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DEVELOPMENT AND APPLICATION OF MODULAR FUNCTION DEPLOYMENT

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1. Introduction

Modular Function Deployment (MFD) is a method [Erixon 1998], which is based on the well-known Quality Function Deployment (QFD) method. The QFD is more and more used because of its orientation on customer requirements on technical products. It is assumed as one of the best Total Quality Management (TQM) method. The goal of QFD is to ensure optimal fulfillment of customer requirements on a single product only. The MFD enables above to ensure the same task by optimal modular product or maybe its part composed only from the selected modules if required. This is considerably more effective both for the producer and the customer.

According to the analyses performed MFD has, in spite of its very careful and detailed form, one weak point. This is insufficient interconnection to a designed product. These relationships are largely generally described in Design Science based on the Theory of Technical Systems (TTS) [Hubka & Eder 1996]. One of the most significant results of this approach is that all phases of the Engineering Design Process and their operations are systematically linked with general knowledge on any designed technical product/system (TS).

2. Enhancement of MFD

2.1 Knowledge support of engineering design process

In general, knowledge support of engineering design process can be hierarchically structured into the following three levels: intuitive, methodical and systematic one [Hosnedl, Vanek & Borusikova 2001]. The intuitive approach: We have “no” theories, “no” methods, only previously acquired general and specialized knowledge and practical experience. In this case e.g. the scope of considered properties of the TS depends only on intuitive decisions of engineering designers. The methodical approach: We have prescriptive and normative instructions, which restrict space for creative design process, e.g. BS 2000, VDI 2221. According to our analyses MFD has been used up to now on this level. The flexible systematic approach: We have moreover a system of pieces of engineering design knowledge and their relations, i.e. Design Science, which enables to manage and optimally support creative engineering design process. The MFD has been enhanced to this level with the use of the above-mentioned theories.

The general structure of the engineering design process is shown in the Fig. 1. It represents synthesis of the known design process models from Eekels, Koller, Hubka & Eder, Pahl & Beitz, VDI 2221, etc. [Hosnedl 1997].

