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# A COMPLETE APPROACH TO MODULARITY IN PARALLEL KINEMATICS MACHINE TOOLS

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**Abstract**: *In this paper a complete subject of modularity in parallel kinematics machine tools has been presented. It contains the following areas: systematic and placement of modularity, method of deriving modules, design methodology of parallel kinematics machine tools.*

## 1. MODULARITY IN PARALLEL KINEMATICS MACHINE TOOLS

The modular design concept is one of the ideas that can make parallel kinematics machine tools more attractive for the industry. This type of machine tools is considered especially good for modularity. During the design it is possible to apply a few kinds of modularity which all together are typical modularity of this kind of machine tools. Defining such modularity makes it possible to modularise the machine tool in a proper way. Then:

> *A modular parallel kinematics machine tool is a sectional-modularity type system with elements of integrating modularity.*

Parallel kinematics machine tool's sectional-modularity system means typical elements that are repeated in many places in the machine's structure: joints, telescopes, power units and designed elements – platforms equipped with such interfaces that enable free joining of elements within the product's architecture.

Integrating modularity could be defined as any other type of modularity where a module consists of a few elements (component-swapping and component-sharing modularity, customer's or manufacturer's modularity). The range and kind of modularity have to be known at the design stage as they influence the design and development process, project costs, manufacturing costs, documentation preparation, service availability etc. Variants of modularity applied to a product depend mainly on the product's structure and the whole spectrum of products in the general product family.

## 2. MODULAR PARALLEL KINEMATICS MACHINE TOOLS' DESIGN METHODOLOGY

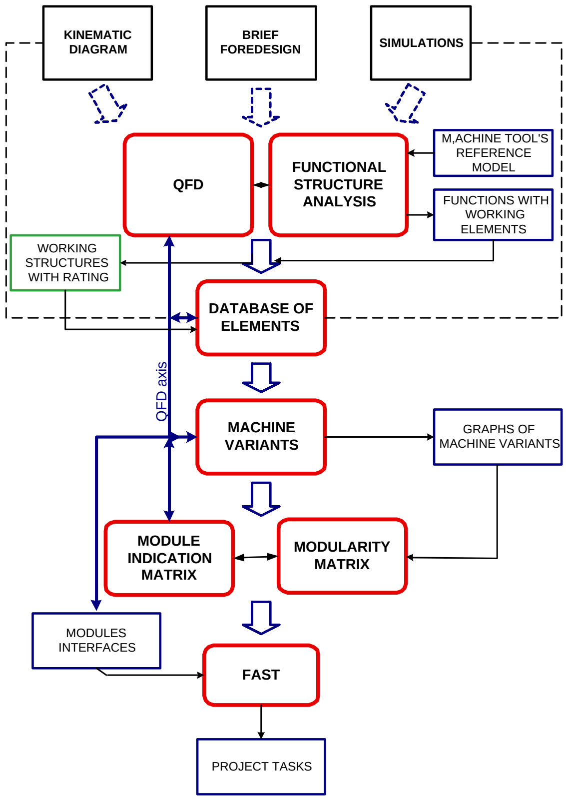


Fig.1. *Schematic representation of the methodology*

The design process in accordance with the methodology (Fig.1) starts with a QFD analysis modified for modularity and concurrently functional analysis of the machine according to functional reference model of the machine. This stage results with deriving a set of machine's active working elements with assigned weights. Application of these weights is a consequence of importance flags assigned by the client to certain machine tool's functions. Having the set of working elements it is necessary to create a database of existing solutions and design new elements. While creating the database and selecting elements it is necessary to bear in mind the results of initial endurance tests and brief foredesign. The database of elements makes it possible to configure machine variants out of existing elements. It is possible to make variants of working elements only or – using the QFD analysis results – create different variant of the whole machine tool where price, availability or main functionality could be the distinguishing factors. It is important to use not only the quantifiable results of the QFD analysis, but also the general analysis of the Quality House. Planned variants are being modularised in accordance with the definition of modularity in parallel kinematics machine tools. Modularity comprises of grouping elements in bigger units – modules, defining interfaces that need to be designed and designing the segment modularity system. Once all data necessary to design modules is set, FAST analysis is carried out for the defined modularity design process. It guarantees that all partial project tasks are taken into account and distributed effectively among the project teams.

