Milosav OGNJANOVIC

Faculty of Mechanical Engineering
University of Belgrade, Yugoslavia

FORM DESIGN IN CONCURRENT ENGINEERING CONCEPT

Summary. *The choice of machine parts shapes, materials and production methods has been presented through the structure of decisions which have to be made thereby. These are defined by limitations in the machine system, by technological limitations and by exploitation limitations. The design process takes place simultaneously with the technological development and in accordance with the exploitation conditions. The correlation of the design process, the manufacturing process and the exploitation conditions is the subject of this work. The architecture of decision making and the architecture of information communications among the indicated entities are given in the concrete example of the development of gear forms.*

1. Introduction

The machine part is defined by its function in the machine system, its shape, the material of which it has been made as well as by method of manufacturing in the process of the machine system realization. It is necessary to achieve a high degree of accordance among the indicated factors, in order to provide for minimal dimensions and minimal price of the machine system. Figure 1 is a schematic presentation of the function, shape, material and production method correlation. The diagram region has been divided into the decisions region, the region of technologically and calculation region. Starting from the function, from the shape and material, decisions 1 to 6 are made which determine the form, material and production method. The mutual accord is solved within the decision making process structure itself. The lower part of the diagram (fig.1) represents the region of testing of the selected factors in the decisions 1-6. The sub-regions 7, 8 and 9 represent the testing of the suitability of the formed parts and systems for manufacture - technologity of forms and materials. Tests are performed to check whether the form, material and production method have been brought into accord in the most adequate way.

Following this testing and any possible corrections, computer or experimental testing follows, which is represented by region number 10. Hereby it is determined whether the chosen form, material, dimensions and production method satisfy the conditions of function performance (the load, temperature, service life etc.). Stresses, vibrations, reliability, safety and other indicators are calculated. The finite elements method is in one of the most applied ones in this aim, for particularly responsible parts.

The accurrence of the concurrent engineering concept has not initiated the necessity for the establishment of this correlation. It exists also in the classic approach. In the development of every machine system, the technology for its manufacture to the tiniest detail as well as the exploitation conditions must be present. In the concept of concurrent engineering these entities must be not only backed-up by programmes, but also simultaneously performed and informationally connected. The problem of programme communication is the key one which should be solved through the development of the decision making process. Numerous hardware problems occur thereby also which direct the development of future computer systems.

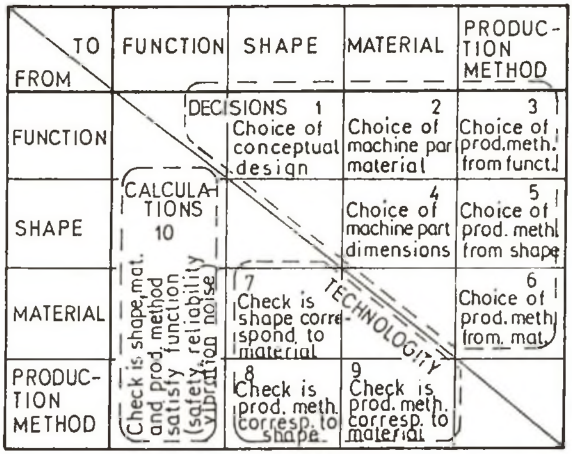

Fig. 1. Decision structure in the correlation of machine part function, shape, material and production method

2. Gear Form Design and Technology Correlation

Gears are machine parts of complex geometric form, and are manufactured by using complex technological methods. Therefore, it is very interesting to analyze the design process especially of these machine parts. Fig. 2 shows the alternatives for every one of the six decisions indicated in fig.1. The decision marked by number 1 refers to the transmission gear concept choice. The selection is made starting from the function which the transmission supposed to perform, with the aim to get the appropriate concept structure. Decision number 2 entails a choice of gear materials, and decision number 3 the choice of method for the gear teeth manufacture. After these decisions, the selection (calculation) of gear dimensions follows (decision 4) and the choice of the production method of the gear blank (decision 5). The previous decisions condition also the final decisions (number 6) which refers to the choice of gear-blank design. In fig.2 the decision making has been shown hierarchically per levels in the form of alternative choice. This is a very simplified presentation. In the background of those decisions many mutual conditions hide, which make the process of decision making very complex.

