently designed to meet the challenges of the vehicle electrification era. A dedicated Computer Aided Engineering (CAE) software has been used for the structural evaluation of different swing-arm designs, through a series of finite element analysis simulations. A topology optimization procedure has been also implemented to assist the redesign effort and reduce the weight of the final design. Simulation results in the worst-case loading conditions, have indicated that the proposed structure is effective and promising for actual prototyping. A direct comparison of results for the initial and final swing-arm design revealed that a 23.2% weight reduction has been achieved. In this article [5] the authors developed a model of all-steel radial tire that has been expanded to include the non-linear stress–strain relationship for textile cord and its thermal shrinkage. Variable cord density and cord angle in the cord-rubber bias tire composite are the major challenges in pneumatic tire modeling. The available FEM code with implemented user subroutines in MSC, have allowed the description of the tire specific properties. The distinguishing feature of the developed model from other ones is the exact determination of the cord angles in a vulcanized tire and the possibility of simulation with the tire mounting on the rim and with cord thermal shrinkage taken into account. The model may be an effective tool in bias tire design. Finally in a paper from aerospace industrial application the paper [6] shows an application of FEM for the analysis of thin-layer composites used for designed load-bearing structures. Due to proposed software enabling quick evaluation of such structure a facilitation of the initial concept has been possible. The proposed procedure used FEM for verification and improvement of the composite component.

Further examples of the application of FEM for the analysis of complex mechatronic issues present in modern production engineering industry is the paper [7] describing the compensation of strain deviation in the machine direction of a web in the roll-to-roll process for optimal mass-production of flexible devices at low cost. According to the results of a comparative experiment conducted to confirm the correcting performance of the optimized roller, the strain deviation in the machine direction decreased by approximately 48% with the proposed roller compared to that of the conventional roller. An industrial solution of engineering problem has been performed in [8]. The aim of the study presented here has been to predict properly the influence of high peening coverage on the Almen intensity and residual comprehensive stress. Therefore a quantitative description of the peening coverage has been developed. Based on the quantitative description, the finite element simulation and Almen test have been carried out. The simulation results of arc height and saturation curve have agreed well with that of the Almen test, by which the effectiveness of the quantitative description and FE simulation have been proved. The further study indicated that in shot peening processes, the excessive peening coverage does not improved Almen intensity and residual compressive stress. Following, an important aspect of industrial safety analysis that is of key importance to the mining industry an interesting FEM application for mechatronic system has been presented by [9] where a thorough analysis has been performed in order to determine how the tensile strength of roof rocks influences the extent of the zone with a particularly high risk of spontaneous coal combustion (endogenous fires) in caving goaves of the long-walls ventilated with the Y-type system. To achieve this goal, model-based tests have been conducted for a region of the long-wall mined with caving and ventilated with the Y-type system. The results obtained indicate that the type of rocks forming the caving affects its permeability and the extent of the risk zone for spontaneous coal combustion. The effectiveness of these measures significantly may improve the safety of mining exploitation.

The complex nature of the analysis of issues related to the safety of machinery and equipment, and in particular the detection and observation of fatigue damage, is the subject of the following articles [10–12]. In this study, [10], the technique of a digital holographic microscope and a digital height correlation method has been applied in combination with finite element analysis using a 2D and 3D model simulating the turbine blades to ensure their safety against damage. Analysis performed have clarified that the change in the surface properties under a small load varied according to the presence or absence of a crack, and elucidated the strain distribution that caused the difference in the change. The difference in the change in the top surface height distribution of the materials with and without a crack was directly proportional to the crack length. The authors here [11] have analysed the effects of impact loading acting on composite panels made out of epoxy resin as a matrix with carbon fabrics reinforced with aramid. The numerical calculations have been performed by the use of FEM and each reinforcement layer has been modeled as an independent part. The performed numerical and microscopy tests allowed to determine some destruction mechanisms of the panels depending on the geometry of the striker. Interesting conclusions have been derived regarding the striker shape and final delamination area properties. Finally in this study [12], a finite element, fully three-dimensional solid modeling method has been used to study the mechanical response of a steel-cored aluminum strand with a mid-phase jumper under a bending deformation. The analysis showed that the swing of the mid-phase jumper in the east–west direction caused a greater bending moment at the lower area of the mid-phase jumper, which led to the stress concentration appearing near the outlet of the tension clamp. This explained why the actual mid-phase jumper breakage occurred at the outlet of the tension clamp. Although this modeling method has been applied to the stress and deformation analysis of a mid-phase jumper in this study, it can be used to study the bending deformation of rope structures with a complex geometry and the main bending deformation. The finite element modeling method of a mid-phase jumper presented in this paper can be implemented in any general finite element software.

