UNIVERSITY OF ZIELONA GÓRA
Faculty of Management
and Faculty of Mechanical Engineering
In association with the Design Society

FOURTH INTERNATIONAL SEMINAR AND WORKSHOP
7th - 9th October 2004
Zielona Góra - Rydzyna
POLAND

Engineering Design in Integrated Product Development
Management of Design Complexity

DETAIL FUNCTIONALITY ANALYSIS USING THE DESIGN GOLDEN LOOP

PROF. DR. JOŽE DUHOVNIK
University of Ljubljana, Faculty for ME, LECAD, Ljubljana, Slovenia
e-mail: joze.duhovnik@lecad.uni-lj.si

ASS. PROF.DR. SENAD BALIĆ
University of Zenica, Faculty for Me, Zenica, LECAD 2, BiH
e-mail: sbalic@mf-ze.unsa.ba

Keywords: Design process, methodology, design golden loop, centrifugal pump, CFx

***Abstract**: Design Golden Loop (DGL) can be used in the Design Process (DP) by the Development and Design Process (D&DP). General paradigm of the DGL is based on the iterative steps in the design process. Iterative process has been known since 1983 as a model. The model presented iterative work between a general task determination, depending on the problem. In the development process we used the generative model, which presents the basic function, values and parameters used in the design process as a framework of a task. Specification and function request, evaluation with iterative comparison between the function and form in general, experts assessment with product improvement and decision of results used is the essens of iterative design process. In the paper shown the detail steps using by the real project. The DGL was not generated at the end of the pump search but we start with the searching when the real problem has been recognized. The results are useful and the methods give opportunity as a model for the future design task.*

1.0 INTRODUCTION

Analysis of details with existing working principles often emerges as a problem in researches. People often adopt a principle with an easily accessible implementation, without a detailed look into it. Later, they apply theoretic and numeric methods for the analysis of details, known from the literature. Sometimes, a comparative test is also carried out and this type of solution is adopted as a possible way. Designers sometimes and researches even more often present the result as an optimum solution to a task.
Many examples are known from the literature when researchers reconstructed a work procedure of a successful solution or quality results. This type of recording a work procedure is then adopted as a design process method or, even more courageously, the Development and Design Process (D&DP) method. [1], [13],[14] and [15]. Each of the presented methods tries to explain the phases of the design process as an integrated D&D process. For this reason, the D&D process tasks are taken separately, which in turn limits the space for the analysis of a technical system, which is in fact a synonym for each product [16].
On the basis of researches, many D&DP researchers only implement a general understanding, required skills, thinking processes, ontology, expert skills etc. [7], [10], [11] and [12]. These researchers try to define the scientific frameworks in the D&D process. Their researches are another reason that calls for a generalized D&D process model. However, their requirements regarding the skills that are being used, should be taken into consideration. Limiting the knowledge about natural processes and systems within technical systems conceals the search for new solutions and possibilities. Processes are therefore not sequential or defined uniquely but iterative,

which enables a continuous development of new products.
Iterative process was presented for the first time in 1983 [4]. The process was defined roughly in that time, however, it did not offer enough relevant definitions for a more general approach to processing. Additional researches and some published articles showed ways to further development. A comprehensive D&DP model with the addition of Golden Design Loop [7] was first developed in 2001. A general presentation of the Loop and results, based on a real product, will be presented later. Several development industrial cases have already been carried out, however, they are not yet ready for publication.

