Computer Design of Mechanical Systems

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Abstract

This paper shows an integrated computer aided approach to the modelling, simulation, automatic drawing and optimization of a typical mechanical devices. The computer model of a spring and a gear-box have been developed using the Powersim simulation software. With the use of the computer model of a device, the work of simulation is easily and precise. The results of the simulation should be then represented in form of drawing. Using AutoLISP language existing in AutoCAD software, special programs have been developed for automatic drawing of the devices. The designer can now anticipate the future results of his calculations and check the fitness of his decisions taking during the calculation and simulation process. Looking for an optimal solution, the designer can easy redesign the whole mechanical system this way that the device satisfies any optimization criterion applied.
Development of a computer model of a mechanical device makes the process of design and optimization easy, attractive and more precise.

Keywords: Engineering Systems, Systems Modeling, Simulation, Optimization, CAD System.

1 Introduction

The creation of a new mechanical device is a long process that requires joint effort of specialists in economy, marketing and engineering. The work of the designer starts when the demand of the market is fully recognized and the technical requirements of a particular device are specified. The traditional design process requires that a few independent groups of designers generate ideas and create a number of possible solutions of the problem. All of these versions of solutions have to be evaluated from technical, economic or aesthetic points of view and one or two selected solutions are then developed in details by one or more design teams. Usually at that stage, there is a need to conduct laboratory experiments and sometimes to construct prototype and to test it.
As a result of the application of computers, the whole process of design can be performed with the use of computer models of the mechanical system, usually without necessity of

carrying out very costly laboratory experiments and sometimes also without constructing a prototype.

The process of design is a process of creation in which a device is built up in successive stages typical for the particular device. Within each stage, the designer makes all necessary calculations, performs simulation and optimization, and creates different versions of the solutions. Finally, the designer decides which version is the best and should be transferred to the next stage of the design. Time and again, he has to go back to the previous stages of the design in order to introduce all necessary corrections. Nowadays all of that work can be assisted by computer, provided a special computer model of a particular device is elaborated.

The computer-aided design process is presented in Fig.1.

As it can be seen from Fig.1, the stages of the design process appear in the following sequence:

- making the list of all variables, which must be considered in case of the particular mechanical device
- gathering of the data (numerical values, graphs, tables, standards and recommendations)
- development of the computer model of the mechanical system
- simulation of the computer model
- automatic drawing of the assembly of the mechanical device
- optimization of the device.

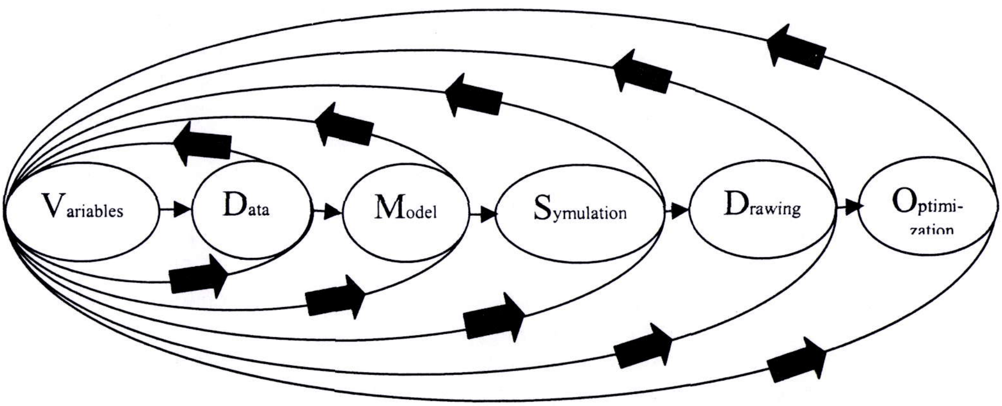


Fig. 1: The design process of a mechanical system aided by computer.

Next stage analysis always depends on the results of calculation and simulation performed in the previous stage. Nevertheless, the results of any stage of calculation can not be accepted if they cause undesired effect in the next stage. This dependence create classical feedback loops which are shown in form of arrows in Fig.2.