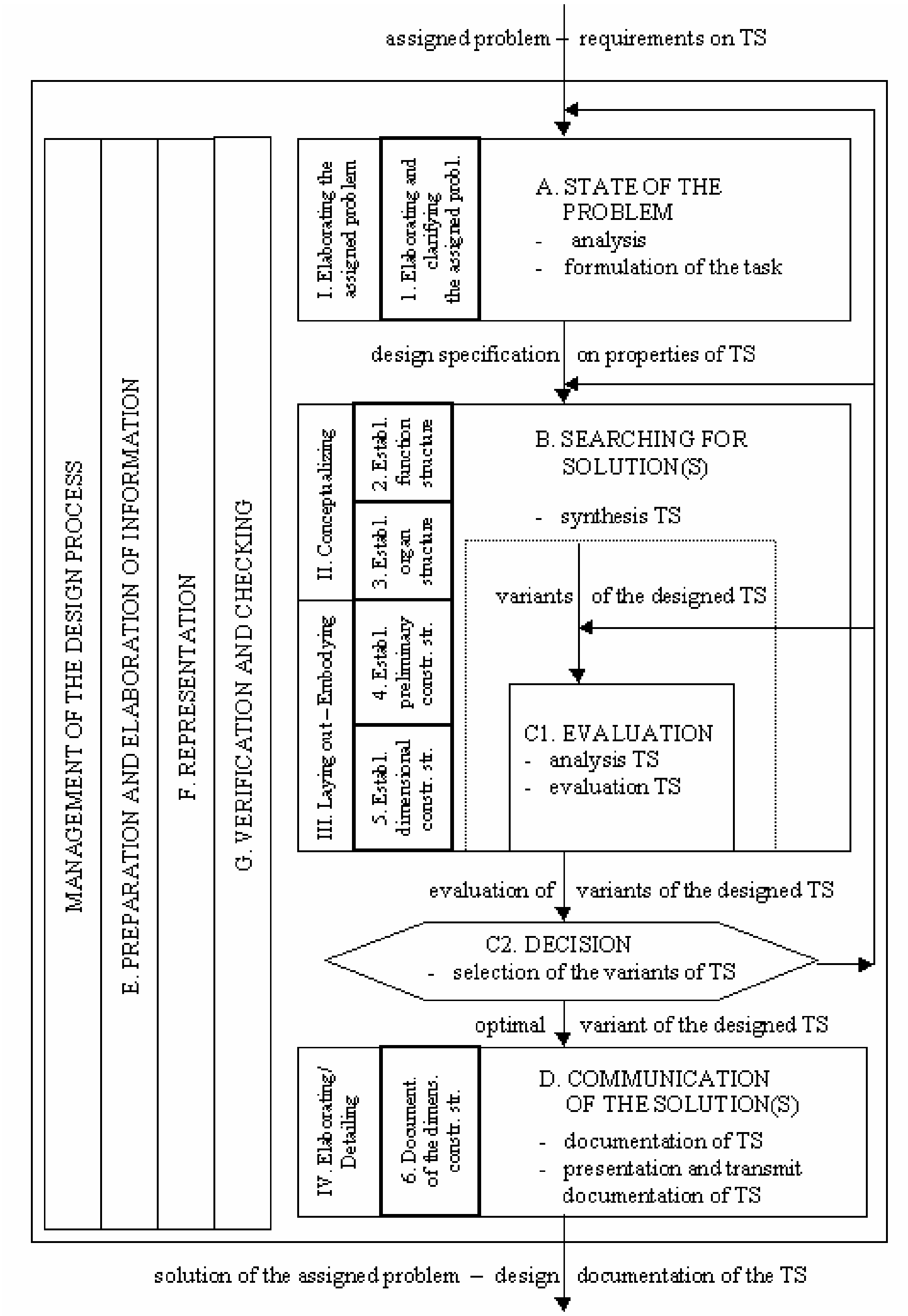

Figure 1. Structure of the engineering design process of the technical system

2.2 What is modularisation?

The modularisation is a decomposition of technical system into building blocks (modules). The modules must have specified interfaces. We can distinguish three levels of modularisation according to the structures of technical systems as follows: function, organ and constructional one. The modularisation on the higher level always includes modularisation on all lower levels, i.e. organ modularisation includes constructional modularisation and function modularisation includes organ and constructional modularisation. A typical example of the function modularisation is a personal computer (PC). The PCs can have e.g. CD-ROM device for reading of CD-ROM (one module), graphical card for displaying of picture (another module) and sound card for reproduction of sound (another module). These modules fulfil different functions. An example of the organ modularisation is a car, which has relatively uniform function structure. The cars can have e.g. engine (module) working on different principles (explosion or Diesel one). This module fulfils the same function. An example of constructional modularisation is a rolling bearing, which has the same function and organ structure. Rolling bearings can differ in sizes, shapes, etc., which fulfil the same functions performed by the same organs.

2.3 Engineering design process with the use of enhanced MFD

We will proceed step-by-step according to the structure of the engineering design process (Fig. 1.) with the use of MFD for organ modularisation of the designed TS.

1.1.1 2.3.1 Elaborating the assigned problem - design specification on properties of technical system

We use the theory of properties from the Theory of Technical Systems [Hubka & Eder 1996]. According to this theory the properties are separated into two basic groups as follows: external and internal one. The external properties are required and judged by customer. The internal properties are generated and controlled by engineering designer. Sometimes the customer has also requirements on some internal properties. The external properties causally depend on the internal properties. Both groups of these properties are separated into twelve classes as shown in the Fig. 2.