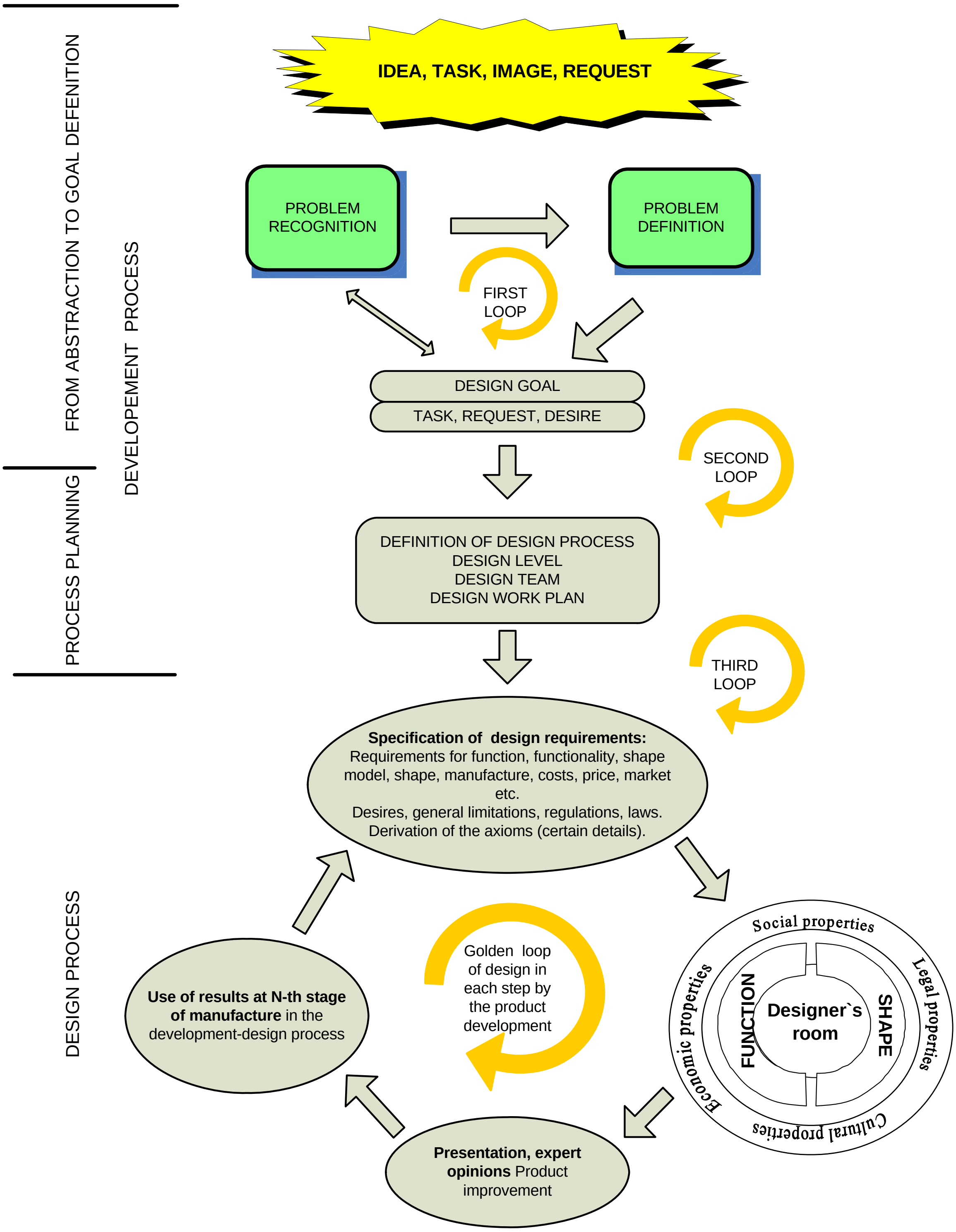

Figure 1: Development and Design Process and activities in particular phases.

2.0 DESCRIPTION OF DEVELOPMENT AND DESIGN PROCESS

For a better understanding, three key parts of the whole D&DP will be presented first. Defining the goal comes first. It is carried out by means of the whole process from abstraction to goal definition. The key elements of process planning are defined in the second phase. They include the level of D&D process, defining the team and planning individual activities. These two phases are the development parts of the D&D process.

The presented model can be taken as a generalized D&DP. In this case, the term generalized means individual phases only and not specific skills or detailed analyses, necessary to define a particular problem. The whole range of skills and understanding the role of science in the described process can be understood in the same way as they have already been presented in the literature [7], [10], [11] and [12]. It is the goal recognition within the D&D process that has the key role in defining the process itself. On the basis of activities analysis we believe that defining or, as we put it, purifying the idea on its way to goal definition is of key importance for a quality application of the design process itself. For this reason, this phase has been termed development. Several authors have already discussed the problem of goal definition [17], [16] and [9]. In the follow-up, we will try to explain very clearly the method of goal definition on a real example.

