PRODUCT REPRESENTATION TO SUPPORT VALIDATION OF SIMULATION MODELS IN COMPUTER AIDED ENGINEERING

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Abstract: Computer aided engineering (CAE) provides proper means to support New Product Development (NPD) by simulation tools. Simulation furthers early identification of product characteristics to reduce costs and time. The applicability of simulation models in NPD strongly depends on their validity, thus validating a simulation poses a major issue to provide correct experimentation results. The authors propose a matrix based approach to combine solution neutral system representation, solution specific product representation, and product behaviour in order to raise system comprehension to support validation of simulation models. A case study exemplifies the suggested approach. This paper illustrates the matrix based product representation at composing a flexible multibody simulation of a highly dynamic linear shafting machine tool. The approach supports preprocessing and validation of a flexible multibody simulation model.

1 INTRODUCTION

New product development (NPD) nowadays grounds on simulation tools provided by computer aided engineering (CAE). It becomes reasonable to evaluate engineering design in early stages before starting physical prototyping and thus enables early anticipation of product characteristics. Simulation also assists further development of existing products or establishing a line of products.

As summarized in (Musselman 1994; Robinson and Bhatia 1995; Robertson and Perera 2002) a simulation project comprises interpretive, developmental, and analytical facets. Modelling includes problem formulation, model conceptualization, data collection, model building, verification, validation, analysis, documentation and implementation.

Validation requires that the model is an accurate representation of the system being modelled taking into account the modelling purpose (Robinson and Bhatia 1995; Sargent 2004). The modelling purpose includes requirements on the model itself. Reasoning and derivation of conclusions by experimentation with the model requires successfully model credibility and thus completed validation. Thus validating a simulation poses a major issue to provide correct experimentation results. The authors propose a matrix based system representation to support validation of simulation models in CAE.

The paper contains in section 2 background information. Section 3 introduces a matrix based product representation to raise system comprehension and thus to support system validation in CAE. Section 4 illustrates a case study of supporting a flexible multi body simulation in further developing a machine tool. Section 5 discusses the application of the suggested approach in the case study. Section 6 concludes the paper.

2 BACKGROUND

According to (Sargent 2004) analysis and modelling derive a conceptual model based on the problem entity which represents the system. The conceptual model represents the system for a particular study. Implementation of the conceptual model leads to a computerized model. Validation of this computerized model by operational validation proves that the model's output behaviour represents sufficiently the problem entity for the model's intended purpose. VDI 3681 emphasises that validation is the proof that a system satisfies the requirements (VDI 2005). Bender narrows down the term validation as "*doing the right things*" contrary to the term specification that comprises "*doing the*

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things properly" (Bender 2005). Sargent summarizes and details several validation techniques (Sargent 2004): (1) Animation, (2) Comparison to other models, (3) Degenerate Tests, (4) Event Validity, (5) Extreme Condition test. (6) Face Validity, (7) Historical data validation, (8) Internal Validity, (9) Multistage Validation, (10) Operational Graphics, (11) Parameter Variability – Sensitivity Analysis, (12) Predictive Validation, (13) Traces, and (14) Turing Tests. Either the developer, or the user or a third party conduct one or more of these techniques either concurrently with the development of the simulation model or afterwards.

In product development concerned with not merely mechanical products several types of relations connect components systematically such as function, structure, and behaviour (Pahl and Beitz 1995; Ariyo, Eckert et al. 2006). A physical form with a specific structure characterizes design artefacts and enables to carry out function. The product structure comprises parts that interact amongst other and cause behaviour.

Based on these various approaches of product representation in NPS have been developed (e.g. seePahl and Beitz 1995; Lindemann 2007). Solution neutral and/ or solution specific system/product representations exist. Solution neutral representations support to lose fixation to specific physical solutions to further generating new conceptual ideas. E.g. functional modelling describes a system abstractly without sticking to specific solutions.

As Browning states the design structure matrix (DSM) is a well established method for handling complex systems (Browning 2001).

Relations within one domain such as function or structure fill the DSM in order to reveal interdependencies between elements. Maurer summarizes and details linking several DSMs by applying domain mapping matrices (DMM), that contain relations between elements of different domains, to gain multiple domain matrices (MDM) (Maurer 2007). Thus MDM methodology enables to interconnect solution neutral representation, e.g. by functional modelling, and solution specific representation e.g. by component structure. Interpretation and application of MDMs is a recent research task, e.g. interpretation of the meaning of specific patterns such as cycles (Biedermann and Lindemann 2008).

