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Design for Vibration Reduction – An Overview of Models for Product Development with Focus on Excitation and Transmission of Vibrations of Technical Systems

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Abstract

There are many influencing factors on the vibration of technical systems. A model can be built to analyze the relationship between embodiment parameters and vibration. Looking at product models an overwhelming number of models exists to investigate the embodiment function relation. To support the product developer in designing the vibration of systems the following research question will be examined in this paper: What kind of models can be used to model the relation between embodiment and vibration with the aim to design a system with required vibrations? In order to influce vibrations, the excitation and the transmission of the vibrations can be influenced by the product developer. Therefore, this paper also adresses the following research question: Which models distinguish between embodiment paramters that excite vibrations and embodiment parameters that transmit vibrations? Based on a literature review relevant models for the investigation of the relation between embodiment parameters and vibrations were identified. The focus of the literature search was on models that have been published in the last ten years in the state of research. Categories for the evaluation and classification of the identified models were developed from the state of research on vibration analysis and models. The 15 identified models were evaluated and classified in a matrix using the developed categories. It is noticeable that, with one exception, in all models identified no distinction is made between parameters that cause vibrations and parameters that transmit vibrations. Also different frequency ranges are only considered in a part of the models. In summary, it can be said that there are models that map the relationship between embodiment parameters and vibrations. However, the investigation has shown that the models should be further developed in following research projects regarding the subdivision into excitation and transmission of vibrations and the consideration of different frequency ranges.

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Keywords: Vibration Reduction; Modeling; Embodiment Design

1. Introduction

Due to the lack of consciousness and the complex determination of vibration behavior, vibrations are often neglected according to BUBERT [1]. When designing technical systems with the aim of vibration reduction, product developers face a multitude of possible influences. REIN [2] stated, that a high degree of experience is essential for the calculation of vibrations. Many product developers do not have this experience. But if you look at the power tool industry, for example, according to DISPAN [3] the reduction of vibrations is one of the major innovation fields.

One way to investigate and represent the relationship between the individual embodiment parameters of the system and the vibration of the system is to model them. According to BUUR & ANDREASEN [4], product models support solution generation by explicating the mental models of the product developers. KOHN [5] stated that this helps to recognize correlations and make them accessible to others. The modelling can, in the context of Design for X [6], support frontloading in the product development process.

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A large number of models are known in the state of research. At the same time, according to Dresig & Fidlin [7], there is still no universal model-building strategy. This leads the product developer to the great challenge of choosing a suitable model for his problem. Weidmann et al. [8] and Kohn [5] analyzed product models and developed criteria for evaluating the product models, Weidmann with the focus on mechatronic design [8]. Matthiesen et al. [9] have conducted an extensive literature research in the field of product models. VDI 3720 [10] gives an approach that can be taken to reduce vibrations. It distinguishes between the excitation and transmission of vibrations. The modeling of the system is not supported. In this research project the following research question is answered: What kind of models can be used to model the relation between embodiment and vibration with the aim to design a system with required vibrations?

Since according to VDI 3720 [10] a distinction should be made between embodiment parameters that excite vibrations and embodiment parameters that transmit vibrations, as different measures can be applied by the product developer, depending on excitation and transmission, to reduce vibrations, the following research question is also answered: Which models distinguish between embodiment paramters that excite vibrations and embodiment parameters that transmit vibrations?

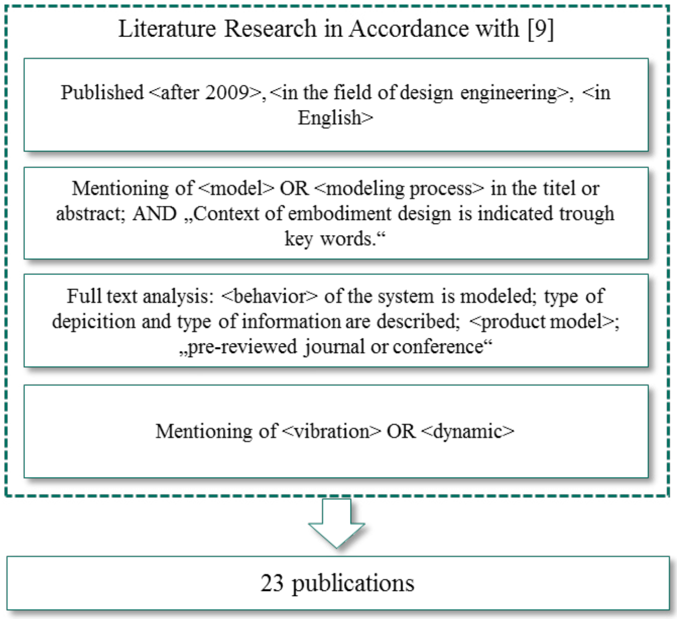
2. Materials & Methods

Based on a literature search by Matthiesen et al. [9] in the field of product models, a literature search was carried out in this research project. From the state of research on analysis of vibration and models categories and criteria were derived to evaluate the models. The models found were classified into a matrix with regard to the developed categories. The following chapter describes which literature was used as basis and which categories and criteria were applied to structure and analyze the literature found.