It needs to be pointed out that the function and functionality descriptive matrix has been used, which enables purifying the idea by means of requirements for a clearer goal definition. In this paper, we do not go into the details about the use of the function and functionality descriptive matrix. The matrix, defined in this way, and the process of its creation can be understood as a genesis of the development from the idea to the goal definition. It has been termed the generative model. In order to clarify things and define the function as well as functionality, certain criteria within the generative model have been used. Function models served as a starting point [3], [5] and [12]. For the needs of natural processes, the skills and knowledge that enable technical processes modelling on the level of natural processes substitutes have been applied within the generative model. Substitutes for natural shapes have been applied and converted into technical shapes. We as well as the model users have made every effort to fulfill the function requirements within individual phases. This is a key difference, compared to existing generalized models [18], based on clearly recognized natural world, natural processes and simple conversion of natural processes into technical processes. We believe that such interpretation is false and even misleading.

For this reason, the product development phase is divided into two jobs: the first one is goal definition and the second one is requests, desires and tasks of the D&D process. Since the two jobs are closely connected, they are not performed sequentially or separately. Their definition is performed iteratively within the first development loop.

When goals and tasks are defined in the first phase, the initial iterative steps are used. Iteration is used in order to recognize the goal according to our knowledge and understanding of the nature as it is impossible to set a goal deterministically, without testing in the return loop.

Figure 1 shows the whole D&D process with individual phases, necessary to understand each activity.

The results of the first phase can be shown as a black box of a particular technical process. When a task mainly depends on the application of a technical process it has been found out that changes of conditions, being part of the nature and environment in general, cannot be defined clearly enough without defining I, E and M and its transformations. For an easier understanding, Figures 2 and 3 show and example of a general black box scheme (Figure 2) and an example of a specific case of material fluid flow within a closed system (Figure 3).

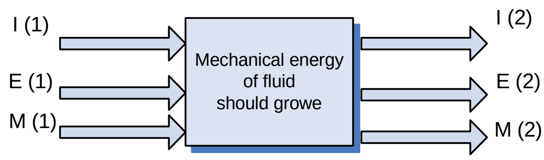

Figure 2: General black box scheme

It is clear that the second step, following the goal definition, already requires an approach to a detailed definition of requests, desires and tasks, which indirectly and clearly defines which natural process is to be used. In our case, the variation of pressure at constant flow volume is used. Due to minimum variations, the temperature can be taken as constant. However, the setting of functions system should allow variations of temperature in cases of particular singularities. If the fluid flow does not occur it is only the variation of energy that remains within the planned process. The variation can be reflected by the rise in temperature. In the nature it means a higher temperature of the medium, which is reflected by energy transfer from one state of aggregation to another.

