7.3 MECHATRONICS AT DESIGNING OF CNC MACHINE TOOLS

The term mechatronics was created to designate such elements/components, whose functions were extended by implementation of electronics and computer control. Thanks to the considerable increase of the information processing speed, the "intelligence" is being integrated to the technical systems in mechanical engineering now. Mechatronic systems are generally characterized by the extension of the mechanical system by means of the functional and/or spatial integration of sensors and actuators, including the control systems to provide functionality.

The contributions of mechatronics exceed the pure additive effect, which is emphasized in its definition [Van Brussel 1996]: "Mechatronics needs the synergic interconnection of various engineering disciplines which include mechatronics, control, microelectronics and information science. Therefore, this is the simultaneous engineering view on the design machine solution."

The solution of the contradiction between the requirements on the manufacturing precision in the big machine working areas and the flexible and reliable manufacture requires to design production machines with the universal system architecture and the typical properties of the mechatronic system – the ability to be readjusted (reconfigured) quickly and the resistance to the failures (autooptimization).

The future demands on the production machines will be determined by the technological trends connected with microsystems and nanotechnologies and with the permanently increasing demands on the accuracy of machine tools following from this [Byrne 2003]. In the globalization conditions, the mechanical engineering production in the countries with high wage expenses is exposed to the enormous economic pressure and the essential possibility how to face this pressure, is the manufacturing process shortening, including the precision increase at the high productive manufacturing procedures.

From this point of view, the particular requirements are the following ones:

- high economic production (life cycles expenses) as the result of the functionally oriented design; improved functional parameters regarding to dynamics and flexibility as the result of reconfigurationability;
- increase of applicability based on the maintenance prediction; monitoring of the machine condition and of the manufacturing process condition; intelligent maintenance; diagnostic functions.

These aspects are necessarily connected with the high level of standardization and modularization (interface, technological modules, independent functional units) and high duty control systems. Therefore, mechatronics has become the established development method of such systems at the current time [Jovane 2003].

The industrial applications use technically more advanced actuators in the high integrated mechatronic components. These actuators are made of the materials enabling the energetic transformation (e. g. precise position setting systems). If such components include also the integrated sensors for the autonomous improvement of mechanical or mechatronic structures, they are designated in the mechatronic engineering as adaptronics. In the future mechatronics will be upgraded in principle by optic technologies (technical seeing, optic waveguides etc.) as the new essential system type.

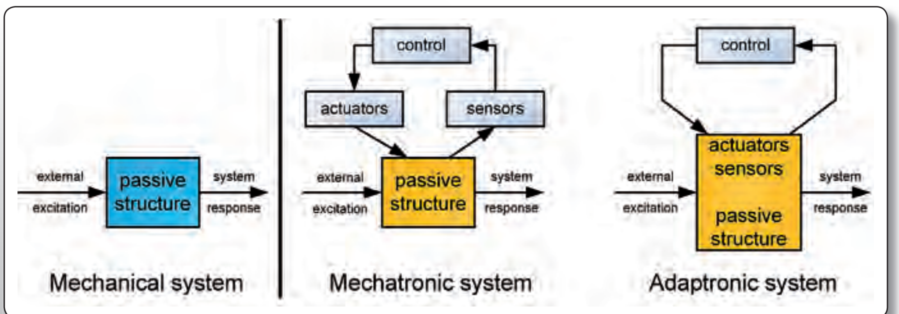

Fig. 7.3.1: Characteristics of the mechatronic systems

The following trends can be considered to be the main trends of the next development of mechatronics:

- information technology;
- adaptronics and manufacturing processes related to the microsystem technologies for the development of light designs and for the increase of the component integration level;
- optics as the universal new essential system type.

