8.3 VIRTUAL PROTOTYPING OF MACHINE TOOLS

The present competitive environment lays increasing emphasis on the quality of production and productivity of labour. The aim of manufacturers is to produce new machines with required parameters in a very short innovation time and with low costs per innovation cycle. Such an effort applying the classical approach to the development of a new product is confined by the lengthy and expensive production of a physical prototype. This limitation can be eliminated by virtual prototyping of new products which applies computer-aided design (CAD) and computer-aided engineering (CAE.).

The virtual prototype of a machine tool is a simulation model of the physical machine, which can be presented, analyzed and tested as a real machine tool. A virtual model makes it possible to assess the technical parameters of the machine tool and to analyze the changes of its behaviour when these parameters change iteratively during the process of the machine tool design. This process can be repeated up to the moment when the required behaviour of the machine has been achieved. If the designer is not able to create a comprehensive simulation of the behaviour of the machine or of its part during the process of development, the optimization of physical prototypes is often based on the trial and error method and on previous experience which can lead to lengthy and expensive development. Consequently virtual prototyping can lead to a reduction of the length of development period and to a reduction of the related costs. The benefits of the system are apparent from Fig. 8.3.1.

By virtual protoyping designers can realistically simulate the static, kinematic and dynamic behaviour of a machine tool including the cutting process. These simulations make it possible to analyze rapidly more variants of the design and to select the optimal one. This approach can be applied if high computer performance and very sophisticated software tools are available [Alintas et al. 2005].

Modelling of a technical system

Virtual prototypes are based on computer simulation. Adequate simulation is essential for the solution of engineering problems. Simulation is a set of activities related to the creation and implementation of a model aimed at the solution of a particular problem concerning a particular object for a selected level of resolution of the implementation process [Janíček 2007]. The process of creating a model is very demanding since it requires synthesis of knowledge and experience from numerous fields. Creation of mechanical models requires knowledge of mechanics, mathematics, machine components, from engineering disciplines, individual types of machines and others. For simulation we are not able to describe a comprehensive set of knowledge and instructions and the process