The first step in the work-out of the mutual conditioning of decisions 1-6, the technological aspect 7-9 and the calculations 10 (as marked in fig.1) has been presented graphically in fig.3. This presentation points to the necessity of parallel (simultaneous) development of gear shape and production method which includes also the assembly. The decisions made in the form development process (1-6) reflect directly onto the technological process of product realization, on its complexity and price. Therefore the limitations which come from the technological process are very significant for decision making in the design process.

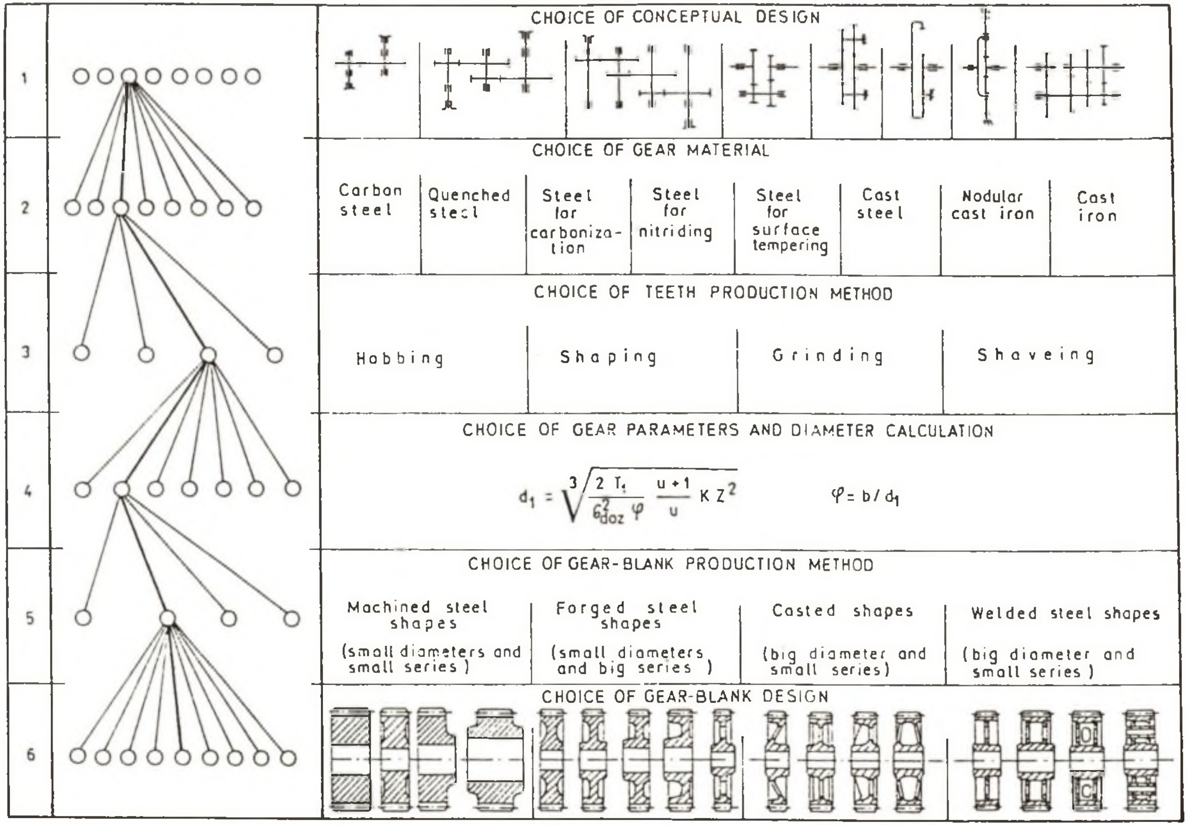

Fig. 2. Hijerarhical structure of partial decisions in the process of gear development