At each stage of the methodology the results of QFD analysis are being referenced. Fig. 1 shows the line of references as "QFD Axis". QFD method in the presented methodology is not only one of the stages. Its results influence the decisions at all later stages. QFD focuses all efforts on designing a modular machine tool in such a way that maximises the probability of market success. The most important feature of this methodology distinguishing it from other methodologies of this kind is focusing the design process around customer's expectations instead of treating them as brief foredesign.

Parallel kinematics machine tool modularisation method (Fig.2.) has to – according to the definition of modularity for this type of machines – take into account two types of modularity: segment, which is dominant in this example; and integrating which integrates a couple of components in a module. Basic criterion of including an element into a module is obviously physical feasibility. But in spite of this another factor of deciding importance is the frequency of the element's occurrence in different variants of the machine. This second factor is more of a financial nature. It is sensible to bear the costs on the design, production and storage of modules or subcontracting the production of modules only if projected demand for modules is high.

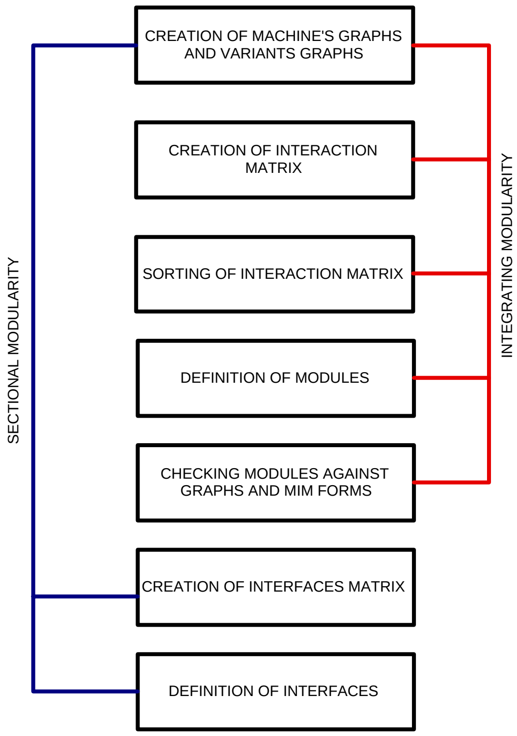


Fig.2. *Schematic representation of the modularisation method*

Fig 3 shows an example of a graph of a machine (simplified) and the corresponding interaction matrix.

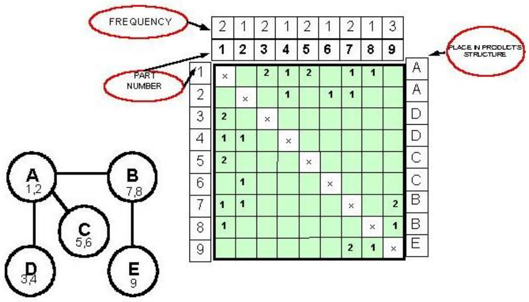


Fig.3. *Interaction matrix*

Next figure (Fig. 4) shows the same matrix sorted by frequency. It is the modularity matrix.

