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systematic designing, machine tool,
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CREATIVE DESIGNING OF MACHINE TOOLS – CONTEXTUALLY

This paper describes the matter how a developed product passes through the company. The important influence is underlined here, which the designing process has on the order passage through the company. The fact is underlined here that innovation cycles have been reduced in a considerable way. Especially in pre-manufacturing stages, the innovation cycle can be reduced in a considerable way by means of theoretically supported system methods of creative designing. The paper describes key principles how to apply these principles which enable apparently contradictory system introduction to designers' work with simultaneous increasing of a space for their demanding creative work, with the target to increase the quality of their work and to increase the passage possibilities of this "narrow bottle neck" within development and order processes.

1. INTRODUCTION

Every successful manufacturing company must be a good manager, i. e. it must dispose of its own means in such a way, that its activities are successful, economical and ethical. In short, this can be characterized with these words – to obtain the maximum profit applying the minimum costs and considering the needs of the society and of the nature. It is true, at the current time some companies would like only to maximalize their profit, but short-term earning of money has no perspective for a long time period. In order to create stability and to enable the permanent development of a company, the essential matter is to develop the company's philosophy which is shared and developed together. The designing process has the key role regarding to the way how an order passes through the company. For example, at TOSHULIN the engineering design department is responsible for 16 of 24 identified processes, i. e. for 67 % of the total process quantity. The engineering design of a product has the decisive influence on all required "complex" properties of a machine tool, considering its total life cycle. The engineering design of a product influences in the share of 70 % the manufacturing costs and it also has the decisive influence on its running time.

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Moreover, exponential increase of knowledge, know-how and requirements put on product properties led in some last decades also in manufacturing industry of the Czech Republic to innovation cycles, which begin to be shorter and shorter. This has caused pressure on considerable time reducing at development activities as well as on the total running time. For the above-mentioned reasons as well as for many other reasons, the design engineering becomes a more and more bottle-neck process. Therefore, increasing the passage possibility of this narrow "bottle neck" results in successful solution of the mentioned problems in a demonstrable way.

A machine tool understood as a product has together with oil the strategic position within international creation of gross domestic products. A machine tool as a product hat its sovereign position on the market as well as in marketing policy of the company which has developed, manufactured and assembled this machine tool. This position is determined by the fact that the machine tool is a general-purpose manufacturing and autoreproduction device. The word "autoreproduction" means the fact that the machine tool manufactures itself and it is able to manufacture machine tools which are more and more precise. The machine-tool sale prices copy the oil price on world markets (Fig. 1). However, oil still remains oil, but properties of CNC machine tools change dynamically.

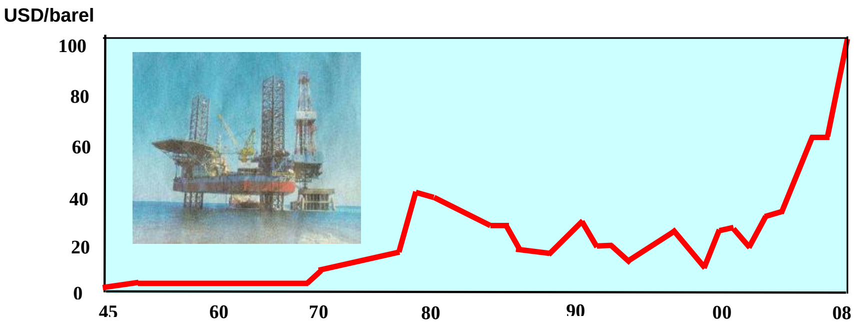

Fig. 1. Course of the oil price on world markets [16] (simplified)

2. SUBSTANCE OF CREATIVE SYSTEM DESIGNING

It is not easy at all to describe an intellectually and technically demanding activity which is called "engineering designing". The engineering designer must uniquely describe, i. e. concretize and "visualize" his or her abstract imaginations which he or she thinks out and which he or she imagines about the next product, which must have the required functions and parameters available and moreover, which must also fulfil a great number of other stated, generally implied and obligatory requirements [ČSN EN ISO 2006]. Therefore, at the beginning, a product is a very abstract and indefinite thought object which must be transferred to the final form of manufacturing detail and assembly drawings, according to which it is possible to manufacture or buy and assemble all product parts. Of course, all of this must be done considering especially the following essential requirements and constraints [4] given on a product which shall be designed:

- stated and generally implied customers' needs and needs of the society;
- obligatory limitation and restriction by various laws, standards, regulations, by the conformity declaration and by safety rules;
- technological, knowledge, capacity and economical company's capabilities.