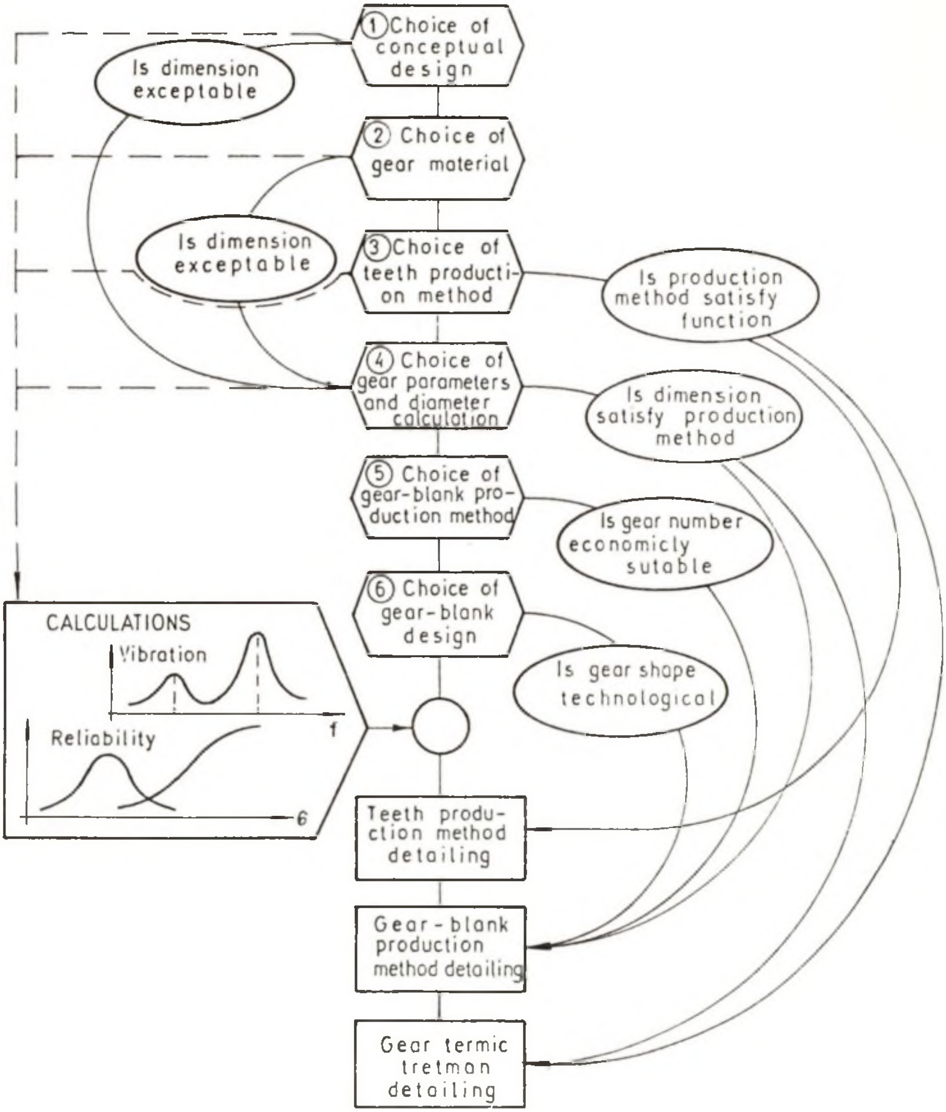

Fig. 3. Mutual conditioning (comunication) in the decision making in the design process with the technology development and the operating conditions (calculations)