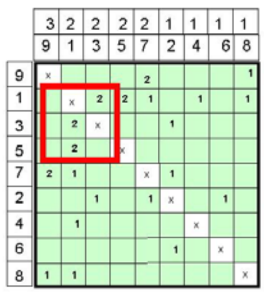


Fig.4. *Modularity matrix*

It is possible to derive potential modules out of this matrix. Modules are verified using Module Indication Matrix (MIM) form. Basing upon the modularisation matrix and the MIM form integrating modularity modules are derived. The next step is to build an interface matrix where certain elements of the production programme are assigned to places in the machine's structure. Such matrix structure makes it possible to define interfaces that need to be designed. An example is shown on fig.5. Carrying out the described steps leads to a full modularisation of a parallel kinematics machine tool.

| | Cz. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | | | 1 | 1 | 2 | | 1 | 1 | |
| | 2 | | | 1 | | | 1 | 1 | | |
| D | 3 | 1 | 1 | | | | | | | |
| | 4 | 1 | | | | | | | | |
| C | 5 | 2 | | | | | | | | |
| | 6 | | 1 | | | | | | | |
| B | 7 | 1 | 1 | | | | | | | 2 |
| | 8 | 1 | | | | | | | | 1 |
| E | 9 | | | | | | | 2 | 1 | |

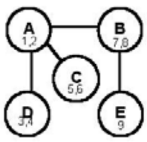


Fig.5. *Interface matrix*

The methodology described herein was used to define a modular system of a parallel kinematics machine tool "Spider". This machine was developed in Institute of Production Engineering and Automation of Technical University of Wrocław. Fig. 6-9 shows the selected steps of modularisation process.

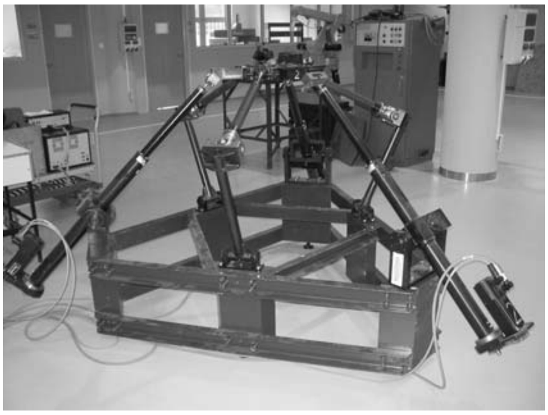

Fig. *6. Machine tool "Spider"*

| | 12 | 12 | 12 | 12 | 9 | 9 | 9 | 9 |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 13 | 11 | 5 | 8 | 10 | 14 |
| 1 | | | | | 9 | | 9 | |
| 2 | | | | | | 9 | | |
| 13 | | | | | | 9 | | 9 |
| 11 | | | | | | | 9 | 9 |
| 5 | 9 | | | | | | | |
| 8 | | 9 | 9 | | | | | |
| 10 | 9 | | | 9 | | | | |
| 14 | | | 9 | 9 | | | | |

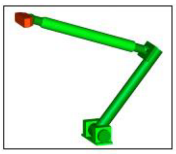

Fig.7. *Fragment of modularisation matrix and an example module*

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| E1 | 1 | | | | | 9 | 3 | | |
| E2 | 2 | | | | | | | 3 | 9 |
| E3 | 3 | | | | | 6 | | | |
| | 4 | | | | | 3 | 3 | 3 | |
| E4 | 5 | 9 | | 6 | 3 | | | | |
| | 6 | 3 | | | 3 | | | | |
| E5 | 7 | | 3 | | 3 | | | | |
| | 21 | | 9 | 6 | 3 | | | | |

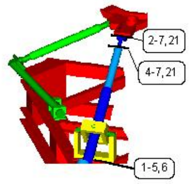


Fig. 8. *Fragment of interface matrix and fragment of the machine.*

Defining modules of integrating type makes it possible to carry out the design process concurrently, subcontracting manufacturing of the module, preparation and storage of ready modules.
Thanks to the application of the described method a modular system is created even if the structure and variants of the machine do not allow configuring modules of integrating type.
Sectional modularity can be applied to the whole machine, it is possible to define a flexible modular system that uses typical elements. Designing a sectional modularity system with use of typical elements can drive down the overall costs and assure better availability of the machine tool on the market.

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