Modular product development with a focus on modelling and simulation of interfaces

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Abstract

Successful simulations of product behaviour and performance during product realisation require reliable and powerful models of both the components and the interfaces between them. The interfaces can be defined as the interacting contact surfaces where there is an attachment relationship between two mating faces. It is at these interfaces that friction, damping, lubrication and wear occur, all of which strongly influence the performance and behaviour of a technical system throughout its life. However, predictions of these phenomena are not a standard aspect of product development. Yet even if there are many different types of interface in a technical system, their behaviour and performance can all be organised and modelled in a similar way.

This paper draws on the framework proposed by Sellgren [1] in presenting a general approach to modelling that incorporates the modelling of interfaces. Some interface models of apparent static contacts are presented. The approach is demonstrated using a system with both apparent static contacts and interface element models.

1 Background

A product can be looked upon as a technical system, which can be defined as a set of interrelated subsystems or machine elements comprising a whole that is intended to achieve a particular goal (function). A subsystem can be an assembly of elementary machine elements, and therefore both subsystems and machine elements will here be referred to as components. The functioning of a component often depends on interacting mechanical contacts within the component and contacts between the component and the surrounding components or the environment. The interacting mechanical contacts can be defined as mechanical interfaces or just interfaces. A mechanical interface can vary from an apparently static contact in a joint to a high-performance lubricated rolling and sliding contact between interacting gear teeth.

When structuring products during product development, the important influence of interfaces on the behaviour and performance of a system are, unfortunately, seldom considered. Even at the early stage where the organ structures are generated, the behaviours of the organ interfaces should be considered. In other words, the organ interfaces should be modelled as joints with reasonable friction and wear properties rather than as ideal joints, since friction and wear often have a strong influence on the choice of concept.

Product structuring includes many aspects that are influenced by the purpose for which development is being done. Sometimes the intention is to develop a product platform. Or it may be to develop a product for variety. Modularisation is one type of product structuring that, although not new, has proved very successful in design for variety and has been the main subject of many research projects at KTH in Stockholm. Among the many reasons for this, an important one is the fact that those companies that have succeeded in modularising their products have been very successful commercially. Successful modular products range from washing machines to measuring instruments, personal computers and vehicles. The modular concept offers both technical and economical advantages. A particularly successful modular product is the Scania truck. In their advertising, Scania stress that "building blocks can be combined in a large number of ways to satisfy almost all requirements. This is the beauty of the modular concept: Few components – many models".

The advantages of a modular concept include shorter development time, quicker product changes, less risk in new development, improved quality in production, a shorter lead time in manufacturing and fewer components to handle and administer. Even if the modularisation methodologies today are good, however, significant improvements can still be made in the treatment of interfaces during product structuring and, more general, in the realisation of the whole product.

In product development there is a clear trend towards the increased use of system models and analyses and simulations of performance and behaviour. However, system models, sometimes referred to as virtual products, can only be attractive and useful if they are both reliable and powerful. The ability to make reliable and powerful system models has increased considerably thanks to improved computer software and hardware. In many areas analyses and simulations are also used extensively. MackAldener [2] recently presented the possibilities and limitations of using advanced models during the development of complex subsystems of modularised machines. He concluded that much can be simulated and predicted, but that the lack of a reliable interface model means that friction and wear, which are important causes of malfunction, cannot be simulated on a regular basis. That is a problem both during product development and for product realisation as a whole.

2 Modularisation methods

Erixon et al. [3] developed a method known as modular function deployment (MFD) to support the generation and evaluation of modules. An important element in this method is the use of different module drivers. Module drivers are important in product planning as well as in product design. Erixon [4] defines modularisation as decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons. The MFD method consists of the following steps: 1. Clarify customer requirements (QFD). 2. Select technical solutions (functional decomposition, Pugh selection matrix). 3. Generate concepts, (MIM, Questionnaire). 4. Evaluate concepts, (interface matrix, evaluation chart, MEC). 5. Improve each module (DFX).

The MFD method has mainly been used for restructuring and clustering already existing technical systems. The natural interfaces between the components are there from the beginning, and the question to be resolved is where the interfaces for the modules should be placed. The method uses an interface matrix to study different options. The interfaces are then classified as energy transmitting interfaces (E) and spatial or geometric interfaces (G). Erixon [4] concluded that "the design of interfaces is a most important activity when creating an efficient modularity. To enable parallel development of modules the interfaces have to be defined as early as possible in the development project." He also concluded that "little is done in order to investigate, and formulate, rules for the design of interfaces."