The existence of the feedback loops cause that any changes introduced at a certain point of the development of the design not only affects the next steps of the design, but usually demand certain changes to be introduced also to the previous steps.

For example, in the case of a gear-box design, if the designer decides to change a bearing, that decision will involve not only the change of the housing (next step of the design), but also require to introduce a change to the diameter of shaft (previous step of the design). These existence of the feedback loops makes the design process difficult and time consuming and the use of the computers appears to be necessary.

The most difficult requirement for the application of a computer aided method of design is the necessity of elaboration a special computer model of the mechanical system. A big help can be obtained from the existing simulation software like Stella, Ithink, Powersim, Pasion and similar.

Various of our works (Switek,Sliwa,1995; Switek,Quiros,1995; Switek,Majewski,1997) have shown a good suitability of Powersim software. The Powersim software is developed by the application of System Dynamic Method based on J.Forreser´s work on Industrial Dynamics (Forrester,1961,1992; Wolstenholme,1990)). The Powersim software had initially been developed for purpose of solving administration problems but it was shown by us (Acosta,Switek,Garcia,1997; Switek,Acosta,1997; Switek,Acosta,Alvaro,1999) to have also good application for solving engineering problems.

2 Specification of Variables and Gathering of Standards

The process of design starts from the specification of all variables, with which a designer is going to deal in order to design a desired mechanical device.

This variables are related to:

- technical requirements (power transmitted, carrying capacity of the device, load distributions and so on),
- geometry of the device (the size of shafts and holes, cross sections and section modulus of the elements, geometry of standard elements applied for the design of the device and so on),
- experimental results related to the elements of the device(graphs, recommendations),
- materials predicted for the manufacturing of the parts (mechanical properties, heat treatment conditions and so on).

In order to design any mechanical system, the designer must use, as much as possible, standard parameters and elements, technical norms, tables and graphs representing the results of experiments and recommendations.

When the variables are specified, the designer has to gather all standards referring to the mechanical system. In practice the standards represent numbers, formulas or graphic functions. All of that data should be stored in a computer program.

Not all of the simulation software fit well that purpose, but the Powersim software, used by us, gives the opportunity to introduce standard numbers and results of experiments in form of graph functions.

Fig. 2 shows the example of the data stored in Powersim modeling software.

In general these data represent constants or variables. Usually the constants are stored in the special text files and the designer himself selects the required data. Later on, in the stage of optimization, the designer can change his initial decision and select different data. A good example of constant data is a material. In Fig. 2, the designer selects steel AISI 1040, but that decision can be changed by him at any stage of the development of the design process.

However, if the standard data represent variables in the computer model of a mechanical system (for example the number of teeth of the gears that has to be calculated), that data appears in the computer program as Edit/Graph function. Since that function represents a sequence of standard numbers, the Edit/Graph function is a staircase function as it is seen in Fig.2. In the process of subsequent iteration, the computer picks up automatically the next value from the Edit/Graph function until the process of simulation is terminated. This way in the process of simulation participate only standard elements or the elements available in the store.

In Fig.2 as an example of variable data it is shown the standard diameter of the wire which can be used for the manufacturing of a helical spring

