Proceedings in MANUFACTURING SYSTEMS

Proceedings in Manufacturing Systems, Volume 6, Issue 3, 2011 ISSN 2067-9238

STRUCTURAL FE DYNAMIC SIMULATION OF COMPLEX CASINGS FOR POWER TOOL

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Abstract: *The presented study aims to overview the development a detailed simulation model for analysis of dynamic behavior of complex casings for power tool, using virtual prototype. Developed simulation model has high level of geometry detail which allows evaluating its dynamic parameters with sufficient accuracy. Various materials application for the examined casings is reviewed too. The target is to demonstrate the approach for dynamic simulation of high loaded mechanical components using virtual prototype and its advantages when applied at earlier design stage. Future steps for design optimization are marked, based on the obtained simulations results.*

Key words: *power tool, structural, dynamic simulation, virtual prototype, optimization.*

1. INTRODUCTION

The globalization of industrial production and services, high technical level, increased share of specific product requirements and the requirements of sustainability of product processes lead to the need for increased quality requirements, based on engineering knowledge [6]. Engineering can be viewed as a *decision-making process* [4]. No decision is, however, better than the best alternative. Alternatives can be created systematically and with intuition. A proper evaluation of the alternatives requires, however, knowledge. New knowledge is created in problem solving processes.

Development of computing, and the appearance of increasingly complex methods, and models to simulate physical processes and phenomena contribute to the development and enforcement of virtual prototyping. With the expansion of opportunities for information transfer, is increasingly expanding the scope of use accuracy and cost effectiveness of technologies for virtual prototyping. The application of virtual prototyping consists primarily in using three-dimensional computer model with a level of functional realism, similar to the physical model. Its performances can be realized as a set of graphical objects, three-dimensional CAD, mathematical, finite elements models or others.

Virtual prototypes application allows optimization simulations to be performed as to improve the structure of the model and thus – its major performance parameters. [1, 7]. The aim for a model is to supply an answer to a specific question. A model can be mental, physical, or analytical/numerical. Analytical models are very important tools for clarifying and solving engineering problems. New computer technologies and new software for computer-based modeling and simulation open the way to new approaches to solve design problems and to optimize artifacts and processes. The term simulation is used here in the broad meaning of imitating the behavior of a real system by constructing and experimenting with a computer model of the system [5]. Tools and methods for creating and manipulating computer-based models, for performing simulations of complex systems, are becoming increasingly important.

The aim of this study is to overview the development of a detailed simulation model for analysis of dynamic behavior using virtual prototype. Searching of possibility to obtain earlier implementation of analysis reduces cost of production preparation, shortens the time and directly provides a good cost-effectiveness. This is possible thanks to the use of virtual prototypes – in particular when implement FE analysis for determining stress-strain behavior and dynamic parameters of the model.

The given example is set on complex shaped casings for power tool – mixer. The examined machine is dynamically loaded and the discussed approach could be applied directly [6].

General parameters of structural dynamic behavior could be evaluated by performing a modal analysis, besides the conventional transient or even harmonic analyses. The natural frequencies and Eigen vectors gives general information about the structure – its rigidity and mass distributions. It also answers the questions whether any vibrations could be expect in work conditions. Reviewing Eigen vectors would give directions of design improvements which is very valuable option at design stage. *This approach is rather relative than absolute, but gives fast and direct results over examined problematics. Widely used, numerical simulations often lead to large*

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computing times without giving sufficient data for analysis-based decisions [2].

The entire process of optimizing design of examined power tool should respond to the increasing requirements of various standards concerning ergonomics and health care factors. All these requirements, set as standards, make this type of evaluations a must condition [3].

Implementation of numerical techniques requires, as it was mentioned, virtual prototype, and consequence of different steps during simulation model preparation are described bellow.

2. STRUCTURAL SIMULATION, BASED ON A VIRTUAL PROTOTYPE

Several steps are needed to be performed as to obtain accurate results. First of all, the objects of the simulation should be defined and proper simulation thesis should be developed. The focus of the study is on the casings – 2 complex shaped parts, that forms the entire out surfaces and electric drive housing. They are connected to the gearbox, which is unimportant object for the scope of current study. Thus, the model should include detailed virtual prototypes of both casings and simplified models of the electric motor (stator and armature) and of the gearbox. Next steps are shown in detail bellow.

2.1. Geometric model (3D CAD model)

The main component of virtual prototyping techniques is the implementation of geometric model. Is it was mentioned above, models of complex casings for power tool are examined to improve their dynamic parameters, together with simplified models of other components that have influence mainly by their mass characteristics. Used models are shown on Fig. 1.