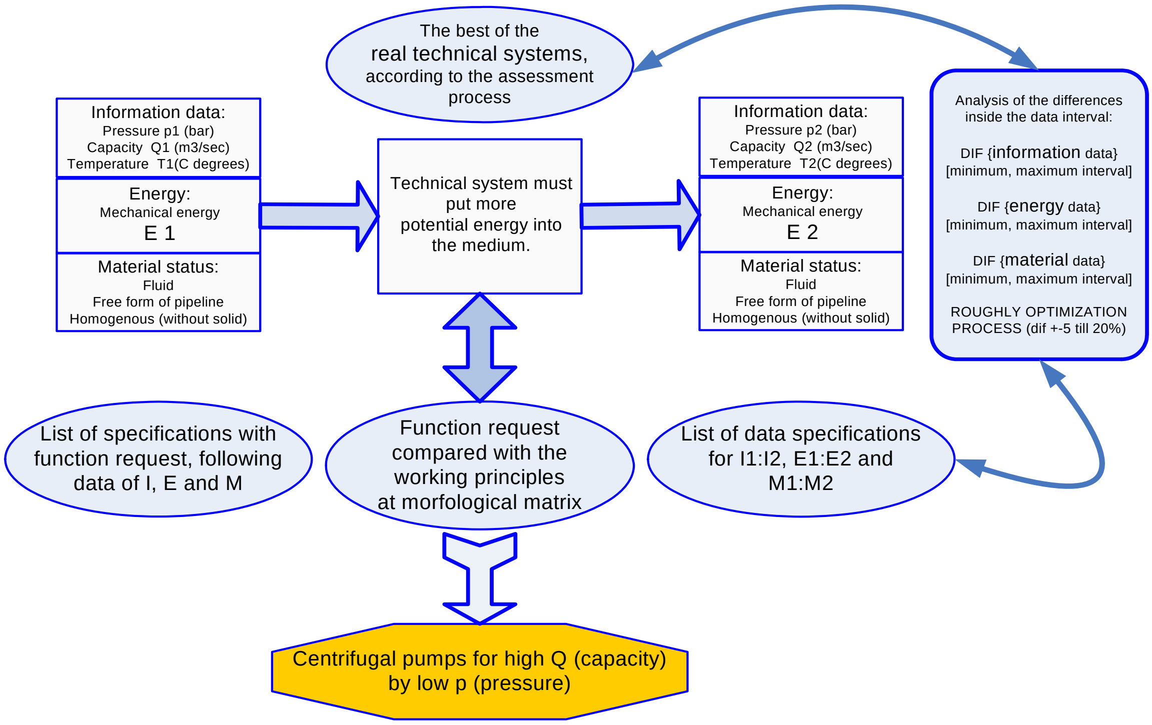

Figure 3: Black box scheme for specific material flow and energy changing from status 1 to 2

In this case, however, quite another question as to what to do with the higher temperature remains. As it is not defined as a goal of the task solution process it can be concluded that such new situation, such singularity, is an error in the use of the natural process.

This phase of the development process is dedicated to a detailed function design, which needs to be converted from the natural system into the technical system. Several methods are possible. One of the oldest ones is the use of the morphological matrix. We believe that the problem with the use of the morphological matrix lies in the fact pure technical functions in the nature can be very easily described. It also explains the success of the use of the morphological matrix at the beginning. However, it is a fact that different non-mechanical technical functions are used in the development phase for the purpose of describing requests and nobody expects results in the form of a schematized working principle, especially because nobody knows the scheme of the working principle in advance in the product development process. However, it can be described. For this purpose, different ways of using the descriptive matrix have been explored. Early results have justified the design. This matrix has been termed the function and functionality descriptive matrix [8].

Contrary to general belief, there are no rigid strict limits in the development and design process. Several cases have proven that the transition to the design process is of special importance for a detailed recognition of the technical process. Transition to the design process is therefore no more a matter of searching for new substitutions of a natural process by a technical one. Systems, be it natural or technical, are the only remaining issue. Therefore, specifying tasks for the design process also includes a detailed account of a technical system with clearer limitations, clearer process transformations, clearer design models and finally, the first outline of the technical shape and mathematically described function analyses. *Mathematically* means analytic as well as numeric solving. Figure 4 shows a detailed structure of energy input into a fluid by means of a technical system. The detailed structure is based on the functional structure. It is solved or defined by means of the generative model for defining the function and functionality descriptive matrix.

According to figure 4 it can be concluded that the method of end volumes in the calculation has not been used at random. It is only a logical consequence of the necessity of a detailed analysis of a process. Other necessary analyses can be recognized in the same way. It should be pointed out that the analytical approach to setting the volume of energy input is not something new as it has already been defined. The problem arises when it comes to a complex approach to solving a system, when the system's boundaries are extended. In the past, up to 1995, this kind of problems was usually being solved by means of tests and defining the direction of flow into the rotor and the spiral by instinct and a great deal of experiences.