Stake [5] has done further work on the conceptual development of modular products and has made important contributions to module drivers. He also studied the interface problem but did not come up with any new concept for interface design. Like Erixon [4], he concluded that interface design is very important

Blackenfelt [6] studied the problem of managing complexity by product modularisation. He found that "the actual modularisation is done in the embodiment phase where the technical solutions are grouped to modules by considering both the functional and the strategic aspects.. . The detailing of the modular structure is done by optimising the degree of variety and by freezing the interfaces after the variety has been considered". He used both a strategic and a functional design structure matrix (DSM) in his studies of both mechanical and mechatronic technical systems. He classified the interactions between components in the same way as many others, namely as spatial, energy, information and materials interactions. However, he introduced scores for the different types of interactions between the components depending on how and to what extent the interaction is necessary and does not affect or is harmful to functionality.

Martin and Ishii [7] recently published a paper on design for variety in which they describe their method, which has many similarities with the MFD method. They examined external drivers of change that may cause the requirements for designs to change over time. They developed a general variety index (GVI) as an evaluation aid. They also developed a coupling index (CI) that indicates the strength of the coupling between the components in a product. The result of a CI analysis using the method proposed by Martin and Ishii is similar to that obtained using the extended DSM method presented by Blackenfelt [6].

The modularisation methods proposed above are intended to support design and include no or very little simulation-driven or simulation-supporting activities. It is characteristic of design support methods that each step and decision must easily be communicated to the people involved in the product development process. Simulation results, by contrast, are often considered hard to communicate in an integrated product development team. Behaviour and performance modelling and simulations are therefore seldom used as a general design support method during the early structuring of products. However, there is a general trend in product development towards increased use of system models and analyses and simulations of performance and behaviour. While this trend has unfortunately not yet made itself felt in product structuring, it is hoped that this will change in the near future.

In their pioneering work on the design of interfaces in modular products, Blackenfelt and Sellgren [8] showed that modelling and simulations can well be used during the design of modular products. They based their work on interface modelling and simulation, topological optimisation and robust design criteria. They showed that not only can an interface in general be modelled and simulated, but also that its form and behaviour can be designed so that it is robust enough to be used in many different configurations. However, for this type of simulation-driven design to be successful, it is necessary to have proper modelling of systems and interfaces.

3 Modelling of technical systems

Different types of models represent different aspects, or views, of a technical system. The behaviour of a technical system can be modelled by a finite set of behaviour models, each of which captures a specific physical behaviour at a specific level of abstraction [1]. When a behaviour model is combined with an environmental model and an initial state and a simulation activity are added, we have a simulation model. To be able to create a model of a system, the intention of each component and each interface must be realised with the required level of detail.

their connections are then identified. Finally the system model is divided into convenient modules with mating faces to produce a modularised behaviour model (modularisation) for reuse, modification and further development. If this general method of modularisation is combined with the concept of interface elements, as used by Blackenfelt and Sellgren [8] in their work on interface design, the result is a new simulation-driven method of modularisation.

4 Modelling of interfaces

An interface is a relationship between two mating features. A mechanical interface, which is the type of interfaces that are discussed here, is defined as a non-causal physical relation between two mating faces. Our goal is to develop a system of interface models that can be integrated with commercial CAE software used for behavioural and performance analyses and simulations during product realisation. The interface models will represent many different types of mechanical contacts, from apparent static contacts of engineering surfaces to high-performance, lubricated, moving contacts. The model system will thus represent the properties and behaviour of a wide range of interacting mechanical contacts. Different levels of detail of the models will be considered depending on the aspect of interest and the features with which it is associated.

The framework and modular approach outlined above make it possible to strictly define the structure of interface models as two mating faces that are in a relation determined by the type of contact modelled and the required level of detail (see figure 1). Mating faces and interfaces can be represented by features. In the literature, the relations between mating faces are often categorised into four types, namely rigid attachment, constraint, contact and field transfer. From a tribological viewpoint, the mating relationships may be structured in a somewhat different way, but the general modelling concept of interfaces still holds true.

5 Some specific interface models

The interface models that have been and are to be developed are intended to represent the behaviour of everything from apparent static contacts of rough surfaces to lubricated real contacts that move relative to each other. They will also represent different properties such as different running conditions and failure modes.