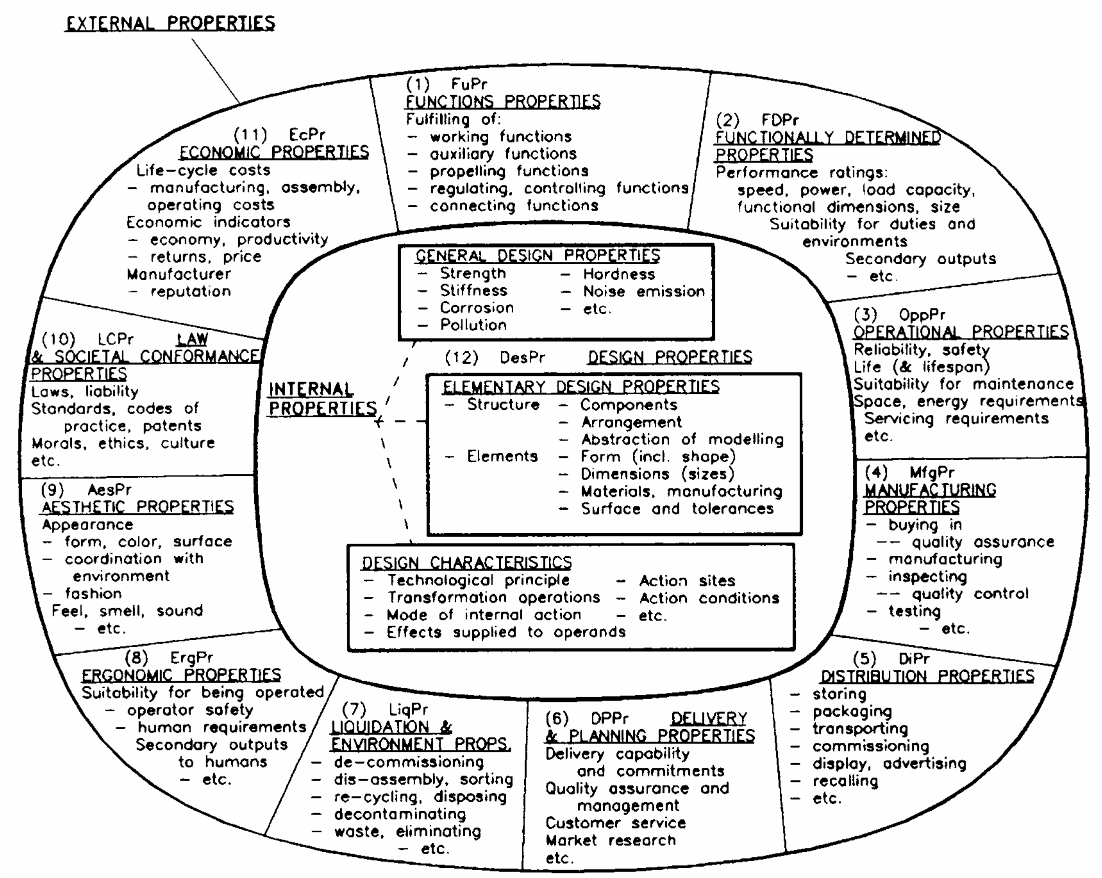

Figure 2. Classes of properties of technical systems (TS) and their basic relationships

To include all life cycle requirements on the designed TS the design specification should be created with the use of these classes of properties. The enhanced MFD is an effective way, how to perform it. This step is using the central organ of MFD, called The House of Modularity, as is shown in the Fig.3.

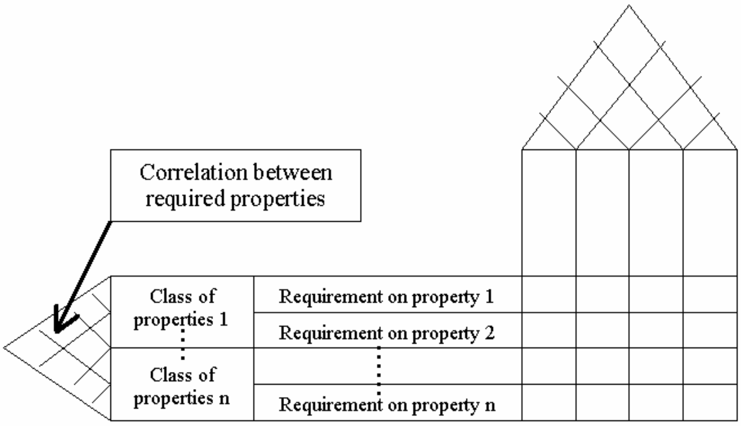

Figure 3. Design specification in The House of Modularity

2.3.2 Establishing the function and organ structure – concept of technical system

Before establishing the function structure the main and assistant operational technical processes related to the designed TS should be analysed. For example if we design a carriage for lathe we must establish the operational processes for the lathe because in this case the technical process of turning is running “in the lathe”. The carriage is a technical sub-system of the lathe only. The established function structure can be represented e.g. in a form of hierarchical function tree. For establishing the organ structure we can use e.g. the method of morphological matrix and/or TRIZ system. The abbreviation TRIZ in the Russian language means “Theory of Solution of Invention Tasks” and TRIZ system in form of a software product is called Tech Optimizer.