Besides the casings, electric motor and gearbox, the connecting brackets and their coupling components (screws) are also modeled – in higher level of detail.

Small modifications on geometry model are performed to simplify the structure without decreasing results accuracy. This includes mainly removing small surfaces, which also improves the mesh quality at all.

2.2. Finite element model (FEM)

Generated meshed structure is shown of Fig. 2 (ANSYS program used). The meshed model contains about 5.8 billions of nodes and 3.7 billions of elements solid type, which guarantees enough detailed geometry representation. Interfaces between included components are linear type, allowing small relative displacements where are expected. In fact, local contact behavior is not examined in detail, which is not problematic for the purpose of current research.

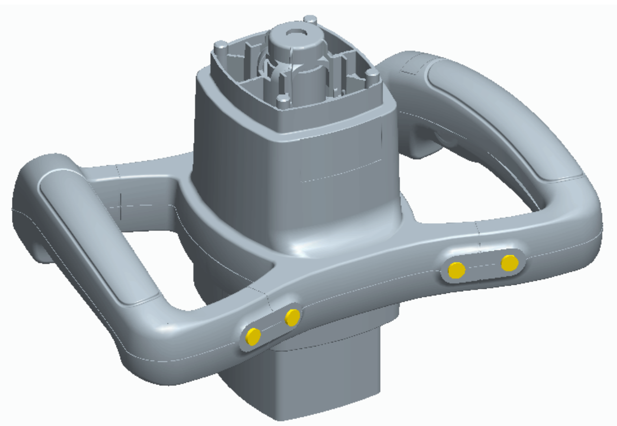

Fig. 1. Geometric model.

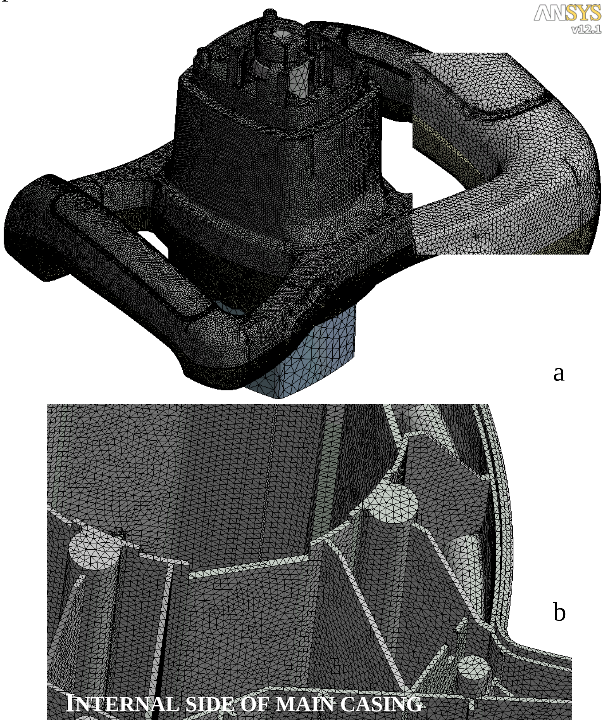

Fig. 2. Finite element model.

2.3. Applied boundary conditions

The target is to represent the work conditions of the examined power tool (mixer). As the tool is not presented in the model itself, the constraint is applied on the bottom face of the gearbox. Performed modal analysis does not require any additional boundary conditions but the constrained degrees of freedom. Structural damping is included in the model by the means of Rayleigh damping.

Modal analysis is used to determine natural frequencies of the structural model. The maximal frequency of excitation is of electric motor in the initial, unloaded condition – about 470Hz. Thus, the analysis will be set in the range 0÷500Hz, where natural frequencies will be calculated and reviewed.

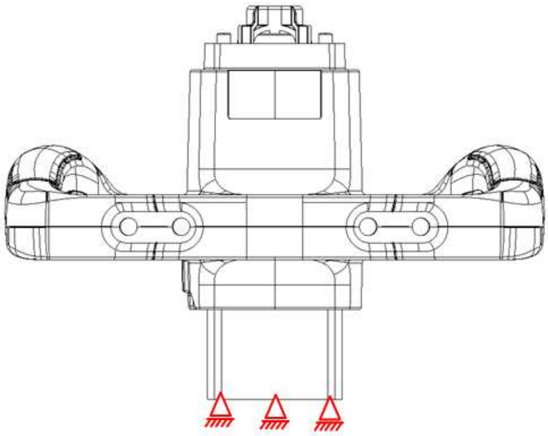

Fig. 3. Boundary conditions.