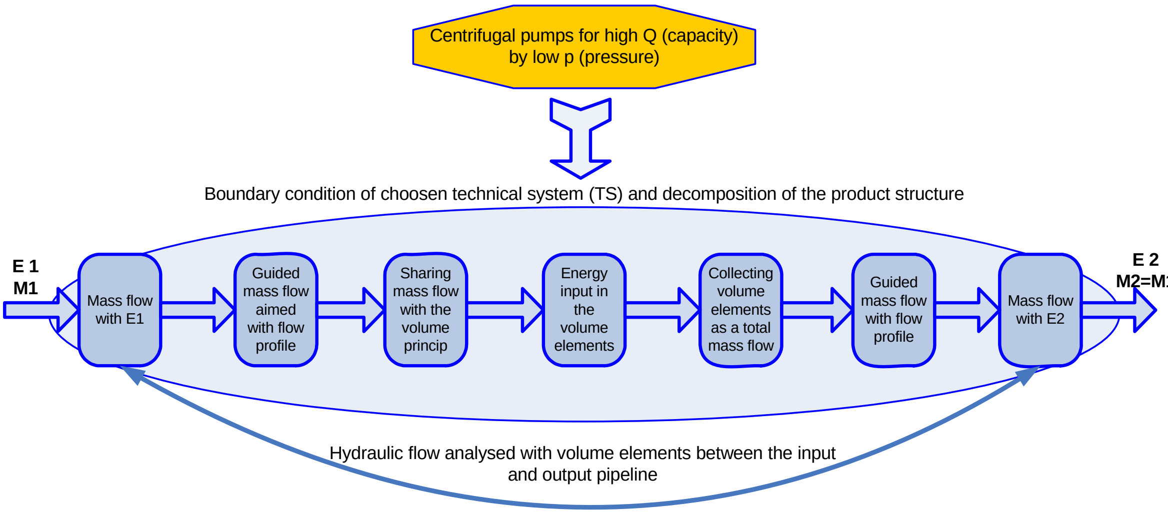

Figure 4: Functional structure of the technical process for energy input into a fluid, taking account of a constant volume and constant temperature or its minimum variations.

Tests were carried out and adequate forms of flow profiles were determined. If the boundaries of a wider system are set in advance and we understand that certain skills allow us to interfere with the scope of analysis, the design process and the detailed shapes analysis provide us with a procedure or a process that can be set in advance and supplemented by means of the iterative approach. Therefore, such process takes place within a loop and it is right to say that this is a characteristic loop within the design process. This is the phase of the design process when the geometry, described in details, appears for the first time. The limits of the real world, real production space, appear for the first time. Figure 5 shows phases of the design process and their relations. The basic construction process, set up in the literature [2], is also mentioned.

When the goal is very clear it is necessary to define the process more clearly and the details of the necessary steps to do so should be determined. This is the second phase of the D&DP. The basic guideline is that the level of D&DP [5] should be established at this time. In addition, the design team and the plan of activities, necessary to achieve the goal [6], should be formed. This part also includes cost analysis. Enthusiastic researchers and the development people do not like it, however, it is of vital importance for a comprehensive monitoring of the economical side of a project.

The shape of the product, resembling the end product, appears for the first time in front of the designer. For this reason, the loop in the design process has been termed the Golden Design Loop. This way, we tried to stress the difference between the aforementioned three loops in the development process and, in our opinion, the essential loop that brings a product into real life.

3. AN EXAMPLE OF THE USE OF THE METHOD FOR A PUMP MODULE

We tried to test the presented process model on a concrete example of a pump module, published in [2]. The procedure was explained up to the design process, making it clear which parameters have been included into the function and rough functionality analysis. The detailed functionality, vital for the improvement in efficiency of the entire pump set, will be explained in the design process itself.

The need for the use of theoretic and experimental methods has already been mentioned during the problem definition process. The CFD method has been used recently. It is based on the use of end volumes and it describes the fluid flow through a complex shape reasonably well. The results were compared to experimental results. The chief goal was to improve the efficiency of the pump module. Therefore, the numeric as well as the experimental part should be carried out in such a way that the efficiency will come out as the end and comparable parameter.

Since the comparison between the numeric and experimental calculations is crucial priority will be given to the quality of the calculated values, which will be achieved by their comparison to the measured values. The first part of the task is crucial for further optimization. As a result, dissemination of the results has been limited to the analysis of comparison of efficiencies.
First, we approached a perfect model of end volume elements for all three key parts of the flowing tract (Figure 6). This way, the compatibility of the numeric part was provided.