Based on system representations methods such as Failure Mode and Effects Analysis (e.g. ((VDA) 1999) or SAE J-1739) guide to reason about e.g. root causes in a structured manner by pointing to relations and evaluating these relations in NPD. They support to document problem solving tasks and application results in overall improvement of the product itself.

Multibody simulations reveal the kinematic behaviour of steep bodies. Schiehlen reviews the history of multibody systems in detail (Schiehlen 1997). A multibody system comprises bodies, force elements, and joints within a global reference frame (Schwertassek, Wallrapp et al. 1999). Additionally flexible multibody systems (fMBS) are capable to handle constrained deformable bodies that undergo large displacements, including large rotations (Shabana 1997).

3 METHOD

The authors propose a matrix based product representation to raise system comprehension and thus to support system validation in CAE. Besides the interconnection of the functional perspective on the system and the component structure of a product the suggested approach takes into account the dynamic behavior of a product (see Fig.1).

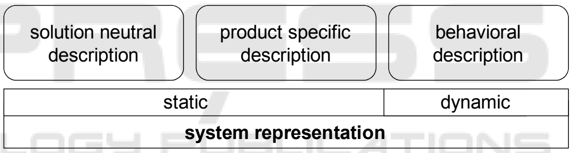

Figure 1: Components of the proposed system representation.

Creation and interpretation of the proposed product representation result in a deep understanding of the discussed product by raising awareness of interrelations between the considered domains. In CAE this understanding supports to define the modelling purpose properly. Additionally extensive collection of specifications enriches preprocessing of the simulation model (see Fig. 2).

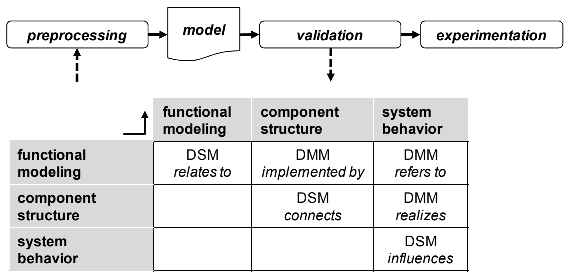

Figure 2: Matrix based system representation supports modelling.

The matrix based system representation identifies relevant elements within the integrated domains and supports model conceptualization by incorporating experience and knowledge gathered along the product lifecycle. The product representation finally assists validation of the numerical simulation model applied in CAE. According to the taxonomy of validation techniques proposed by (Sargent 2004) the suggested approach furthers historical data evaluation, whereas the data proofs is the model behaves as the system does. The following section summarizes a case study carried out together with an industrial partner. This technique may be applied by the developer assisted by the user concurrently with the development of the model.

4 CASE STUDY

In this case study a specific linear shaping machine tool for fabricating crankshafts is modeled. The authors apply the matrix based product representation to support machine system simulation as fMBS.

Measuring operation induced oscillations at the machine tool itself confirmed the existence of structural oscillations. The fMBS model is to represent the structural bending induced by mass forces that cause lower fabrication quality by deflecting the tool from the manufacturing part. By representing this problem entity the simulation provides a means to finally evaluate design concepts of sub assemblies to reduce the structural machine misbehavior. Based on detailed product comprehension the main purpose of applying the suggested approach is to carry out system analysis to support validation of the simulation model.

Figure 3 depicts a simplified component structure of the shaping machine. It consists of (1) machine bed on that the (2) machine column is mounted. The (3) shaping head is connected to the machine column and comprises the (4) tool that moves highly dynamic up and down to machine the (5) part that is fixed to the machine bed. Within the shaping head the cutting tool moves up and down along vertical-axis up to 700 times per minute with a shifted weight of about 20 pounds and up to 20g. Due to the moved mass mass-forces induce bending of the whole machine structure that limits processing quality.