Utilization of Engineering Design Science (EDS) [11], [5] knowledge currently seems to be one of progressive ways how to open the narrow "bottle neck" of engineering design departments; this can be done, when an order passes through the company as well as during development innovations. Application of knowledge granted by Engineering Design Science can enable an engineering designer e. g. to perform efficient designs and to choose optimum solutions from several variants. EDS is a relatively new branch of science, which has been developing in the world since the forties, and in our country since the sixties [2]. In the last decade, after a number of development periods, the development of EDS knowledge reached to a qualitatively new level which can be specified as a support of the knowledge-integrated system engineering design [7]. In a simplified way it can be compared with searching an engineering design solution on the approximately recommended "ideal" way in a "map" of systematically arranged and interconnected EDS knowledge from theory and practice [4].

Unlike the traditional explicitly procedural methodical ("guideline") approach, this approach considerably stimulates engineering design creativity, and doing this, it enables to use optimally also traditional established and during many years proved intuitive processes, prescribed procedural methodics and – if necessary – also approaches like "trial and error (and sometimes even success)". But the solution always returns to the basic "map" of knowledge and then, it continues optimally in dependence on other current requirements, limitations and restrictions. The "map" of EDS knowledge and methods grants permanently the common environment ("interface") for operative and strategic communication among all members of a development team, also for running and final quality evaluation of designed solutions; however, this evaluation must be performed only systematically and objectively. Essentially, every skilled creative engineering designer has established such a "map" of knowledge and methods during many years of his or her practice. However, the basic problem is that this "map" depends necessarily on the previous education and especially on practice; this map is generally "structured" and "named" in another way, even if the practice is the same one. Of course, creative abilities of engineering designers remain irreplaceable also in the future, because even the best "map" cannot replace the insufficient "orientation" sense.

The general "map" of EDS knowledge about and for design engineering of technical products can be concretized in the analogic structure for an arbitrary product branch, kind or also for a product type. The knowledge then becomes to be more easily utilizable in the real design engineering and company's practice. However, the EDS "systematical" background – in addition to the essential advantages (and disadvantages) of system approaches – increases in a considerable way their utilization possibilities, if the engineering design situation changes, if the product scope is modified, it increases utilization possibilities of cross-sectoral knowledge transfer, and last but not least, it also increases flexibility of engineering designers' thinking.

3. KEY KNOWLEDGE FOR CREATIVE SYSTEM DESIGNING

EDS includes general knowledge about and for design engineering of any technical product which is generalized in EDS as a technical system (TS). Like any other product, according to [3] a technical product consists generally of four generic heterogeneous units: hardware, processed materials, software and services. However, in compliance with EDS, it seems to be necessary to divide technical products in the five following elements [8]:

- **Hardware (HW)**: substantial formed / rigid (material) TS component – almost explicitly understood as TS up to now;
- **Formlessware (FW)**: substantial independently formless (material) TS component – charges, filling, coating, etc.;
- **Software (SW)**: insubstantial (information) TS component – information "included in" and "granted with" TS;
- **Asistenceware (AW)**: service TS component – granted "with" or "for" TS;
- **Energyware (EW)**: energy TS component –"included in" and "granted with" TS;

Many (technical) products include elements which belong to various generic components. How the (technical) product is called then – whether hardware HW, formlessware (processed material) FW, software SW, assistenceware (service) AW, energyware (energy) EW, it depends on the dominant element. The term "Technical System (TS) is understood as an existing (real) technical product as well as an information description of a technical product (either an existing (real) one or in its design states) with the dominant HW component. The term "Technical System" underlines the system view of a technical product. To simplify the whole issue, this paper is oriented most of all to the dominant "hardware", i. e. which is traditionally substantial TS component

One of the essential system elements of the EDS knowledge "map", from which a number of other derived EDS models is deduced, is the logical model of the artificial "Transformation System (TrfS)". This model shows the system of main elements participating in the real world in any artificial change of an "object", from an input state to a required state. Because the model is a completely general one, it includes state changes (changes of contents/structure, form/shapes, position changes or time changes) of material, energy, information and living beings. Therefore, the changed "object" is substituted in EDS with the general term "operand". The factors participating generally in its artificial changes are complementarily called "operators". The operand change under the influence of operators runs in dependence on selected technology in the "Transformation Process (TrfP)". The principle of TrfS model origination and its structure are shown in Fig. 2 and Fig. 3.

The operand can be influenced directly (physically) only by effects of the "executive system", i. e. of human (HuS), of technical means (TS) and of active (and reactive) environment (AEnv). The effects of two remaining operators, i. e. IS (professional information system) and MgtS (management information system) are performed by means of the executive system. The simplified example how to concretize a general model of the transformation system from Fig. 3 for wire drawing is shown in Fig. 4. These TrfP with the dominant share of technical means are called "Technical Processes" (TP).