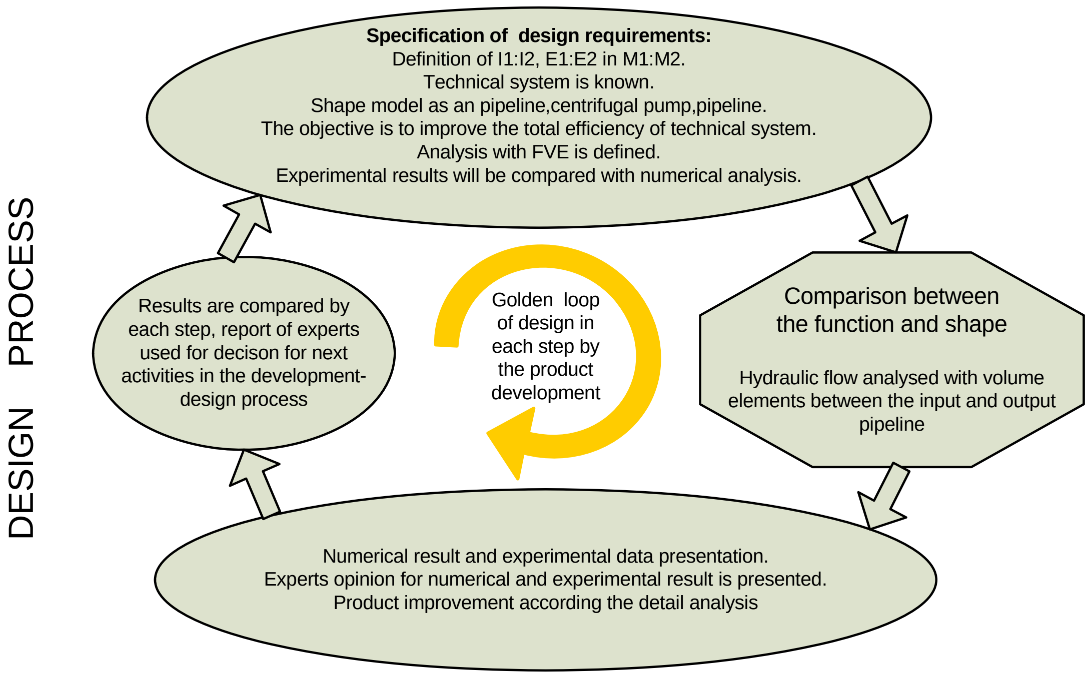

Figure 5: Design process with Golden Design Loop

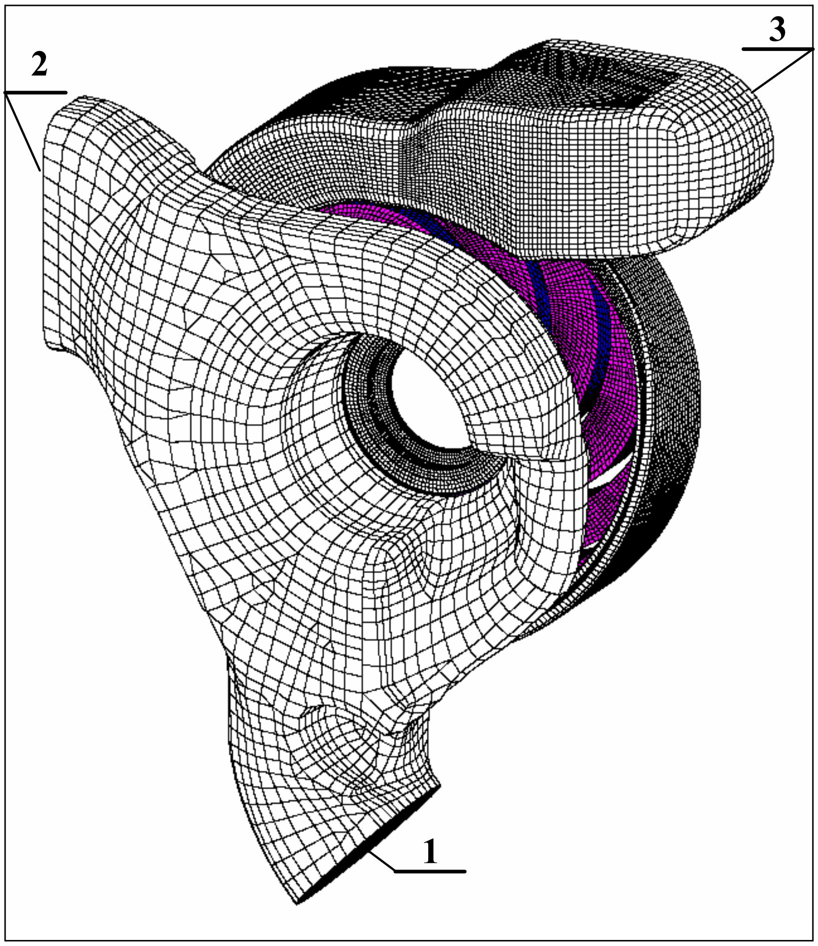

Figure 6. The mesh of analysed automotive turbopump model's entire flowing tract

1) motor inlet, 2) radiator inlet, 3) pump outlet

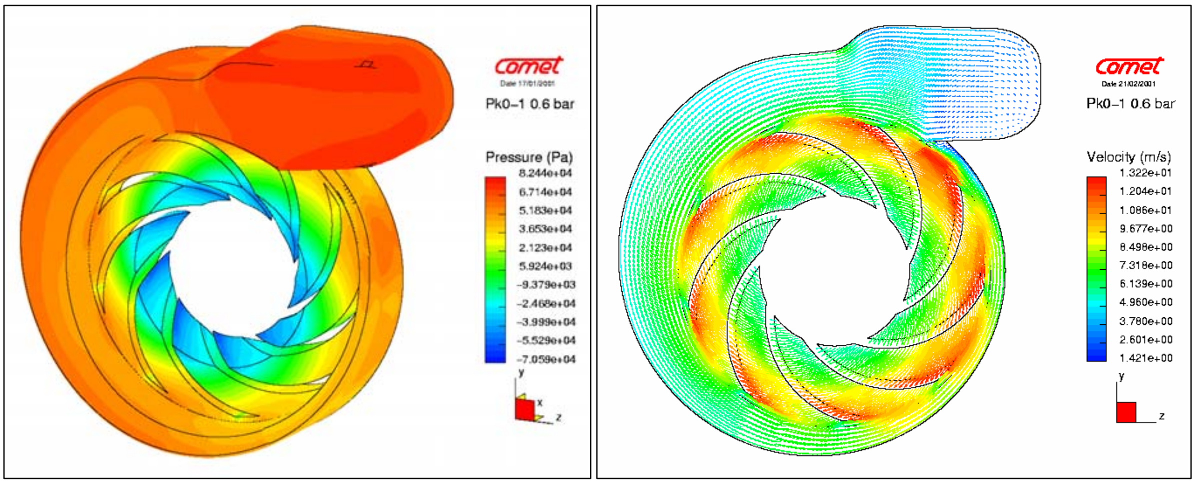

Figure 7. Distribution of pressure and velocity in one model's part of analysed automotive turbopump's entire flowing tract
a) distribution of pressure *p*, b) distribution of velocity *v*

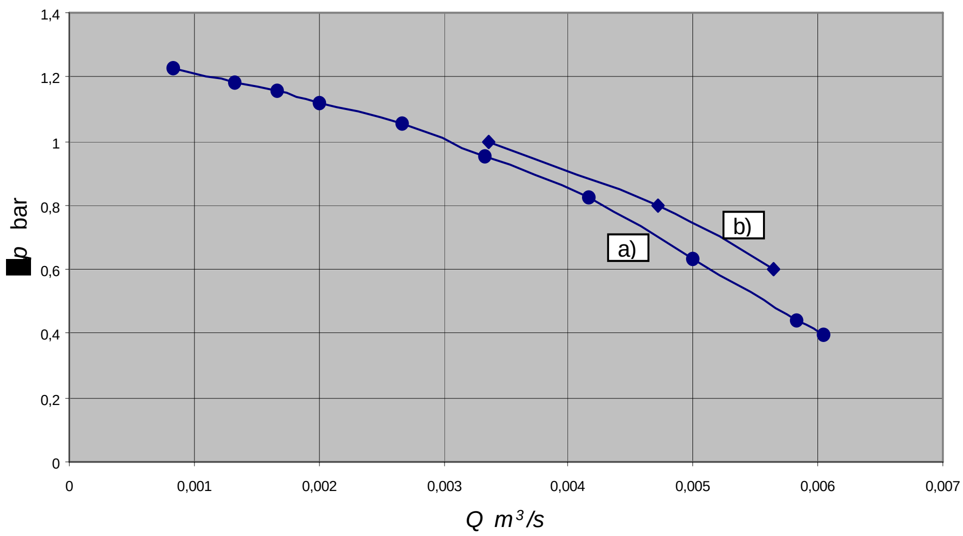

Figure 8. Q-Δp curves of the analysed automotive turbopump at n = 3000 min^{-1}
a) based on the experiment results,
b) based on results from the numerical calculations

Compatibility means a quality paralleling of the volume elements of both fixed parts with the rotating mesh on the rotor. It is a proof that the fluid flow in the dynamic field (Figures 7a and 7b) has been mastered. For a better understanding it is good to know that 7 iterations within the golden loop were necessary to assess the quality of the mesh. In each phase we used the expert assessment from the numeric field as well as from the field of turbo engines, where a pump module belongs. When comparability between the input and output parameters was achieved their values were compared to the measured values. The results are shown in Figure 8. Differences were minimal, which proves the quality of monitoring the fluid flow through a complex shape of the pump module and provides a considerably more accurate monitoring of the pumping process when the flowing tract is changing.