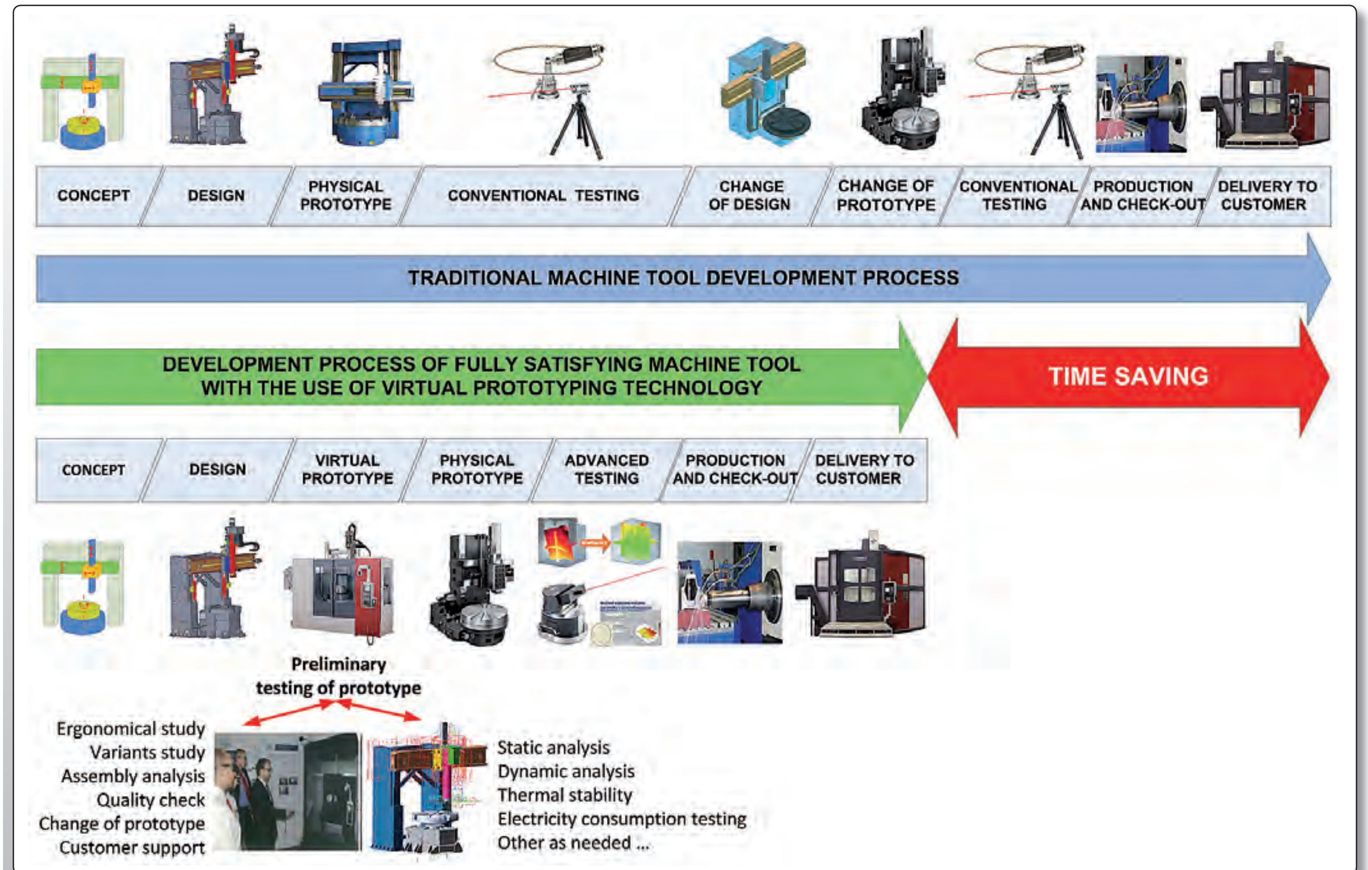

Fig. 8.3.1: Comparison of the traditional process of development of a machine tool with that applying virtual prototyping

of their systematic application [Valášek 2011], [Hadaš et al. 2012], [Vetiška, Hadaš 2012], [Březina, Hadaš, Vetiška 2011], [Březina et al. 2012].

The basis of the process of simulation (of machine tools) is the transformation of real objects into fictitious abstract objects (mechanical model) with idealized properties. The properties of real objects more or less only approach the idealized ones. These so-called ideal objects (material point, perfectly rigid body, linear spring, etc.) do not exist in reality, but physics, mechanics and other engineering sciences formulate knowledge only on these fictitious abstract objects. Mechanics is not able to assert anything about a real machine, its conclusions are exclusively concerned with the model of mechanics comprising ideal objects. The rate of agreement between the properties of a real object and its idealized version is essential for the rational work of an engineer. This is why, at present, simulation is of essential significance in engineering and this significance only increases with the growing opportunities of using computers for studying properties of idealized models of real objects [Valášek 2011].

As it is apparent from Fig. 8.3.2 the creation of a model can be presented as a number of separate steps, during which the real object (machine tool) is transformed into an idealized model of reality.