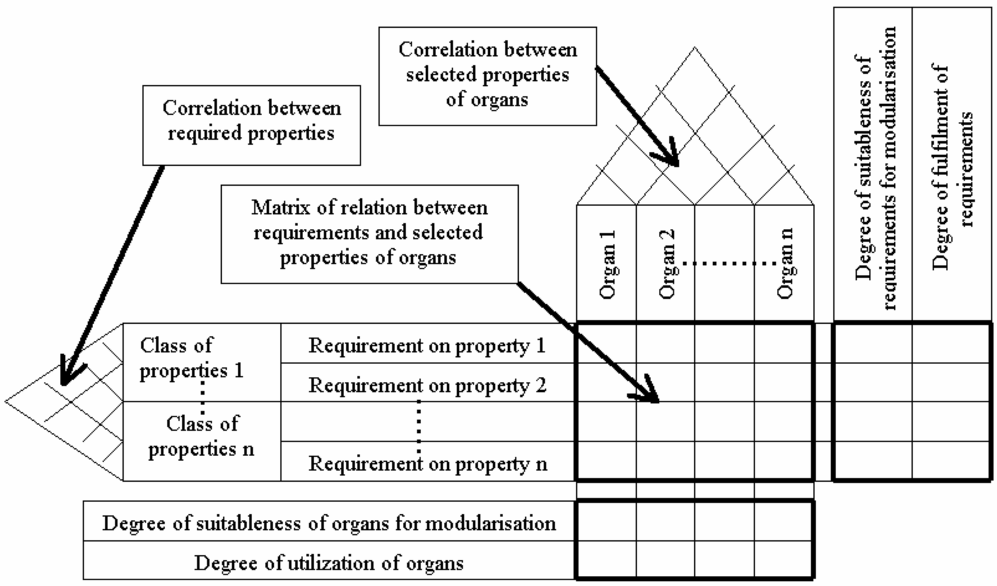

Figure 4. The House of Modularity

We then put organs for each variant of organ structure to The House of Modularity (Fig. 4) and evaluate suitableness of their properties both for fulfilment of the given requirements and modular design of the designed TS. The optimal organ structure from the viewpoints of design specification and modular design can be then evaluated.

3. Concept and support of application

The application has been focused into the area of engineering design of frames for machine tools, specifically on the development and evaluation of their optimal modules. The first problem here deals with the identification of functions ensured by organs of the constructional structure. This has been performed by evaluation of frame modules with the use of Finite Element Method (using software MARC, ANSYS and I-DEAS).

A straight constructional module with rectangular cross-section has been designed because it has different properties in all directions and is simple (Fig. 5). It is suitable for mutual comparing of single properties of constructional variants of this module. The sizes of the cross-section have been determined thus that the height is double of the breadth. The length of the module has been calculated on the base of a theory of buckling thus that in case of compressive loading the module will be strained by buckling. The material of module for determination of its length is isotropic steel because it has the highest limiting depth-thickness ratio from current frame materials. The module for stating its length is a plate one. The module is rigidly fixed at one end and loaded by forces and moments in all three directions (F_x, F_y, F_z, M_x, M_y, M_z). Orientation of axial force has been chosen thus that the module will be strained by tension.

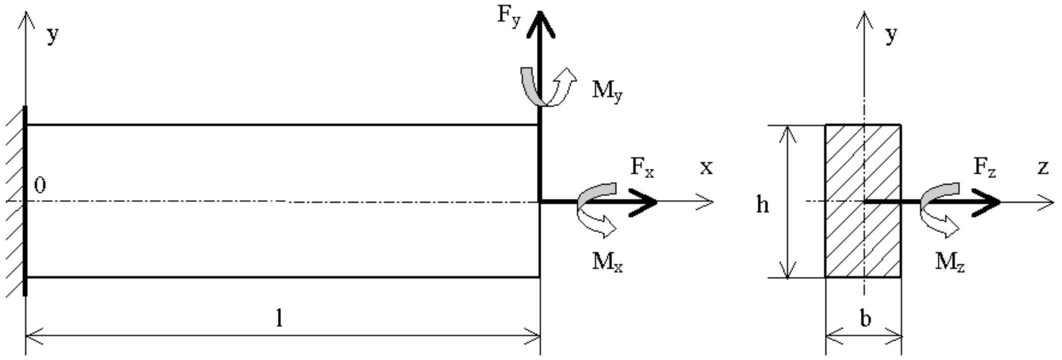

Figure 5. Module for evaluation with loading

The sizes of cross-section: b = 100 mm
h = 2 b = 2   100 = 200 mm

The limiting depth-thickness ratio: $\lambda_m = 100$

The limiting length of module (from the theory of buckling):

$$l_m = \frac{b\lambda_m}{\sqrt{48}} = \frac{100 \cdot 100}{\sqrt{48}} = 1443mm \quad (1)$$