Table 1

Material properties

Property \ Material	PA6 GF 30	PP GF 30	ABS 801L
Young modulus, *E*, GPa	7.8	4.7	2.6
Density, ρ, kg/m^3	1350	1110	1050
Poisson’s ratio, μ	0.35	0.35	0.36

2.4. Material properties

The focus of the study is set on the casings – originally produced of glass fiber filled polyamide. All other components are used mainly as mass characteristics and are considered unimportant for the current examination. The material properties of material PA6 GF30, and its possible replacements, are shown in Table 1. No material-dependent damping is included in the presented simulation model.

3. DYNAMIC ANALYSIS TO DETERMINE NATURAL FRIQUENCYS OF INITIAL MODEL. RESULTS

Performed examination shows 6 natural frequencies in the range of interest (0 to 500Hz) for both PA 6 GF 30 and PP GF 30 materials. ABS material shows 9 frequencies up to 500 Hz range. Summary is shown in Table 2, where all the three examined materials are entered for the first 6 natural frequencies.

Above shown natural frequencies are illustrated for the original material as Eigen vectors on the next figures.

Shown deformation distribution fields are general, as the calculated model does not include damping. The results are indicative for the shape and their exact values could not be used, as damping would change them significantly. The target is to explore the natural modes and frequencies rather than obtain exact values for force-deflection behavior of the structure. Next comments and results analysis are oriented to the original material – PA 6 GF 30.

Two of all 6 frequencies, that are calculated to be in the range of interest, are shown in detail – the first (on Fig. 4) and the last 6th – on Fig. 5. They are found to be essential for the research model, as they present two typical types of deformation, that could be viewed in the other Eigen vectors too – torsion of the casings (Fig. 4) and bending of handles (Fig. 5).

Torsion deformation type has relatively low frequency – that corresponds to the work rotation speed of the electric motor and respective measures should be taken to avoid it. It is defined mainly by the local rigidity of the ribs, that connects the stator to the outer covering shell, as it is shown on Fig. 4. This zone requires definitive design modification as to increase local rigidity and to achieve better performance of the examined hand-held power tool. A possible solution is by adding second concentric rib.

Table 2

Modal analyses results. Natural frequencies, Hz

Material type:	PA GF 30	PP GF 30	ABS801L
1st mode	241.7	205.7	157.3
2nd mode	296	261	200.2
3rd mode	367.5	323	247
4th mode	433.5	374.3	286.2
5th mode	469.5	420.2	321.3
6th mode	496.7	429.7	328.6

The bending of the handles is defined by their mass/rigidity proportion, but it is not critical as it is over the maximal rotation speed of the electric motor – 470Hz.

All other intermediate frequencies are defined mainly by the rigidity of the connections (ribs) between electric motor and the outer covering shell, i.e. they are very similar like weak part to the first natural frequency. This shows once again the importance of the examined zone and its influence over vibrations of the machine.

Analyses results for the remaining two types of materials – PP GF 30 and ABS 801L show *lower values for the natural frequencies at the same shape of deformation*. ABS 801L even shows 3 natural frequencies more in the range of interest, comparing to the other materials. Modified homopolymer PP, used for injection molding, is suitable for the current purpose. It is lighter and stiff enough for current purposes. Generally, this is a good alternative of commonly used PA6 GF 30, and could be recommended for the examined power tool.