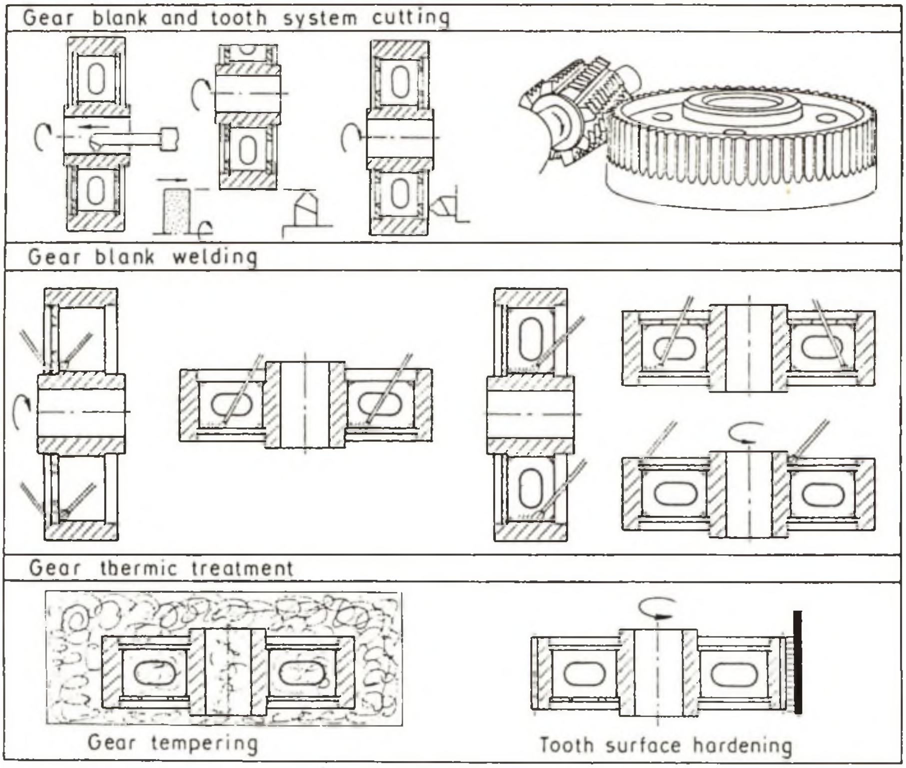

Fig. 4. The shortened presentation of the technological process of gear manufacturing which represents the source of limitation for decision making in the design process

Fig.4 shows the example of the work-out of the production method of manufacture of the selected gear example. The method is given in a very shortened form, with the aim of indicating more details about the content of the segments 7, 8 and 9 in fig.1. In the concept of concurrent engineering simultaneously with the machine parts shape, technological operations are also worked out. The simultaneous process is backed-up by the intelligent (expert) system which analyzes its technological aspect following every partial decision regarding the shape details. Following the work-out of the technological operations it evaluates the suitability (efficiency) of the selected detail. The decision about the appropriateness is made following the interactive analysis of a greater number of solutions, if they are possible.

The simplified example given in fig.4 points to the necessity for a high degree of complexity of the expert systems for this purpose. The manufacture of one gear comprises three technological entities. One referes to the manufacture of the toothing, the second one to the manufacture of the gear blank and the third to the thermal treatment. The manufacture of the blank of the welded gear entails the manufacture of the constituent parts such as are the hub, rim, radial ribs, side ribs etc. These parts are manufactured by cutting, and then follows connecting by welding. The of many of the details on the gear blank depend on the connection method by welding. Besides this, the global form depends on many other influences which are the subject of decision number 6 in fig.1-3. On technological limitations depend primarily details such as are the rib supports, positions and intersections of welded seams, connection of seams by ribs etc.

After welding follows the heating procedure i.e. keeping the gear for a long period on the temperature of glowing for the purpose of getting rid of the remaining tensions which are the consequence of the welding process. After this follows processing by cutting for the purpose of getting the definite gear blank form so as tooth cutting can follow after that. Finally, thermal tooth processing follows, in the indicated example, that is, surface quenching.

The technological method of manufacturing is supported by CAM programme packages, which have to be composed in concurrent engineering programme packages. In that concept the key role is in the communication of the expert system for form development with the CAM programme. This combination makes the system very intelligent. Besides this, it imposes the necessity for parallel (simultaneous) work process of these programmes in several branches. This imposes besides big memories, the necessity for special hardware solutions, which are still being developed.

3. Form Design and Operating Conditions Correlation

The stress, vibration, reliability etc. calculation (10 - fig.1) is also an important limiting condition in the process of design making. On the basis of accepted material, production method, shape and dimensions, a calculation is done of the indicated values for the expected gear operating conditions. The machine system operating conditions in correlation with the design process and the production method are included through these calculations. The calculated indicators make possible prediction of machine system service quality. If it is insufficient, improvements of made decisions are made by the feed-back corrections (fig.3).

The tension statuses in the gear teeth are determined by applying the finite elements method i.e. by standardized methods. The operating conditions and critical statuses of gears are statistical values. Thereby the calculations spread onto the reliability field [5]. The reliability prediction process includes also the influence of vibrations which depend on the rigidity and precision of teeth on gear dimensions and mass etc. If the safety or reliability is insufficient, corrections of already selected values are performed by feed-back dimension and parameter corrections.