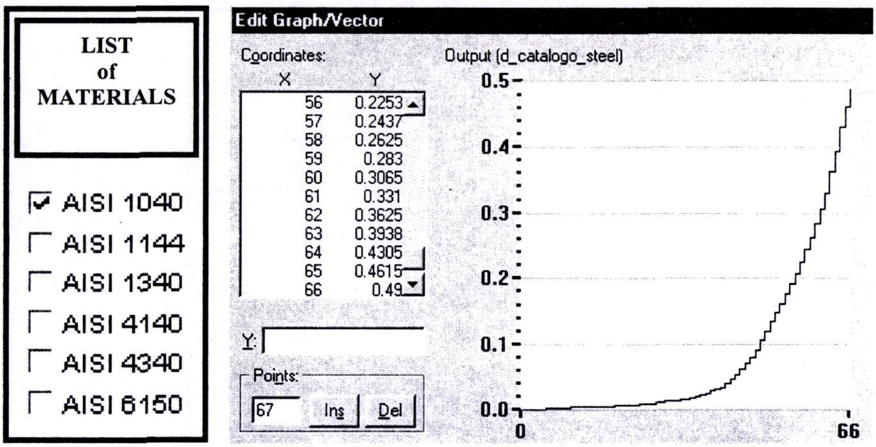


Fig. 2: Standard data stored in Powersim modeling software:
- the materials used for a gear-box construction (to the left),
- the standard diameter of the wire which can be used for the manufacturing of a helical spring (to the right).

The results of experiments and graphs of various coefficients can also be introduced to the Powersim software using Edit/Graph Vector shown in Fig. 2. The only difference is that in the case of this results the graph is a continuous but not a step function.

3 Development of a Computer Model

The System Dynamic Method has been applied to develop a computer model of various mechanical systems. The Powersim 2.5 b software has been used. 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 shapes with the arrowheads called "connectors" show the flow of information. Visualization of the calculation process by the construction blocks of the Powersim software makes it easy to understand the logic of the calculation and to introduce any required changes to all of the parameters.

The next step in the computer design process is to build a computer model of the calculations.

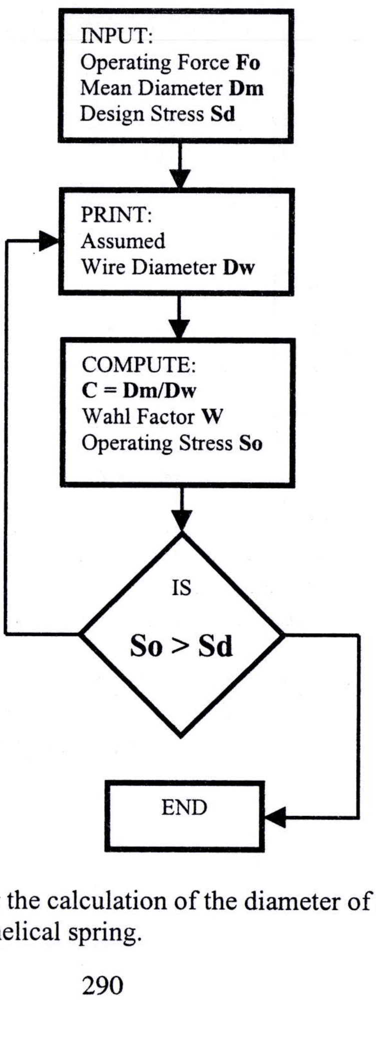


Fig. 3: The flow chart for the calculation of the diameter of the wire for compression helical spring.

Depending on the kind of the device, the calculations may contain a static, kinematics, dynamic or thermodynamic calculations leading to the determination of the form and dimensions of the device. The theoretical method of calculation determines the steps of the calculations and their sequence. Showing the sequence of calculations in form of a flow chart helps a lot in building the computer model of calculations.
The flow chart contribution to the elaboration of the computer model of calculations explains an example shown in Fig. 2. Fig. 2 represents a flow chart of the calculations leading to the determination of a diameter of wire which is going to be used for a manufacturing of a helical compression spring.

The operating force Fo, mean diameter of the spring Dm and designing stress Sd form an initial data representing the technical requirements. The diameter of the wire Dw is assumed by the designer then the necessary calculations are to be performed in order to determine the operating stress So existing in the spring. If this stress is higher than the design stress So allowed for the selected material of the spring, the diameter Dw must be increased and the calculations are repeated. The end of the calculation process is reached when the operating stress So reaches the level of allowed design stress Sd.

The flow chart represents the logic and the sequence of the calculation. It has to be translated into the symbols of simulation software that is going to be used to elaborate the computer model of a mechanical system. Using the construction blocks of the Powersim simulation software described earlier, the calculations represented in Fig.3 can be transferred into the form of the computer model shown in Fig.4.