2.1. Literature Basis – Product Models

The search for relevant models was based on the approach of Matthiesen et al. [9]. The research method is shown in Figure 1. In order to identify models that are currently being used, the search was narrowed down to publications created after 2009. Also, only models that are accessible in English in the field of design engineering will be considered. The titles and abstracts of the found publications were screened using the key words *model*, *modeling process* and the context embodiment design, indicated through key words. The vibration of a system represents the actual behavior of the system. Since the subject of this research is models for embodiment-vibration relations, only the models where the behavior of the system was modeled were used. In a full text analysis it was also examined whether the type of depiction and the type of information are described in the publication, wether a product model is described and whether it is a peer-reviewed journal or conference. Since the models were examined with regard to their use for modeling the relationship between embodiment parameters and vibrations, the last step was to narrow down the publications with regard to the keywords *vibration* and *dynamic.*

Figure 1. Preselection and further limitations of the basis literature pool



2.2. Categories and Criteria for Evaluation of the Models

In order to narrow which models can be used by product developers to design systems with definite vibrations, six categories and their respective criteria are derived from the state of the research in vibration analysis and models. The categories were integrated in a matrix and the models evaluated according to the categories and criteria. The categories, their criteria and their basis in the state of research are presented in the following section.

Subdivision into Excitation and Transmission of Vibrations

As described in VDI 3720 [10], different physical phenomena are responsible for the excitation and transmission of vibrations. Since the phenomena can be influenced in different ways, a distinction should be made between vibration sources and transmission paths in a model that is to be used to design a system with reduced vibrations. In the matrix the category is classified in two criteria:

- A distinction is made between excitation and transmission.
- No distinction is made between excitation and transmission.

Consideration of Different Frequency Ranges

Due to the natural vibrations of technical systems and their subsystems, different system behavior can occur in dynamic systems, depending on which natural vibrations are excited. That is why the product models were divided into following criteria in order to make it possible to evaluate usability for dynamic problems:

- Consideration of different frequency ranges.
- No consideration of different frequency ranges.

Qualitative or Quantitative Model

Depending on the stage of the design process, different information is available and necessary. In order to be able to use the matrix in different stages, the models are classified into models that model qualitatively or quantitatively relationships between embodiment parameters and vibrations.

Degree of Concretization of the Model

According to MATTHIESEN [11], it is important for a product developer to understand the details of the embodiment in order to be able to design a system. KOHN [5] also recognizes the classification of product models between different stages of concretization. In this research project, the degree of concretization is evaluated on the basis of the criteria *characteristic* and *property*. Their definition according to WEBER [12] is used for this purpose. Characteristic are parameters, that can be influenced or determined by the product developer directly, as for example shape, materials and surface of a product [12]. Properties cannot be influenced directly and describe the behavior of a product [12]. Investigating the publications a distinction was made between the following criteria:

- *characteristic* is mentioned.
- *property* is mentioned.

Purpose of the Model

In this research project two specific areas of application of the models are to be investigated in more detail:

- investigation of relation between embodiment parameters and vibration with the model
- visualization of relation between embodiment parameters and vibration with the model

Therefore, the suitability of the models is assessed with regard to the areas of application.

Form of Presentation of the Model

With regard to the representation of the model, the following criteria have been used in accordance with WEIDMANN et al. [8]: analytical/numerical, graphical, table/matrix, textual and physical. Analytical means a characterization of the relations in mathematical equations that are analytically solvable, numerical means mathematical equations that are numerically solvable after being discretized [8]. The assignment to the individual criteria was carried out and is consistent with the assignment of MATTHIESEN et al. [9].

3. Results – Models for the Product Development

The models were analyzed with regard to each category and criterion. The results were classified in a matrix. In the following section the matrix is presented. In the second part of the chapter, different observations are examined in more detail.

The result of this research project is shown in Table 1. The models in the pool of 23 publications can be divided into 16 different models. The models and the publications that are linked with the models are shown in the left column. The first two lines contain the categories with their respective criteria.