The chosen length of module: l = 1700 mm

The values of loading:

$F_x = 500$ kN $M_x = 12\,000$ Nm
$F_y = 10$ kN $M_y = 7\,000$ Nm
$F_z = 15$ kN $M_z = 10\,000$ Nm

These values have been chosen thus that they would cause real strains within module.

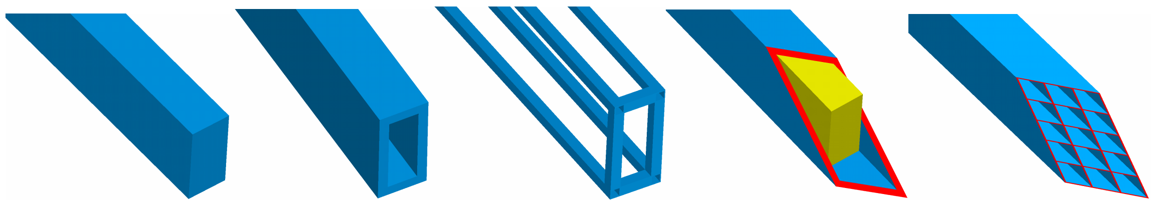

Figure 6. Several types of modules for evaluation

Each variant of the module for evaluation have the same external sizes (breadth, height and length), gripping and loading. The material or the internal structure of modules can be different. The solution of the module will be performed by FEM software. The displacements of point in which the loading has been will be read after the solution. Six stiffnesses (k_x, k_y, k_z, k_{tx}, k_{ty}, k_{tz}) will be then computed from loading and displacements as follows:

$$k_x = \frac{F_x}{\Delta x} \qquad k_{tx} = \frac{M_x}{\Delta \varphi_x} \tag{2, 3}$$

The answer to the question: "Which organ of the module fulfils required function at the best?" will be found according to the computed stiffnesses of all the solved modules. If we would like to get other results we will take the same modules and we can solve e.g. buckling, dynamics or durability. These results will serve as a support for engineering design of optimal frame module for machine tools according to the procedure, which has been described, in the previous chapter.

4. Conclusion

The paper presents flexible systematic procedure of engineering design of modular technical system. The modular technical system is more and more important because joints together the process of standardisation with multifarious solutions, which fulfil customer requirements at the best. The modular solution also simplifies reconfiguration of TS if the customer requirements are changed. It is achieved with the use of modules with clearly defined interfaces. The next advantage of a modular solution is that producer or customer can accomplish the reconfiguration himself. The paper proves the importance of application of the Finite Element Method for evaluation of different concepts of modules for the design of frames for machine tools before the concrete constructional structure of its modules is achieved. This evaluation answers the question which organ of the constructional structure fulfils a required function at the best. These results can serve for the re-design of the developed modular structure and its modules to fulfil the given requirements optimally. It will contribute to the higher quality of engineering design of frames for machine tools and to shortening of the design time.

References

Andreasen, M., M. and Blessing, L., Proceedings of "European PhD-Course "Engineering Design Research 2001", Part I – II, Vasteras SE and Magdeburg D, 2001.

Erixon, G., "Modular Function Deployment – A Method for Product Modularisation", ISSN 1104-2141, The Royal Institute of Technology, Stockholm SE, 1998.

Hosnedl, S., Vanek, V. and Borusikova, I., "Design Science for Engineering Design Practice", Proceedings of ICED 2001. Glasgow UK, 2001, pp 363-370.

Hosnedl, S., "The structure of diploma design projects", University of West Bohemia in Pilsen CR, 1997.

Housa, J., " Design of highly dynamic machine tools and usage of laser in cutting", CTU Prague CR, 2001.

Hubka, V. and Eder, W., E., "Design Science", Springer-Verlag London UK, 1996.

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