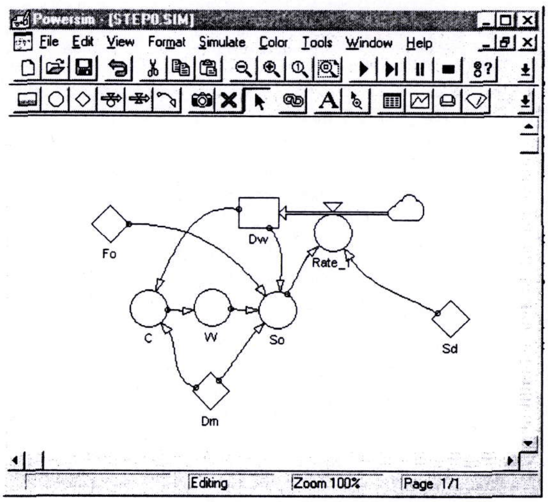


Fig.4: The Powersim model for the determination the diameter of wire for manufacturing of a helical compressive spring.

In Fig.4, the operating force Fo, the design stress Sd and the mean diameter of the spring Dm represent the given constants. The diameter of the wire Dw required to make the spring is shown in the model by a construction block called the Level variable. Level variables blocks generate numbers that increases or decreases in successive iterations with the rate determined by the block called the Rate. The initial value of Dm is introduced to the system and the operating stress So is then calculated. If stress So is higher than the allowable stress Sd, the block Rate_1 sends "a flow" to the block Dw to increase the number Dw by a specified value and repeat calculation until the condition So>Sd is satisfied. At this moment, the information coming from Rate_1 commands to stop increasing the number Dw.

In more complex model of a helical spring working for compression (Switek,Majewski,1995; Switek,Oviedo,2000), presented in Fig.5, also the following additional conditions were considered:

- the spring index C = Dm/Dw can not be less than C = 5
- the stress in the spring at the solid length deflection can not exceed also the allowable stress,
- the deflection of the spring is not too high to cause buckling.