Table 1. Models for the Product Development

	Subdivision into Excitation and Transmission		Consideration of Different Frequency Ranges		Only Qualitative	Degree of Concretization of Model		Visualisation of Interrelations	Form of Presentation of the Model				
	a distinction is made	no distinction is made	considered	not considered		characteristic	property		analytical/numerical	graphical	table/matrix	textual	physical
Digital Mock-Up [30]		x	x			x		x	x	x			
FEM Simulation Model [29]	x		x			x	x		x	x			
Kinematic Model [24]		x		x		x	x		x	x			
Multibody Model [35]		x	x			x	x	x	x	x			
Physics-Based Model (Iwan Model) [31]		x		x		x	x		x	x			
Pseudo-Rigid-Body Model (PRBM) [16, 17]		x		x		x	x		x	x			
Rihtarsic [34]		x		x			x	x	x	x			
Statistical Model [28]		x		x		x	x	x	x	x			
C&C^2-Model [13, 14]		x		x	x	x	x	x		x			
SysML Model [20-23]		x		x		x	x	x	x	x	x		
Characteristic- Property Model (CPM) [33]		x		x		x	x	x		x	x		
Models based on Gero [25-27]		x		x	x	x				x	x	x	
Behavioral Matrix [19]		x		x		x	x				x		
Design Structure Matrix [18]		x		x		x	x	x			x		
Integrated Function Model [32]		x		x			x	x			x		
Prototype [15]			x			x	x	x					x

The subdivision into excitation and transmission of vibration is not taken into account, with exception of *FEM Simualtion Model*, in any of the models examined in this project. With exception of *Digital Mock Up*, *FEM Simulation Model* and *Prototype*, different frequency ranges are not considered in the models examined. In the category *Qualitative or Quantitative* there are 14 models that represent quantitative relationships and two models that only depict qualitative relationships in the publications examined. In the category *Degree of Concretization*, with the exception of *Integrated Function Model* and *Rihtarsic*, characteristics are used in all models. Some models combine these with the properties of the system. Looking at the purpose of the models, none of the models is only used to represent relations between embodiment parameters and the vibration of the system. 10 of the models examined visualize the relationship between embodiment parameters and the vibration of the system. 11 of the models examined use a combination of different representation types. The textual representation is only used additionally.

4. Discussion – Models and Potentials

In the following chapter, the models identified are discussed with regard to their suitability for influencing vibrations through the design of the system.

At first sight, there are many models in the state of research that can model the relationship between embodiment design and behavior. Looking only at the models that can be used in the field of vibrations, only a small part of models remains. So far, only *FEM Simulation Model* supports the distinction between excitation and transmission of vibrations. According to the authors, however, a subdivision into excitation and transmission is conceivable in the following models: *C&C²-Models*, *CPM* and *SysML Model*. According to VDI 3720 [10], subdivision support the product developer to influence vibrations through the design of the system. Only a few models consider different frequency ranges. However, the product developer should be aware of the frequency ranges when developing a system with regard to vibrations, e.g. in order to be able to excite a natural vibration of the system.

According to MATTHIESEN [11] knowing a system in detail supports the product developer during the design phase. Looking at the degree of concretization, it can be seen that, with a few exceptions, all models consider the characteristics of the system. *Rihtarsic* and *Integrated Function Model* are exceptions to this. In addition to investigating unknown relationships, it is equally important for the product developer to know both the strength of an influencing variable and the relationships between influencing variables. According to BUUR & ANDREASEN [4], this can support the product developer in generating solutions.

Considering the purpose of the examined models, the relationships between embodiment parameters and vibrations are visualized for the product developer in 10 of the 15 models. According to KOHN [5], visualization can help to recognize correlations and make them accessible to others.

The term *dynamics* was very often found during literature research in connection with models. *Vibrations*, on the other hand, were rather rare. This could point to research potentials regarding models for mapping the relationships between embodiment parameters and vibrations.

5. Conclusion

It can be concluded that there are already models that help to investigate and visualize the relations between embodiment parameters and vibrations. With expection of *FEM Simulation Model* none of the models in the publications examined so far meets the category *Subdivision into Excitation and Transmission*. Excitation and transmission of vibrations are based on different phyisical phenomena. They can therefore be influeced in different ways by the product developer in the design of his technical system. One possibility to integrate the distinction into a model could be for example the assignment of an embodiment parameter to the excitation or transmission of a vibration and visualize it if needed. Likewise, in the category *Consideration of Different Frequency Ranges* only in the models *Prototyp*, *FEM Simulation Model* and *Digital Mock Up* a distinction is made between frequencies. These two categories should be integrated into future models in the field of system vibration. A model that also supports these two categories can help the product developer in the development of systems with for example reduced vibrations.

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