A first example of an interface relationship involves the contact stiffness and real contact area between normally rough surfaces. The work of Sellgren, Björklund and Andersson [10][11] show that the stiffness variation in the normal direction of an apparently static engineering contact is directly dependent on the measured Abbott curves of the surfaces. This finding opens up the possibility of relating the interface behaviour to the actual surface properties, which in this case are the elastic modulus and surface topography

A second example of interface relations that have been studied at KTH is the tangential relations between real rough contact surfaces [12]. The friction variation with small displacements between the interacting contact surfaces can be determined using knowledge of the shear modulus, surface roughness and surface waviness. Small displacements and friction variations in complex structures have a strong influence on damping, and therefore reliable interface models of apparent static contacts are often requested by system builders.

A third example of an interface relationship comes from the work by Eriksson and Andersson [13], which modelled the friction between the sliding contacts in a hydraulic cylinder. By using a friction relation dependent on both the tangential displacement (micro-slip curve) and the sliding speed (Stribeck curve) between the interacting contact surfaces, the control of the hydraulic cylinder was considerable improved when compared with a relation determined using the more common Coulomb friction.

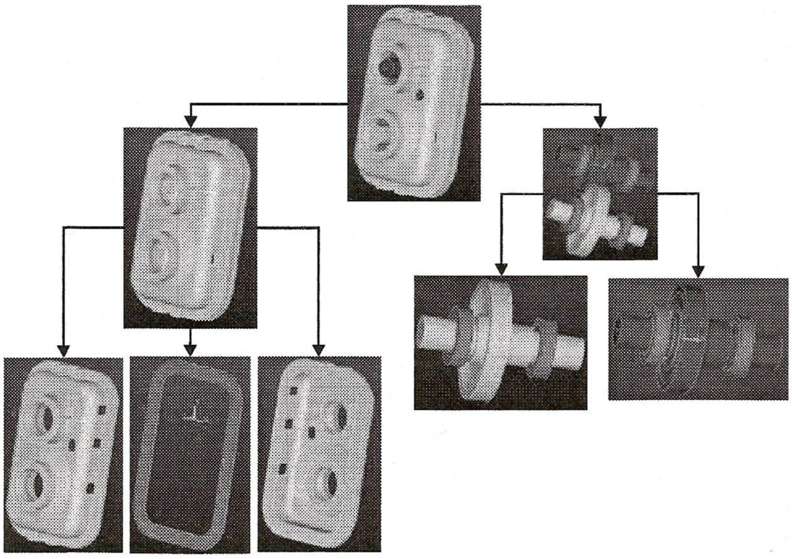

Figure 3. A test gearbox: A mechanical system with marked interfaces (red)

A fourth example of interface relations is a test gearbox (see figure 3). The behaviour of the gearbox has been found to be strongly dependent on how the test system is re-assembled after every test. In order to study how different interface behaviour may influence the dynamic behaviour of the gearbox, the test gearbox was modelled according to the principles outlined above. The interfaces considered were the static distributed contact between the two housing halves as well as the roller bearings, which are more properly considered as interface elements. An initial analysis or simulation shows that the preloading of the bearings seams to have the most significant influence on the dynamic behaviour of the gearbox. The test gearbox will be further studied since we believe that the results may explain the mysterious variations in vibration and noise properties sometimes observed in production.

6 Conclusions

Efficient realisation of advanced systems requires extensive behavioural and performance analyses and simulations in order to meet demands that are often challenging and contradictory. Behaviour and performance must be predicted, imitated and monitored under different conditions, in different situations and after different times in use.

Although system structures are often based on some platform approach or modular concepts, the available methods for developing such structures are effective only as design support methods. They do not support a simulation driven development methodology. Since we believe that for most products analyses and simulations are both necessary and efficient during most steps of the product development process, new methodologies have to be developed.

A drawback of the methods currently used to design for variety is that not much effort has been put into learning how to deal with interfaces, despite the fact that most researchers dealing with product configuration and related tasks consider the design of interfaces very important. Sellgren [1] addressed this problem in his important work on a modularised approach to modelling. He continued this pioneering work in collaboration with Blackenfelt [8] in an investigation of how to design robust interfaces in modular products. His approach may be seen as a new methodology for simulation driven design for variety or modularisation. This paper presents some further work done at KTH on interface modelling and design

In order for modelling and simulations to succeed, reliable interface models must be available. The main goal of our research is, therefore, to develop a system of interface models that can be integrated with CAE programs and used for behavioural and performance analyses and simulations during product realisation. The model system will represent the properties and behaviour of a wide range of interacting mechanical contacts.

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