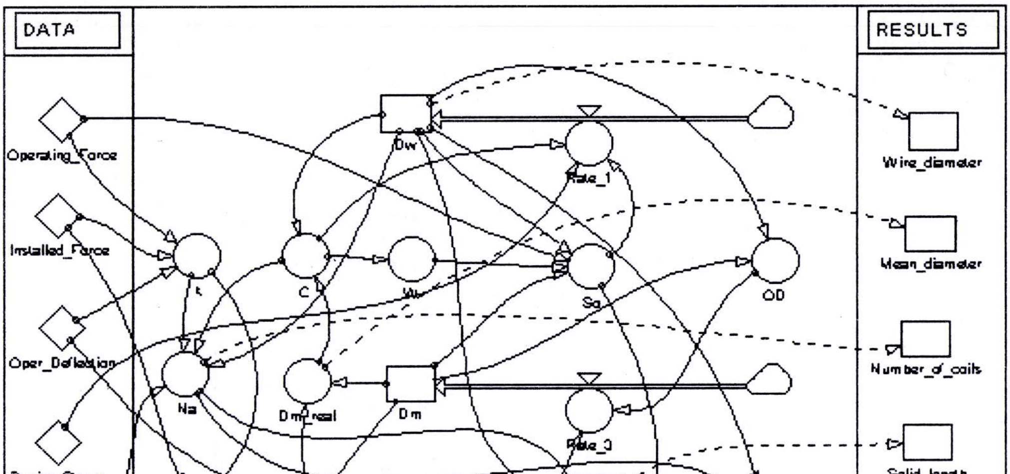


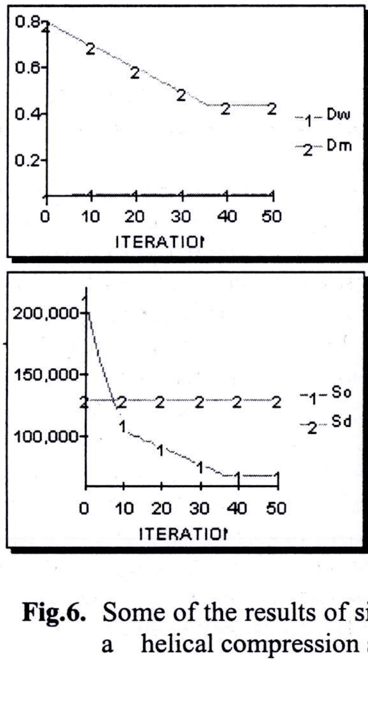
Fig. 5: The complex computer model of helical compression spring.

The model shown in Fig.5 is arranged this way, that the initial data necessary for the design of the spring are displayed in the left column but the final results of the calculations are indicated in the right column.

4 Simulation of the Computer Model

When the computer model of the mechanical system is developed, it can be used for simulation. The simulation is performed in order to determine the geometrical parameters of all of the parts of the mechanical system. The results of simulation in Powersim software can be presented in form of graphs and tables.

The example of simulation leading to the determination of the diameter of wire of a helical compressive spring is shown in Fig.6. The diameter of the wire Dw is considered to be the independent variable in this simulation. The design stress is constant and equal to Sd = 130.000 psi. As it is seen from the Fig.6, when the variable Dw = 0.05", the operating stress So = 211.919 psi and is much higher than allowable Sd stress and the condition So < Sd is not satisfied. The program increases the value of Dw and repeats the calculations. For bigger diameter of the wire Dw the operating stress decreases until it reaches the value of Sd. This point describes first possible parameters of the spring which fulfil the condition of the sufficient strength.



Time	Dw	Dm	So	Sd
0	0.05	0.80	211,919.37	130,000.00
1	0.051	0.79	197,684.69	130,000.00
2	0.052	0.78	184,599.13	130,000.00
3	0.053	0.77	172,552.16	130,000.00
4	0.054	0.76	161,445.58	130,000.00
5	0.055	0.75	151,191.99	130,000.00
6	0.056	0.74	141,713.43	130,000.00
7	0.057	0.73	132,940.23	130,000.00
8	0.058	0.72	124,809.97	130,000.00
9	0.059	0.71	117,266.66	130,000.00
10	0.06	0.70	110,259.99	130,000.00
11	0.061	0.69	103,744.64	130,000.00
12	0.061	0.68	102,392.15	130,000.00
13	0.061	0.67	101,039.50	130,000.00
14	0.061	0.66	99,686.70	130,000.00
15	0.061	0.65	98,333.74	130,000.00
16	0.061	0.64	96,980.60	130,000.00
17	0.061	0.63	95,627.29	130,000.00
18	0.061	0.62	94,273.78	130,000.00
19	0.061	0.61	92,920.09	130,000.00
20	0.061	0.60	91,566.19	130,000.00
21	0.061	0.59	90,212.07	130,000.00

Fig.6. Some of the results of simulation searching for the diameter of the wire of a helical compression spring.

But in the program considered, the simulation is performed until the operating stress decreases to 60 % of the allowable stress. In fact all of the spring parameters satisfying the condition So < Sd can be accepted and this is the responsibility of the designer to decide which of the parameters to accept for the next step of the design.

The similar way all computer models of mechanical system has to be elaborated and all parameters of the device are to be determined. In the case of the design of a gear-box (.Mott,1992; Norton1996), the designer has to develop the following computer models for:

- kinematics calculations of the gears,
- strength calculation of the gears,
- strength calculations of the shafts,
- selection of the bearings, and
- the design of the body of a gear-box.

All of the models are connected with each other, because usually the outlet results of one simulation, approved by the designer, form the inlet data for the next step simulation. There are also various feedback loops between all of this steps that must be introduced into the computer model of the whole mechanical system.
Computer simulation leads to determination of the geometrical parameters of all parts of the device. When the parts fulfil the technical requirements and satisfy the static and dynamic requirements, they can be represented in the form of an assembly drawing.