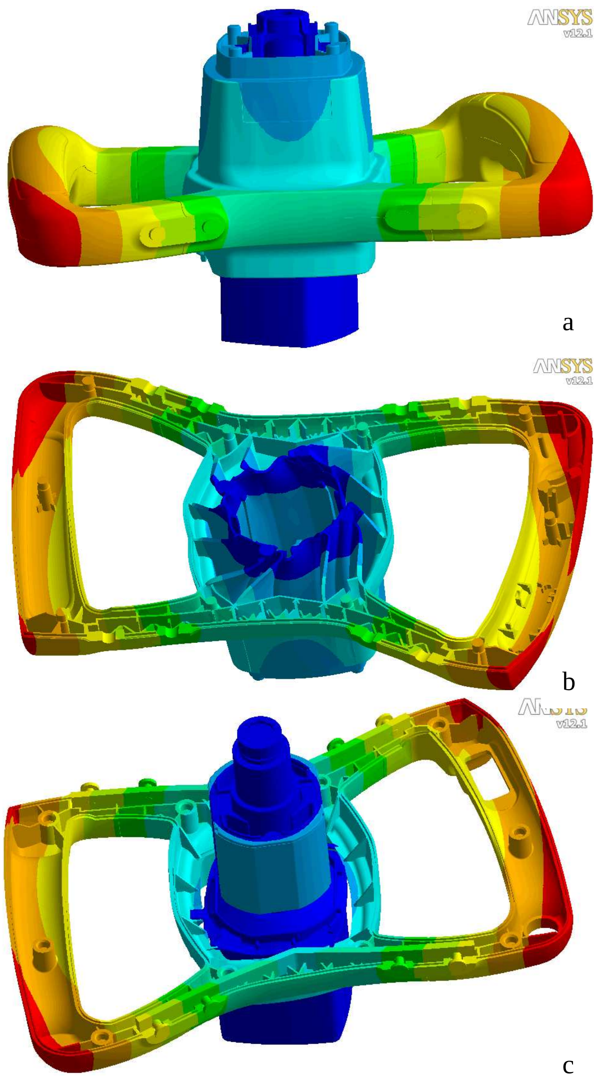

Fig. 4. First natural frequency – rotation around the axis of the electric motor.

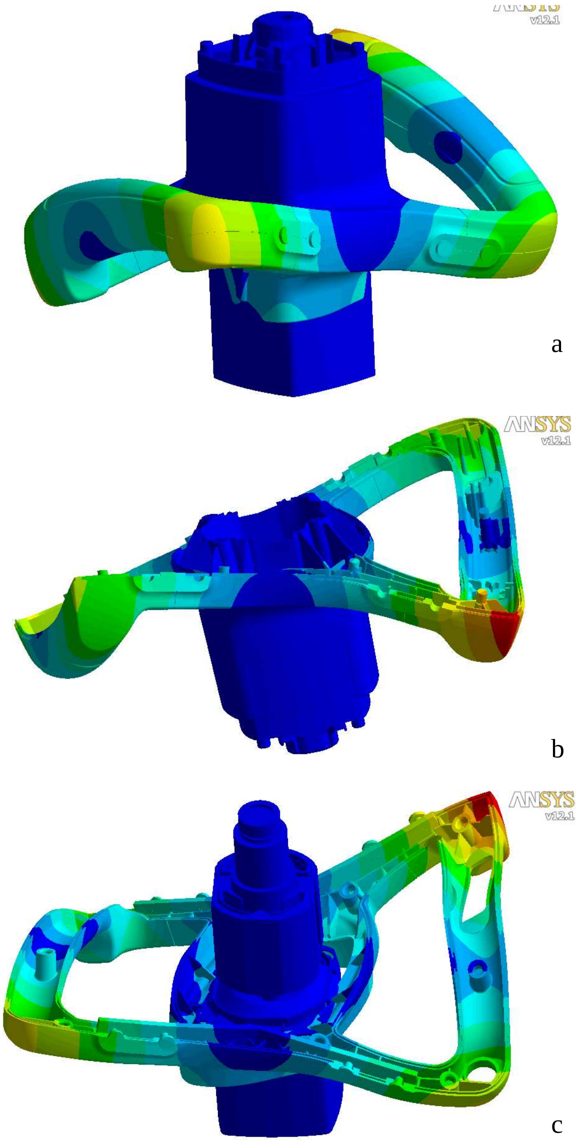

Fig. 5. Sixth natural frequency – determined entirely by handle.

4. CONCLUSIONS

The presented approach facilitates the evaluation of dynamic behavior of complex mechanical components in early stage of their design development that helps to avoid expenses for design modifications. The approach involves virtual prototype in combination with numerical techniques that helps to understand the source of potential issues and, on the next stage – to avoid it. Each iteration for optimizing the behavior is performed over the virtual prototype and decreases also the cost of product development. It is important to note that the physics-of-failure description is a very important step in the described approach.

A major point in the presented study is the application of modal analysis instead of transient analysis – to examine dynamic behavior of the structure. Together with the performed simplifications of the studied structure, this helps to reduce total time for analysis preparation and gives important directions for design modification.

Presented example refers to complex plastic parts with expensive mold equipment. Used 3D models include all major geometry details which allow obtaining results very close to real parts behavior, especially local rigidity of different design components.

Performed structural dynamics simulation shows a problematic zone – the connection between outside shell and internal motor cage. Local rigidity influences the first five natural frequencies, that are in the work range of up to 500Hz. Further design improvement should be directed in this zone – by adding concentric ribs, increasing the thickness of existing ones, etc.

Finally, optimized design will be checked by applying the same methodology and compared to already obtained results.

Generally, the combination of virtual prototyping and engineering analyses could be a powerful tool that could speed up product development and decrease its cost.

ACKNOWLEDGEMENTS: This research study is performed by the support of project DUNK-01/3 of National Science Fund, Ministry of Education, Youth and Science, Bulgaria.

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