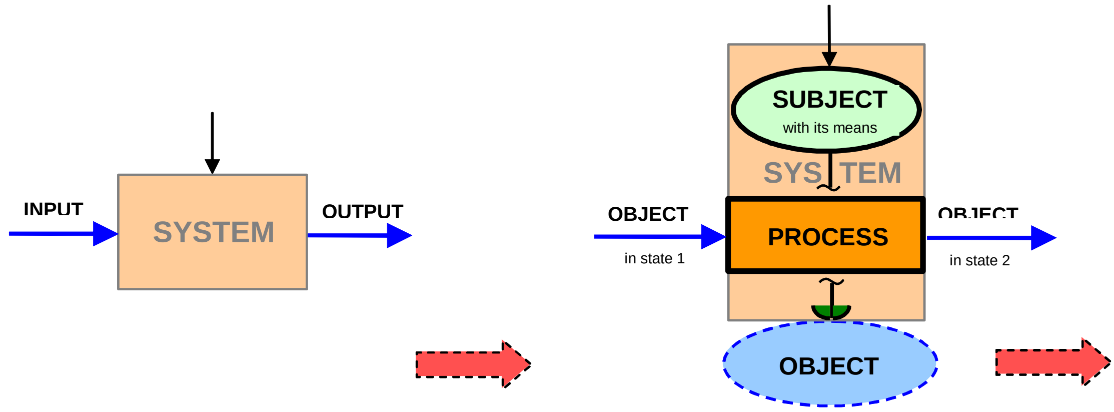

Fig. 2. Essential model of the "transforming" system and corresponding "Action" model [5]

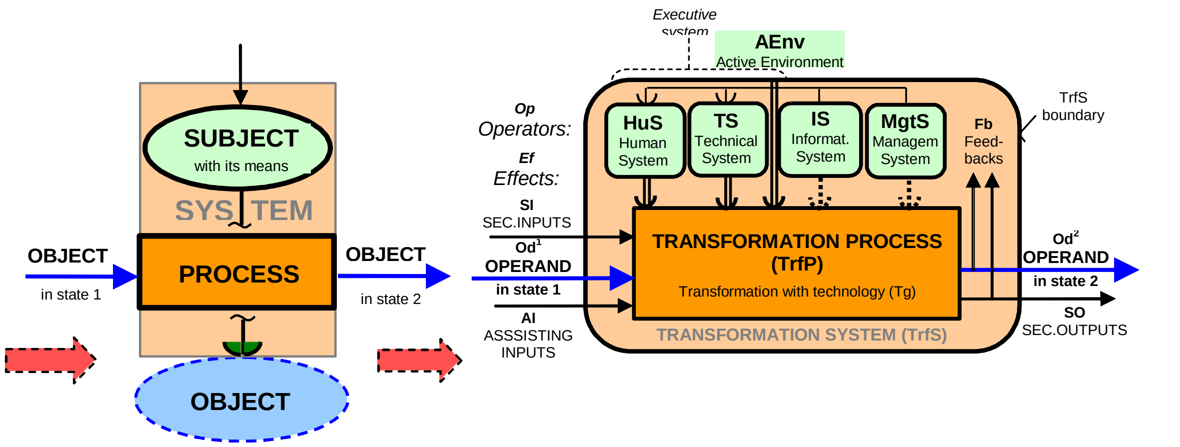

Fig. 3. Essential "Action" model and corresponding EDS model / "map" of the "Transformation System (TrfS) with the "Transformation Process (TrfP)" [10]

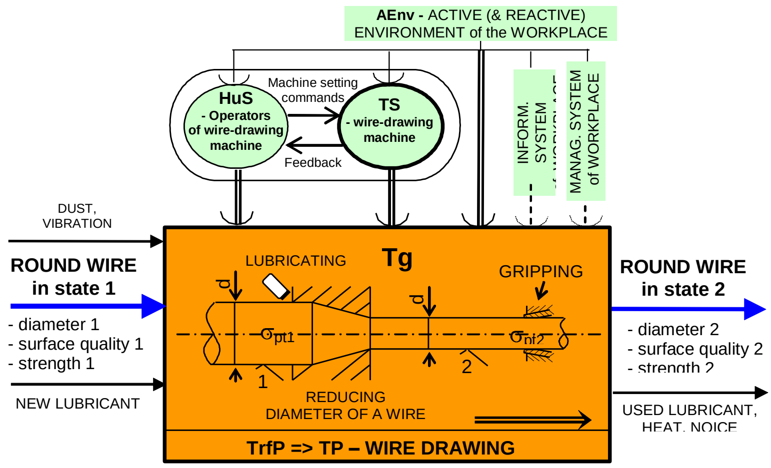

Fig. 4. Concretized model / "map" of the operation "Transformation System" (TrfS) with the Transformation Process / Technical Process (TrfP/TP) for wire drawing [Hubka 1988]