Mechatronics and adaptronics

The term adaptronics [Janocha 1999] covers the research in material sciences and engineering which were inspired by bionic design principles, like e. g. the structure of the human muscle. This work was aimed at the creation of efficient and light designs for aviation and astronautics by the direct integration of the materials used in sensors and actuators into the design of product structure itself (so called intelligent agents), see Fig. 7.3.1. These materials change energy directly from one form into another one, and therefore they can behave as sensors and actuators. These are especially piezoelectric materials, alloys with elastic memory, magnetostrictive materials, electrically and electromagnetically activated liquids and polymeres. When the composite elements behaving like sensors and actuators are connected and the suitable adaptive control is used, the dynamic properties of the basic mechanical structure are influenced directly. At the current time work is performed on the distributed integration of these materials into design materials. The creation of the active composite materials with utilization of the complicated mechanical and information technologies is at the beginning and it is the object of the intensive research.

Mechatronics is naturally embedded in the design of production machines, where it considerably changed their functionality. In order to be able to utilize the latest technical possibilities offered by mechatronics in the optimum way, the adapted procedures for the design elaboration [VDI 2004] as well as the tools are required for the unified design. Especially such procedures and tools are

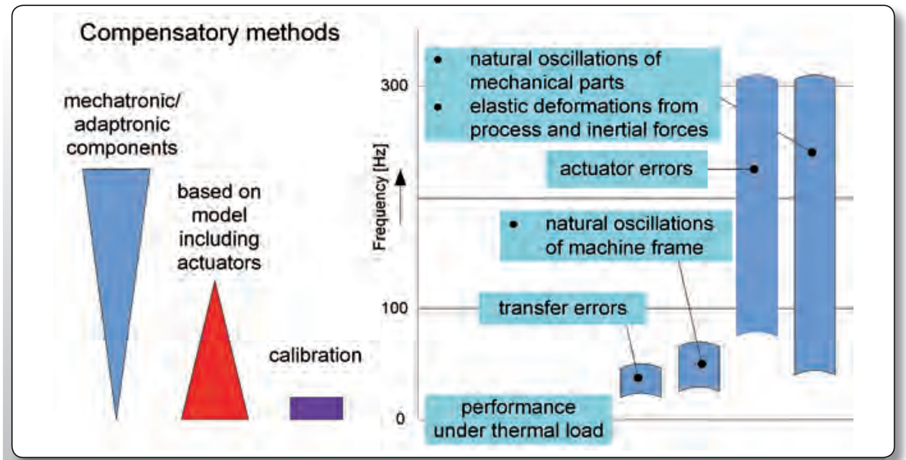

Fig. 7.3.2: Error zone width of the machine tool and possibilities how to correct errors [Neugebauer 2007]

necessary which increase the functionality and eliminate the undesirable increase of the system complexity which a priori leads to the decrease of the system reliability. The essential contribution to this field is represented by the book [Neugebauer 2007] which deals with mechatronic systems in the machine tools. Considering the various errors and the machine error zone width (see Fig. 7.3.2), the hierarchic concept is important for the next improvement of the mechatronic production machines.

Fig. 7.3.2: Error zone width of the machine tool and possibilities how to correct errors [Neugebauer 2007].

It is purposeful to distinguish the following three system levels:

Mechatronic components of the machine tool

These components include especially the main drives and the feed drives. These elements and their integration within the information technology determine the abilities of the actuator and the zone width of the solution frame on the system level of the whole mechatronic system of the production machine. Therefore, the optimum result of the system integration is the main expected contribution.

Integration of the auxiliary mechatronic components to the essential machine components

The interventions on this system level shall suppress the incorrect machine function by the autonomous components which act either directly as auxiliary actuators for compensation of the geometric errors near to the failure source or which improve the behaviour of the controlled processes of the components of the production machine for the needs of the control system higher level. The advantage of this type of the intervention to the systems can be seen in the design which is adapted to the local problem in the optimum way as well as in elimination of the zone width limitation of the errors which shall be compensated.

Plug & Play modules represent the solutions interesting for implementation of the reconfigurationability.