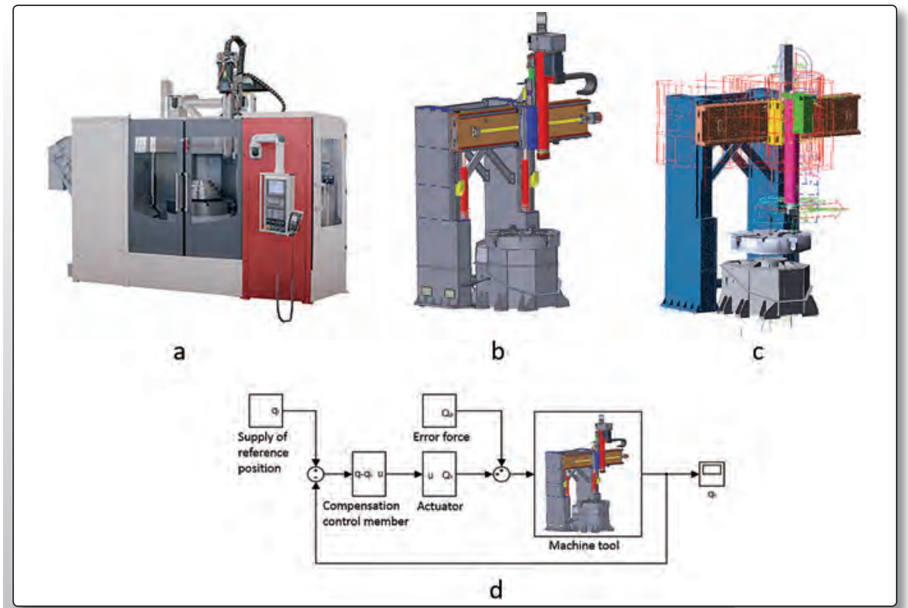

Fig. 8.3.2: Transformation of a real machine into an idealized model of reality;
a - real machine, b – conceptual model, c --physical model, d – computer simulation

In the first step analysis proceeds of a real world object (technical system – in our case a machine tool). The real object is investigated within a certain environment – experimental framework (force, magnetic, temperature patterns, etc.). Within this framework we focus on the behaviour which is of interest to us and formulate certain questions on the behaviour of the object as goals of our interest (for instance, what is the resistance of the particular machine tool to self excited vibrations). Consequently a real world system is created, for which we try to find an answer (solution of problem) to our question [Valášek 2011].

In the second step the real world object is transformed into a conceptual object. This transformation is based in the hierachical dissipation of the real world system into individual components it is composed of, or components which will be considered in its investigation (a vertical lathe comprises a bed, table, supports, crossrail, toolhead slide, headstock spindle, headstock spindle drive, axes drives, cooling, control system, control, housing...) Here it is decided about how detailed will be the description of the real object (for example if it is necessary to simulate the elastic behaviour of individual components or not). Simultaneously with this hierarchical description of the real object and of its environs a description is created of its function and physical interactions as a basis of the causal and functional explanation of its behaviour. During this process numerous assumptions are made which lead to a gradual simplification of reality into an idealized model. The real world system is thus transformed into a conceptual model and model of the environs. The issue related with the behaviour of the real world system is transformed into the goal of simulation. The conceptual model can often be represented by a drawing or CAD model [Valášek 2011].

In the third step transformation proceeds of the conceptual model into a physical model which is also called a computer model. A physical model is an idealized model of a machine, which is subject to ivestigation by physical and engineering sciences. In mechanics we speak about a model of mechanics. In the process of modelling we obtain a physical model by gradually replacing elements or groups of elements of the conceptual model with corresponding ideal objects. Here we can proceed in two ways. Either one element of the conceptual mode can be replaced (simulated) by coupling more ideal objects (the frame of a machine can be simulated as a flexible body composed of a number of flexibly coupled rigid bodies) or more elements of the conceptual model can be replaced (simulated) by one ideal object or by only a certain number of ideal objects (for instance a motor and a gearbox can be replaced by a single block). In this transformation process most of the assumptions made on the simplification of reality were incorporated into the final model of mechanics. Similarly the model of the environs is transformed into the inputs (excitations) of the model of mechanics and the goal of simulation is transformed into the investigation of simulation outputs. The model of mechanics should not be more complicated than absolutely necessary for the given purpose [Valášek 2011].

The model of mechanics is governed by laws and principles of mechanics by means of which we can describe mathematically the behaviour of a mechanical model and hence create a so-called mathematical model. This is what mainly proceeds in the fourth step of the transformation of a real machine into an idealized reality model. Simultaneously with the mechanical model the investigated inputs and outputs of the model are also described mathematically. Further it is necessary to select an appropriate method of solution of the mathematical model and to assess its solvability [Valášek 2011].

The actual search for an answer to the question related with the real object (in our case a machine tool) proceeds in the **fifth step.** The model of the effect of the environs on the investigated object is attached to the inputs of the ultimate mathematical model, an appropriate solving method is selected and the values describing the answer to the given question are analyzed and appropriately interpreted on the outputs of the mathematical model. The correct formulation of this answer requires a broader assessment of the obtained results. It includes an assessment of whether the created model and the results of the solution meet all assumptions formulated during the gradual creation of the mathematical model of the machine. Here it must be realized that the results obtained from the mathematical model will never be completely in agreement with the real behaviour of the real object. The extent of agreement depends on the extent of simplification of the mathematical model and on the correct preservation of the substantial properties of the real system [Valášek 2011].