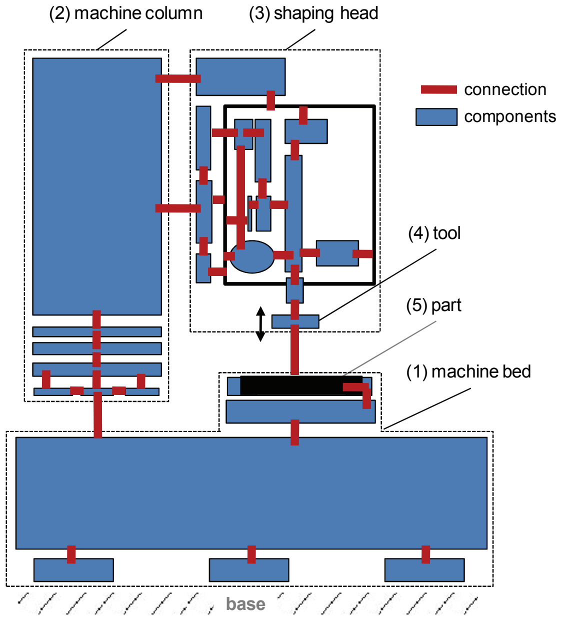

Figure 3: Simplified component structure of the shaping machine.

Physical components' specification, the assembly structure, and constraints between components are input data for modeling. Detecting tooth flank quality of the manufacturing part is an indirect measure of structural bending and denotes the machine tool behavior. Machine tool parameters (hydraulic system pressure, lateral offset of the column, …) as well as cutting parameters (feed, speed, …) influence the machine behavior. Each shaping application of particular crankshafts requires specific cutting parameters, whereas machine parameters are quite independent to select. fMBS is considered a means to raise the awareness of the actual structural bending during cutting conditions in a new scale.

5 DISCUSSION

Figure 4 exemplifies information extracted from the proposed matrix based product representation. Aggregated information summarized vital aspects of the system. It represents the domains component, function, and behaviour. The mechanical parts are connected by the flux of force (jack screw, machine column, and guide rail of machine column) and are interlinked to the functional modelling (perform feed, vary part position) and the machine behaviour (lateral offset of machine column). Additionally component specification such as stiffness, damping and geometrics is attached.

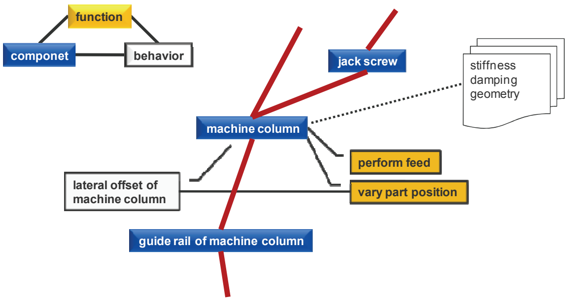

Figure 4: Aggregated cluster of information.

This kind of data aggregation supports to set up an enhanced fMBS simulation regarding important modelling parameters and thus supports focusing the modelling purpose and checking if the model's characteristic is as consistent to the system as needed. The assembly shaping head is a rather complex mechanical and functional structure and needs to be discussed in detail regarding the modeling purpose. Comprehension of interrelations within this assembly is a key to become aware of the system and thus vitally determines the preprocessing of the fMBS. When modeling the system the developers focus on representing the machine complexity as far as needed, especially when integrating machine parameters and flexible parts. The matrix based machine tool representation supported the determination of both the appropriated system boundary and the level of detail in preprocessing the fMBS. Besides it also supported the identification of particular parameters, which were primarily considered less important to sufficiently represent the structural behavior of the machine tool. The matrix based representation provided the base for this information to become worthy. Besides the matrix based representation also measurements of operation induced structural oscillations, and physical experiments supported the validation of the fMBS. Concurrent model validation enables to mature the fMBS simulation model further. In order to provide a means to evaluate the cause of tool deflection a properly validated fMBS is needed. Currently the fMBS represents the deflection of the tool identified by indirectly by measuring crank shafts, but sensitivity analysis is still been carried out. In modeling the iterative approach is quite time consuming and it becomes difficult to determine when the model is completely validated. Validation of the model takes place quite objectively by integrating the model developer and the user systematically.

6 CONCLUSIONS

The exemplified case study has proven that the suggested matrix based product representation could successfully support preprocessing and validation of a fMBS. Supported by the method specifications and machine parameters are identified to be integrated in the fMBS to represent structural bending induced by moved mass. Applying the suggested approach of matrix based product representation enables a holistic view of the system regarding component structure, functional modeling, and product behavior to support both preprocessing and validation of the simulation model. The significance of the suggested matrix based product representation strongly interrelates with the level of detail gained in each domain.

The authors will detail the presented case study further more to deeply illustrate the method and will apply the suggested approach to different products to enrich the application areas. Another task will be to evaluate the transfer of the suggested matrix based product representation to other simulation methods in CAE.

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