Computer aided optimal design of mechanical device

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**Abstract**

This paper presents an integrated computer aided approach to the design of any mechanical device involving modeling, simulation and automatic drawing of the device. The process of computer design is presented on the example of a design of a gear speed reducer using the POWERSIM simulation software. The use of the computer model of a device allows the designer to perform easily the simulation, in order to find optimal technical solution to the elements of the device. In first step the logic of mechanical calculation of a device and their sequence is represented in the form of a flow chart. That helps to develop a computer model in terms of the symbols of a particular simulation software. The next step is a computer simulation which helps to determine the best geometry of the elements of the device. The results of the simulation should be then represented in form of an assembly drawing of the device. Using AutoLISP language existing in AutoCAD software, the special programs have been developed for automatic drawing of the gear speed reducer. The designer can now observe the final results of his calculations and check the fitness of his decisions taken during the calculation and simulation process. The final step of the development of a particular design is the work of optimization in which the designer is seeking for the optimal solution of the whole device. Any changes introduced at a certain point of the design usually demand certain changes to be introduced to the previous steps of the design. Without computer model of the mechanical structure the process of optimization of the device is difficult and
time consuming. A computer model of a mechanical device makes the process of design and optimization easy, attractive and more precise.

1 Introduction

The process of design of mechanical equipment is a combine effort of different specialists in economy, marketing and engineering. All the initial works connected with the creation of a new product (recognition of the need existing in the society, market study, feasibility study etc.) lead to the specification of the device that is going to be created. Specification of the technical requirements of the equipment to be designed is necessary to begin the work of design. Quality design of mechanical systems has to be based on thorough knowledge of theory of strength calculation, engineering drawing and various standards and recommendations existing in the particular area of design as well as the personal experience of a designer. Computers nowadays usually aid the process of creation of any complex mechanical equipment at the early stage of design (CAD) as well as at the final stage of manufacture (CAM). Since the process of design and the process of manufacture mutually depend on each other, both of the computer packages are usually integrated into one computer system called CAD/CAM. In reality uniform CAD/CAM package can be developed only in the case of the design and manufacture of simple mechanical parts. In a case of the design and manufacture of compound mechanical systems, the design process should be based on a specially developed computer model of the mechanical structure. That computer model should allow the designer to perform computer simulations, which are necessary in order to obtain the most optimal solution of the design. The application of computers to the process of design and optimization of mechanical systems can affect in saving time and money for carrying out costly laboratory experiments and sometimes also constructing a prototype. Integration of the results of the simulations with the AutoCAD by creating an AutoLISP software program allows for the automatic creation of the assembly drawing of the device.

2 Computer model of a mechanical system

The process of design begins when the demand of the market is fully recognised and the technical requirements of that device are specified. Design and calculation of the device advance in some typical stages. They start from the design of the most principal systems deciding about the functionality of the machine and then are followed by design of subsystems and details of the device. This process of design, aided by the computer, will be presented in this paper on the example of the design of a gear speed reducer.

The general sequence of that design can be advanced in the following stages:
- kinematics calculation of the gears, leading to the selection of the number of teeth of the gears that satisfy the input and output rotational speed of the reducer,
- strength calculation of the gears, defining their dimensions and drawing of the gears,
- calculation of the bending and torsion moment distributions, normal and shearing stress distribution and design and drawing of the shafts,
- calculation, selection and drawing of all the bearings existing in the reducer,
- design of the body of the gear speed reducer.

Usually the outlet results of the calculation made at one stage, form the inlet data for the next stage. Since the above stages of calculation must follow each other, it is recommended to develop a computer model for each of the stages separately in order to make it possible to perform optimization independently within each of the stages. In practice there are feedback loops existing not only within a stage but also between the stages. All of them should be introduced into the computer model of the device.

The flow chart representing the logic and the sequence of the calculation appears to help significantly the process of development the computer model. As a matter of example, Fig. 1 shows the flow chart which serves for the calculation of the teeth of the gear reducer. The structure of the flow chart shows the need of elaboration of two computer models of the calculation: first for the selection of the number of teeth of the gears (kinematics calculation model) and second for the definition of the size of the gears (strength calculation model).

Mechanical design must consist, as much as possible, of standard elements and finish goods like bearings, keys, retaining rings or semi-finished products like sheets, plates, steel sections and so on. It should also respect standard parameters, technical norms and practical recommendations. All of the standards, norms, catalogues of the materials connected with particular mechanical device which is going to be designed should be stored in the computer model. This necessity makes a special demand concerning the simulation software that can be applied for elaboration of computer model of a mechanical structure. There are number of computer simulation programs available in the market, but most of them can not be used for the modelling of mechanical structure.

Some of the most important requirements, that the computer model developed for the computer-aided design should satisfy, are as follows:

- the computer model must strictly fit the reality. It is necessary to built the computer model of the mechanical structure that involves all correctly interconnected constants and variables which influence the mechanical system. The result of calculation must be in agreement with the behavior of the system in real conditions,
- the model should be legible. The model should be arranged in such a way that the designer can clearly understand all the parameters involved, and the mathematical and the logical connections between them.
- it should allow to introduce the changes to the variables. The computer model should arrange all the variables and constants in a pictorial representation
Figure 1: The flow chart for the calculation of the gears of the gear speed reducer.
in which the relation between parameters is immediately seen, and changes to those parameters can be simply introduced.