5 Automatic Assembly Drawing

The actual results of simulation must be observed and controlled by the designer on an assembly drawing which shows the position of the parts in the whole structure of the device.

The use of AutoCAD software equipped with AutoLISP programming language allows us to create an automatic assembly drawing. The data from Powersim to AutoCAD can be transmitted in many different ways, but the most recommended one is the transmission through the text files, as the quickest and requiring the least memory.
Special program developed in AutoLISP language allows the designer to see the results of his simulations in an automatic assembly drawing like this one shown in Fig. 7.

The analysis of the assembly drawing allows the designer to detect cases of interference of the parts, wrong geometrical proportions, incorrect position of mating elements and so on. For the corrections of these errors, the designer has to introduce changes to earlier steps of the designing process. Applying the anticipatory process the designer may at current time buit variuos potential alternatives for the next time step and check their fitness to the design. Because of the existence of the feedback loops between all of the stages of the process, the corrections introduced to any stage of the design cause various changes in the following stages. However using the computer system of design that process runs automatically, and the results can be immediately observed and actualized by the designer.

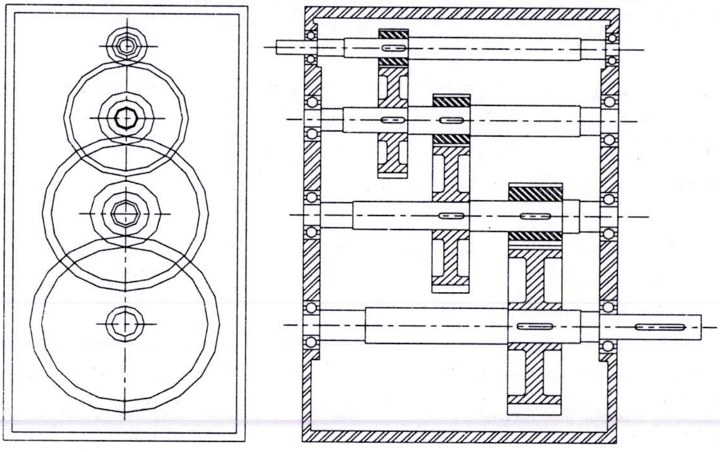


Fig. 7: An AutoCAD automatic assembly drawing of a three-step speed reducer.

6 Optimization of the Device

The final step of the design development is the optimization stage in which the designer is seeking for the optimal design.

The optimization is always based on various criteria. Depending on the application of the device and the way of operation or economical and technical capacity of the company, the optimization criteria are very different. The most important of them are always the safety and reliability, but also productivity, the weight of device, low cost of production and operation, aesthetic or ergonomic factors should be also taken into consideration.

The gear-box shown in Fig.7 can be optimal from the point of view of thermal requirements, because the capacity of the box for a coolant can be sufficient, but at the same time, the gear-box is not optimal when the minimum total weight requirement is applied as an optimization criterion. In that case, the length of the shafts must be reduced, and the space between gears should be minimized. To introduce this changes the designer has to go back as far as to the calculation of the shafts. The change of the proportions of the shafts practically effects all of the following stages of the design. However, with the use of the computer model of the mechanical system and having the assembly drawing developed in an automatic, computer way, the work of optimization becomes easy and quick.

7 Conclusions

- the process of mechanical design is progressing 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,

- in order to aid this work, there exists a possibility of elaboration of a computer model of a mechanical system and the System Dynamics Method can be successfully applied for that purpose,

- the computer model elaborated with the use of Powersim software allows to make the simulation and optimization of a mechanical system, and AutoLISP language of AutoCAD software helps to make an assembly drawing of the mechanical system in an automatic way,

- the application of computer models of mechanical systems makes the process of mechanical design easy and attractive because allows the designer to visualize the results of his actual work, helps him to control better the process of design and, as a result, improves the quality of design.

- the computer integrated design described in this paper should find applications for teaching mechanical design course at universities, as well as for solution of professional problems in the industry.

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