4. Decision Making Principles and Information Communication

The chosen example of the transmission gears is sufficiently complex to condition the necessity for the application of several different approaches in decision making. It is possible to apply successfully the following three approaches: "if...then" principle, then the principle of selecting the optimum solution from the set of previously rationally (on the basis of ratio) established solutions and the optimizing principle. The "if...then" principle is the widest applied, and it is particulary suitable for the choice of calculation gear values and parameters. The decision number 4 (fig.1 and 2) is very characteristic in that respect. The algorithms and a large number of loops for iterational approach to the optimum parameters and dimensions have been worked out on this principle. Besides this, the "if...then" principle is very suitable for the search and development of expert peelings on the principle of the trunk of decision making.

The principle with previously established variants entails the creation of these variants in the development of algorithms and programmes for decision making. The number of possible variants is limited and represents alternatives for the transition from states A to status B. The most suitable alternative is selected, most often from the technical and economic aspect - two criteria. This approach is very efficient. It provides for high automatization of the decision making process. Due to the limitation in the number of alternatives it does not provide the possibility of also achieving new alternatives outside the already selected set.

The optimization principle entails the usage of mathematical methods of milty-objective optimization for finding the compromise solution which will at the same time also fulfill to the highest degree all set criteria. These criteria can be the minimum dimensions, i.e. the minimum mass, minimum price of costing, maximum work characteristics (load, reliability etc.). The region of possible solutions is limited by the limitation functions such as are the gear meshing possibility, load, speed, tensions etc. The number of possible solutions in this region is not limited. They are generated on the principle of random numbers, whereby no member of this set is outside the optimization region which is limited by the limitation functions. The inadequacy of this approach is in the fact that it is not always possible to put all the indicated functions into mathematical form.

A more detailed work-out and application of these principles in decision making is given in works [4], [6] and [7]. Some of the decisions 1-6 grouped in logical entities have been solved algorithmically in these works.

The concurrent engineering concept entails a permanent communication among the entities which cover the design, technology and exploitation work-out. These three or more processes should take place simultaneously with mutual information exchange. One of the possible communication forms are the answers to the question whether some of the selected characteristics of the design form or material satisfy the technological limitations. In fig.3 these questions have been marked by disposition paths. Those are only some of the communication paths which require special software and hardware solutions in the concurrent engineering concept. The lower level of concurrent engineering entails communication among several computers i.e. members of the design team, on the interactive principle.

5. Conclusion

The form development of machine parts in the concurrent engineering concept entails the use of highly intelligent systems in which two levels of information procession and communication can be singled out. On the first level that is the decision making within the design process, then within technological process work-out or within the behaviour analysis during the system exploitation. The second level refers to the mutual information exchange (limitations) among these entities. Both levels for the example of part development and gear dimensions have been treated globally. Decisions which are made in the design process have been defined, and then a survey of possible communications for the other two segments in the process of development of gear transmissions has been given. Reference has also been made to the possible principles of decision making in the development of expert system with automatized decision making, but without detailed work-out in this article.

REFERENCES

[1] Jakobsen K.: The interrelation between product shape, material and production method, Proceedings of an International Conference on Engineering Design, ICED-89, Harogate 1989.

[2] Boer S.: Systematic Decisions in Methodical Engineering Design, EVAD - Reading - WDK-17, Heurista, Zurich 1990.

[3] Andreasen M., Olesen J.: The concept of Disposition, Journal of Engineering Design, Vol.1, No.1, 1990.

[4] Ognjanovic M., Subic A.: Some Appoaches in Machine Parts Modelling using CAD Software, Journal of Engineering Design, Vol.4, No.2, 103-112, 1993.

[5] Ognjanovic M., Subic A.: Gear Quality Prediction Using Vibration Analysis, Machine Vibration Journal, No.2, Springer Verlag, London 1993.

[6] Ognjanovic M.: Decisions in Gear Transmissions Design Process, WDK - Workshop "Evolution and Decision in Design", Praha 1992.

[7] Ognjanovic M., Rosic B.: Modelling, Quality and Optimization of Gear train transmissions, Iternational Journal for Mechanics, Engines and Transportation Systems NVM, Vol.19, No.4, 1993.

Revised by: Jan Kaźmierczak