4. CONCLUSION

The paper presents the D&D process for a particular case, using the Golden Design Loop. The GDL is used as part of the design process, which represents the development of functionality in all details of the presented technical systems. In the product development process, the generative model was used in order to define the correlation between the function and functionality. For this purpose, the function and functionality descriptive matrix was used.

On the basis of the model it can be proved that the use of end volume elements in the fluidics is logical. The boundaries of a particular system can also be extended by means of end volume elements. A pump module was used as a proof. We also used it as a proof that a quality analysis is possible when the technical system concerned is described in details. It should be stressed that the CFD analysis is set up in the design process as part of the function analysis at a particular functionality. It is our aim to prove that this is part of the design process and that the CFD method is not used in an undefined space and environment but within a technical system with its own dimensions. Therefore, defining activities by means of CAE and CAD systems outside the D&D process is false. For this reason, we face problems concerning the choice of suitable software for tasks that are to be performed by means of the D&D process.

References:

[1] Arcidiacono G., Campatelli G., Lipson H.: *A Measure for Design Coupling,* Proceeding of ICED 01, Glasgow, 2001, Professional Engineering Publishing

[2] Balic S., Duhovnik J.: *Design of Centrifugal Turbopumps by Numerical Analysis of Entire Flowing Tract,* 3th DAAAM International Conference on Advanced Technologies for developing Countries ATD 04, 2004, Split, Croatia

[3] Braha D., Reich Y.: *Topological Structures for Modelling Engineering Design Processes*, Proceeding of ICED 01, Glasgow, 2001, Professional Engineering Publishing

[4] Duhovnik J., Kimura F., Sata T.: *Contribution to methodic in CAD*. V: TEN HAGEN, Paul J. W. (ur.). Eurographics '83 : proceedings of the International Conference and Exhibition, University of Zagreb, Faculty of Electrical Engineering, Zagreb, Yugoslavia, 31 August - 2. September 1983. Partisipants ed. Amsterdam; New York; Oxford: North-Holland, 1983, str. 113-132. [COBISS.SI-ID 7709145]

[5] Duhovnik J.: *Functional relations between various physical laws*. V: MARJANOVIĆ, Dorian (ur.). Proceedings of the 5th International Design Conference DESIGN 98, May 19-22, 1998, Dubrovnik, Croatia. Zagreb: Faculty of Mechanical Engineering and Naval Architecture: Centre of Technology Transfer; Zürich: Workshop Design-Konstruktion, 1998, str. 5-15. [COBISS.SI-ID 2581019]

[6] Duhovnik J., Starbek M., Dwiwedi S. N., Prasad B.: *Development of new products in small companies*. Concurr. eng. res. appl., 2001, vol. 9, no. 3, str. 191-210. [COBISS.SI-ID 4930331]

[7] Duhovnik J., *From Desktop to Product Golden Circles*, Summa Minerva, TU Delft University, 2002, Delft

[8] Duhovnik J.: *Function and functionality descriptive matrix*, Proceeding AESD, 2004, Plzen in print

[9] Eloranta K. T., Hilliaho E., Riitahuhta A.: *Radical Innovation: A Quest for Conceptual Creativity*, Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[10] Horvath I.: *A Contemporary Survey of Scientific research into Engineering Design*, Proceeding of ICED 01, Glasgow, 2001, Professional Engineering Publishing

[11] Hubka V., Eder W. E.: *Function Revisited*, Proceeding of ICED 01, Glasgow, 2001, Professional Engineering Publishing

[12] Jarratt T., Eckert C., Clarkson J. P.: *Development of a Product Model to Support Engineering Change Management,* Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[13] Labrousse M., Bernard A., Veron P.: *Generic FBS Concept for Process/Product/Resource Integration*, Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[14] Nilsson P., Andersson F.: *Process-Driven Product Development – Managing Manufacturing Requirements*, Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[15] Ottoson S.: *Verification of Product Development Methods*, Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[16] Poelman W.: *Technology Management in Product Design*, Proceedings of the TMCE 2004, Lausanne, Switzerland, Horvath&Xirouchakis, 2004 Millpress, Rotterdam

[17] Tomiyama T., Yoshikawa H.: *Extended general Design Theory in Design Theory for CAD*, Proceeding from IFIP WG 5-2, Amsterdam, 1987