- it should provide the possibility of optimization. The best computer model of a mechanical structure is that, in which optimization of the parameters can be made automatically, but there are only few so well-developed models offered in the market. In most cases, the designer himself has to find the optimal parameters by the method of successive approximations, with the aid of the computer program,

- the results of simulations should be presented in form of graphs and numbers to make it possible to analyze the changes of the parameters until they reach their optimal values,

- the model should store standard parameters,

- the software must accept the graph functions for calculation,

- the transfer of results to other software like for example AutoCAD should be allowed.

All the above requirements are fully satisfied when the Powersim software [1] based on System Dynamic Method [2] has been applied. That software initially developed to help to solve the problems of administration, has been found to have also good applications in various engineering problems [3-9]. The Powersim software allows the designer to deal with the standard values and gives also the chance to create a „store” of standard elements which are actually available to the designer, what brings the process of design closer to the workshop reality. Another advantage of the Powersim software is the possibility to introduce any graphic function into the process of calculation. Thanks to that, the results of experiments can be applied to the modelling and simulation of mechanical structure as easy as the theoretical formulas.

In that software only four constructing blocks are used to build a model. The main block is called “level variable” which is represented in the shape of a rectangle. The function of that block is to generate numbers with the rate controlled by the “auxiliary variable” represented in the shape of a circle. That constructing block can also perform various mathematical or logical operations. Constants are introduced to the system through the square blocks. Lines of different shape with the arrowheads called “connectors” show the flow of information, which makes it easy to understand the logic of the calculation system. The construction blocks of the Powersim software are shown in Fig.2. Fig.3 shows the computer model of the calculation of the number of teeth of the gears of the gear speed reducer which is represented in terms of constructing blocks of the Powersim software. The Powersim model for determination the geometry of the gears is shown in Fig.4. In both cases the models refer to the wormgear speed reducer in which there are only two gears. The models of most compound gear speed reducers developed by us can not be presented in this paper because of their complexity.

The models based on the similar principals have been developed also for the remaining stages of the design. When the complete computer model of the gear speed reducer is produced, it is easy to calculate the forces between the teeth, the torsion and bending moments, and the shearing force distributions along the shafts. This information allows to calculate the diameters of the shafts and, in the
next stages, to select bearings and to make other strength and control calculations.

Figure 2: The construction blocks of the Powersim software.

Figure 3: The Powersim model for the selection of the teeth in the wormgear reducer [10].
Fig. 4: The Powersim model for determination the geometry of the gears in the wormgear speed reducer [10].

3 Simulation and optimization

With complete computer model of the speed reducer the designer can perform simulations in order to find the optimal values of the variables. The numerical results of this simulation can be observed in the tables or in form of graphs similar to these presented in Fig. 5.

Each of the stages initially approved by the designer, may appear not to be optimal in the light of the results of the next stage. In that case the designer has to return to the previous stage to introduce corrections. These feedback loops exist within each of the stages as well as between the stages. Furthermore, the development of optimal design solution requires to compare the number of different versions of the design, for which usually the calculations have to be repeated, what makes the process of design very difficult and time consuming. But with the application of the computer model of the mechanical system presented in this paper the process of design and optimization becomes quick, easy and attractive with simultaneous increase of the quality of the design.

The results of the calculation of geometrical parameters of the gear reducer approved after the simulation process should then be represented in the form of an assembly drawing. Using AutoLISP language existing in AutoCAD software, the special computer program has been elaborated for automatic drawing of the gear speed reducer. In this program all geometrical parameters of the speed reducer are treated as variables, what allows the designer to observe on
Figure 5: The results of the simulation of some of the parameters of the gear speed reducer.

the screen of computer the actual geometry of the elements drawn to scale, similar to that presented in Fig.6.

Figure 6: The automatic assembly drawing of a tree step gear reducer [11].

The analyses of the assembly drawing gives the best opportunity for the designer to check the fitness of his decision taken during the process of the design. All the
geometrical disproportion or possible interference between the elements can be discovered and eliminated.

But at this stage the design is usually not yet optimal and require optimization. The optimization of the design is made on the bases of certain criteria. Depending on the application of the device, the way of operation or economical and technological capacity of the company, the optimization criteria are very different. But the most important of them are always the safety and reliability of the equipment. The design must also be considered from the point of view of productivity parameters, the weight of the device, low cost of production and operation, aesthetics, ergonomics and also should satisfy the ecological requirements. In the process of optimization the geometry of the elements and their mutual proportions are changing what is immediately reflected in the automatic drawing.

By the use of the software developed in this work, the designer has the opportunity to perform easily the process of simulation and optimization of the gear speed reducer in order to obtain the most optimal design.

4 Conclusions

- The process of mechanical design is advancing in stages that follow each other in a strictly defined sequence. All of the stages are mutually dependent and there are number of feedback loops between them, what makes the process of design a time consuming and difficult,

- System Dynamics Method can be successfully applied for developing a computer model of a mechanical system in order to aid the work of design,

- the computer model of a mechanical system, elaborated with the use of Powersim software, allows to make the process of simulation and optimization easy and attractive and contributes to the improved quality of the design,

- AutoLISP language of AutoCAD software allows to make an assembly drawing of the mechanical system in an automatic way,

- the computer integrated design described in this paper should find different area of applications for solution of engineering problems in the industry.

References