This book includes also papers from which it is clear that increasing interest in the scientific community is being shown for problems whose solution requires cooperation of many scientific disciplines [13,14]. Furthermore, so the problem of active control in certain structures has been analysed in [13]. Due to the fact that modern technology allows to design dedicated structures of specific features the authors have performed numerical research on a beam element built of periodically arranged elementary cells, with active piezoelectric elements. The control of parameters of this structure enables one for active damping of vibrations in a specific band in the beam spectrum. For this analysis, the authors propose numerical models based on the finite element method (FEM) and the spectral finite element methods defined in the frequency domain (FDSFEM) and the time domain (TDSFEM). An interesting example of another multidisciplinary application of FEM has been presented in [14], where an application of FEM analysis for printed circuit analysis, especially to determine the stress by changing the misalignment to below 30% of the primary channel width. The motivation for the research is based on commonly known fact, that printed circuit heat exchangers (PCHEs), which are used for thermal heat storage and power generation, are often subject to severe pressure and temperature differences between primary and secondary channels, which causes mechanical integrity problems. After the analysis performed it has been concluded that for this particular application the mechanical integrity of the PCHE with low-pressure molten salt or liquid metal and a high-pressure steam channel is acceptable in terms of utilization factor.

Mechatronic systems are not only advanced industrial systems, but also less complex mechanical systems requiring the determination of important parameters resulting from specific operating conditions. In this group may be placed papers [15–17]. In the study [15] the authors applied nonuniform-rational-basis-spline (NURBS) curves for the design of torsion springs, analyzed the displacements of these springs using finite-element analysis, and verified the design of these springs through experimentation. A method was proposed for deriving the coordinates of a control point for shifted elements by applying the inverse method on the basis of data derived through finite-element analysis. In addition, the relationship between the movement of the control point and stiffness matrix was identified and formulated by varying the torsion-spring parameters. In this paper, [16], according to the needs of large-diameter core drilling, a core barrel joint has been designed with an outer diameter of diameter 135 mm and a trapezoidal thread profile. Subsequently, a three-dimensional simulation model of the joint has been established. The influence of the external load, connection state and thread structure on the stress distribution in the joint has been analyzed through simulations, from which the optimal thread structure was determined. An example of FEM implementation for the analysis the designed metrology system may be found here [17]. In this paper, simulations have been performed to compare the distribution of temperatures developed in the measurement system for thermal conductivity of solid materials, which operates under a condition of permanent heat flow. The radial heat leaks, which affect the measurement parameters for an aluminium bar has also been analysed. The authors used copper bars as reference material. On that bases the authors implemented a thermal conductivity measurement system for solid materials limited in its operating intervals to measurements of maximum 300 °C for solid conductive materials.

In spite of the fact that FEM is very popular and most of the commercially available software allows obtaining reliable results there are occasional situations where the quality of obtained results is affected by potential numerical errors, therefore it is especially appreciated that this book contains works that address this issue [18,19]. In the first of them [18] may be found the algorithm of transition piezoelectric elements for adaptive analysis of electro-mechanical systems with analysis of numerical effectiveness of the models and their approximations in the contexts of: ability to remove high stress gradients between the basic and transition models, and convergence of the numerical solutions for the model problems of piezoelectrics with and without the proposed transition elements. In the second [19]—proposed detection algorithms assigned for the hpq-adaptive finite element analysis of the solid mechanics problems affected by the locking phenomena. The algorithms have been combined with the M- and hpq-adaptive finite element method, where M is the element model, h denotes the element size parameter, and p and q stand for the longitudinal and transverse approximation orders within an element.

In conclusion, the editors would like to thank all the authors whose careful work and dedication has resulted in so many interesting articles. The editors also hope that after reading this book, the reader will find answers to the questions in the area of FEM applications to the analysis of mechatronic systems.

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