Mechatronic system of the production machine

The process state and the machine state are displayed by the sensors of the particular components together with the auxiliary sensors. The production machine drives are controlled with the support of models so that they can correct the process errors. The suitable application area is especially calibration of machines or elimination of quasistatic error sources, e. g. thermal dilatations. The increase of reliability and applicability of the production machine is also enabled by the extensive data from sensors.

The above mentioned system levels are especially purposeful in relation to the total production machine functions and at the current time they enable various improvement degrees in applications. Therefore, the optimum result can be obtained only by means of the system integration concept which takes into consideration the mechanical substance as well as signal and energetic flows of the whole architecture.

Elaboration and tools

The mechatronic systems are comprehensive systems whose solution field is the interdisciplinary one. They have higher functional density due to the concentration of functions compared to the traditional mechanical and electrical systems. Therefore, the functional aspect comes to the foreground in their design considerably, in comparison with the purely mechanical geometric aspects. On the other hand, this brings the considerable increase of the system complexity and the distinctive merit is represented by the origination of requirements on the research and development of new solutions and/or new technologies, so the innovation potential arises.

Due to this, the main design processes of mechatronic systems were set for the development stage and their utilization is aimed fundamentally at an applicable product. The design of mechatronic systems represents the iterative process and the united approach is designed in [Seo 2003] to solve this task having the inversion character. This approach uses topologic optimization to represent the system using the coupling graph supported by the evolution algorithm.

The mechatronic approach is based on alternation of the design method from above downwards, when the functional elements/modules are separated from the design of the whole structure and the particular elements/modules are specified more exactly within them, and the design method from below upwards (integration of the separately developed and optimized units) as the subsequent iterative step to optimize the system. The advanced design stages are usually distinguished by alternation between both development strategies (so called yo yo effect).

In order to reduce the development time, the virtual prototyping tools become still and still more important. Simulations on the model are used to make experiments with the system properties and to reach the necessary knowledge. These simulations can be transferred to reality.

7.3 MECHATRONICS AT DESIGNING OF CNC MACHINE TOOLS

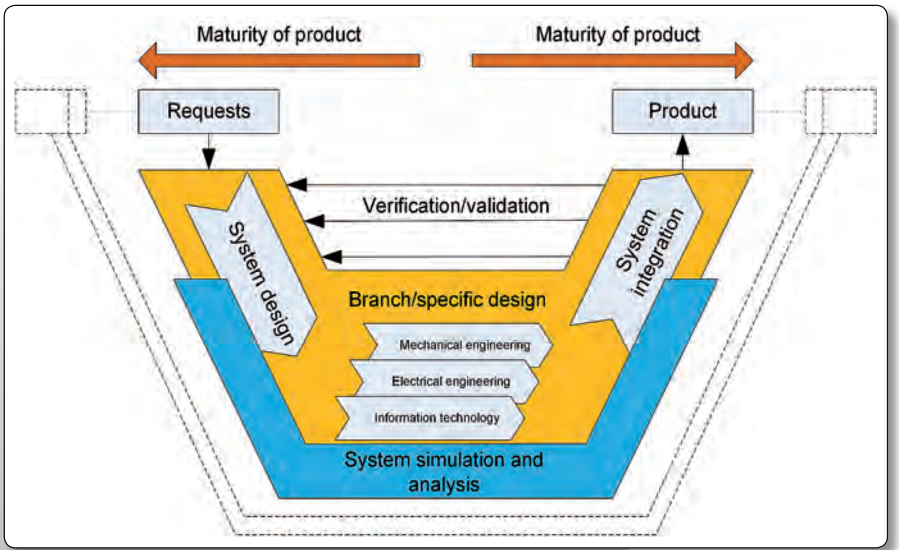

Fig. 7.3.3: V-model of the mechatronic system design process [VDI 2004]

The V model, see Fig. 7.3.3, represents the macrocycle which prepares the system design in dependence on the requirements put on the developed product. This design is transferred subsequently to the already parallelized branch design. Then, the integration is made resulting in the virtual prototype and in the verification and validation of the system design. This cycle can be repeated to reach a higher maturity level during iteration. The design cycle is supported by simulation modelling. The microcycle is adopted from the system engineering for the particular task parts. Moreover, standard procedures are recommended to solve particular tasks, see Fig. 7.3.5.