The **fourth and fifth steps** described above represent a standard solution. At present already an essential portion of these steps is performed on a computer applying simulation and other programmes. In an ideal case the fourth step is performed by implementing the mechanical model in the simulation programme, which directly contains the equivalents of ideal objects as its basic structural elements. The mathematical model is then generated automatically and the computer engineer must verifiy the correctness of the implementation by means of test inputs. In the fifth step the tuned simulation model is used for solving the problem formulated in the question pertaining to the properties and behaviour of the real system. This procedure is called a (calculation) computer experiment [Valášek 2011]. The complete procedure is clearly presented in Fig. 8.3.3.

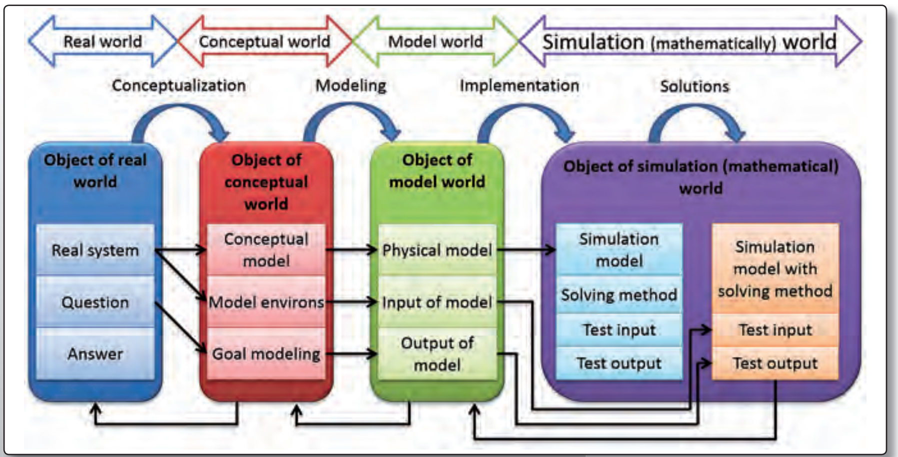

Fig. 8.3.3: Planning of the simulation modeling of a technical system

Computer simulation

Computer simulation is basically a computer experiment with a mathematical model implemented into a computer software programme. The goal of the computer modeling experiment is to find what properties will the monitored object have for various values of the entered input data. By repeating simulation experiments with various input data the user can find an optimum solution of the analyzed problem. Expansion of the application of computer simulations depends on the development of computer technology. The first significant application of computer simulation appeared within the scope of the Manhattan Project in the process model of a nuclear explosion, where the numerical solution of the problem by means of the Monte Carlo method was applied. Since then numerous different types of computer simulations have been developed the application sphere of which includes among orthers:

a) Optimization of business processes
- assessment of "optimum" production strategy;
- prediction of "real" costs per commission;

b) Planning and control of production
- planning of enterprise-wide sources;
- shop control of production;

c) Improvement of logistic concepts
- minimization of inventory stock;
- reduction of work in progress (unfinished work) and execution time;

d) Designing production machines
- designing innovations of existing production machines;
- concept of layout;
- optimization of arrangement of individual subassemblies of the machine;
- prediction of the behaviour of a machine in operation;
- ergonomic studies;
- analyses of variant solutions;
- analyses of assembly;
- training of operating personnel before the end of the production of the machine;

e) Analysis of production systems
- assessment of requirements for capacities assuring flow production;
- identification and elimination of bottlenecks;
- uncovering reserves by thorough analysis of all kinds of activities;
- what-if analysis.

Modeling technologies

In the field of the virtual prototyping of machine tools mainly the development steps described below are applied.

CAD modeling systems serve for creating conceptual models of machines and their components. They are able to create a model of a new machine in 2D or 3D and are often a source of data for other simulation environs and for the creation of production documentation. State of the art CAD applications not only replace drawing boards but include a number of supporting tools for engineering work. These tools can help, among others, in calculations of bolted joints, concepts of shaft supports etc.