The virtual prototyping tools serve most of all:

- to reach the specified product properties by means of experiments with system properties using simulations on the model;
- to reduce the development time/to save the costs.

However, it becomes apparent that there is no generally applicable exact design process available. The known processes have more likely the character of methodical instructions. The initial process of the mechatronic system design and the related system support are mentioned in [VDI 2004]. In fact, the mechatronic system consists of (see Fig. 7.3.4) the basic system which can have the mechanical, electrical or another physical nature. By means of sensors and actuators it is connected to the elements processing information. The sensors measure the system state quantities and the observers can be also used like sensors, i. e. they can be implemented by means of software. The data processing from the measured values determines the required effects influencing the state parameters in the desirable way. The impacts are shown in the activity of the essential system by means of actuators.

The comprehensive mechatronic system can be divided into the modules. The interface definition facilitates modularization and it creates the product structure. The modules need not be located only on one level, they can be arranged in the hierarchic structure in such a way that more modules are connected by utilization of their functional structure. The examples of the hierarchic organization can include monitoring and diagnostic error functions, generating of parameters for a group of mechatronic modules and the system ability to learn.

The integration of mechatronic modules which can be reached by utilization of the material, energy and information flow has two aspects – functional integration and spatial integration. In spite of this, the product structuralization determined by the integration must be able to reflect the whole product generating process; therefore, the so called housing free integrations are possible, where the assembly structure can be seen. The spatial integration of components which belong together from the functional point of view enables to prevent the housing free concepts, to increase the function density, to save weight and dimensions of the unit and to increase

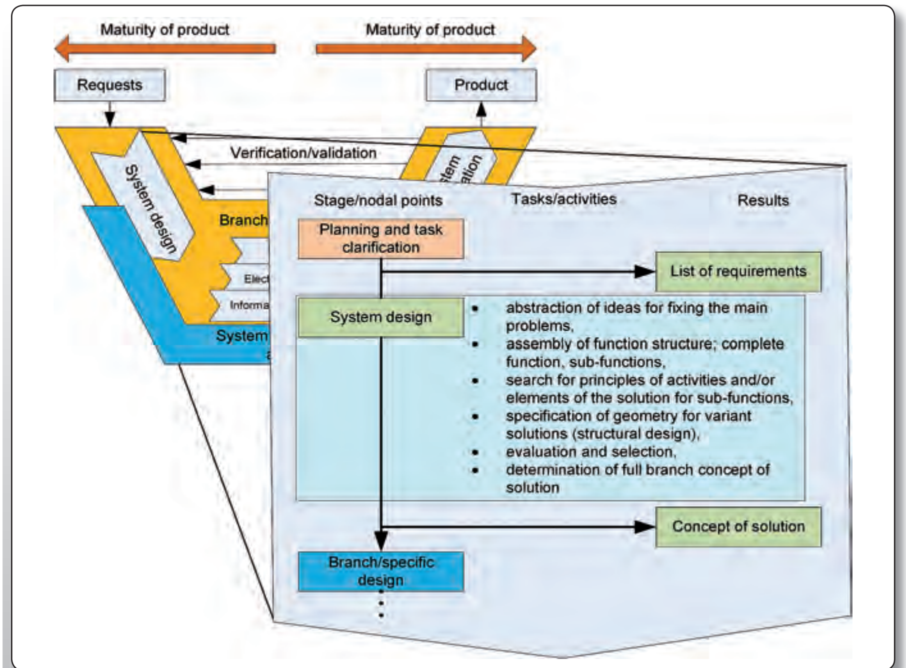

Fig. 7.3.4: Mechatronic system with the basic mechatronic modules [VDI 2004]