4. EDS RELATION TO PRODUCT LIFE CYCLE MANAGEMENT (PLM)

The life cycle of a technical product / technical system (TS) can be divided in its particular periods. The most usual method is the "form" of period list in dependence on the place of their realization. These lists differ one from each other. However, the above-mentioned model of the Transformation System (TrfS) enables transparent division according to particular transformation processes (TrfP). This division is useful for TS engineering designing and development as well as for PLM Fig. 5. This EDS life cycle model of the technical product / technical system (TS) enables e. g. to include transparently "all" essential system factors (e. g. requirements of particular TrfP and their operators put on TS properties) to TS requirement specification, to TS evaluation, to risk analysis, etc. Doing this, it is possible to predicate and include also the different quality of particular factors, e. g. of a person, of technical means, etc. in the manufacturing and operation stage, during distribution, operation, liquidation, etc.

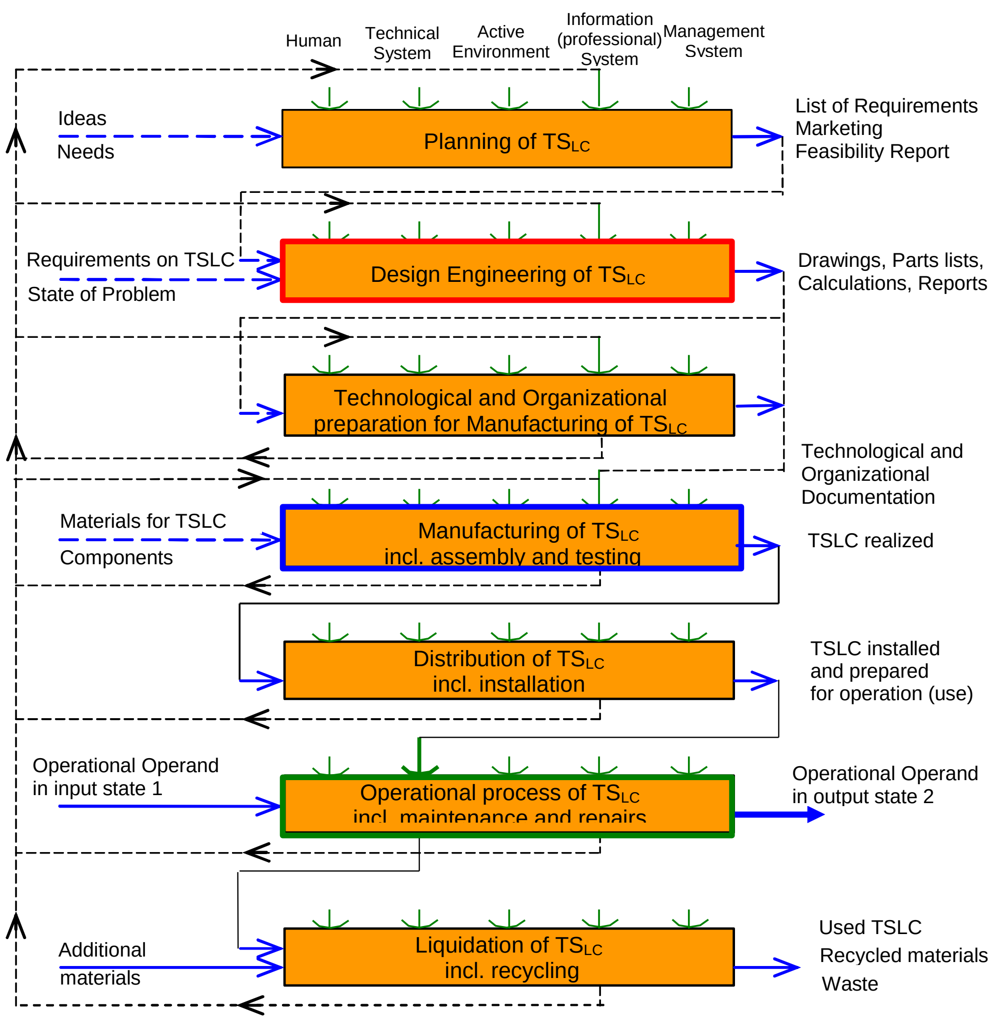

Fig. 5. EDS life cycle model / "map" of a technical product / technical system (TS_{LC}) shown like a "Transformation System" (Fig. 3) in its particular stages [4]

5. BARRIERS RESTRICTING THE EDS MASS APPLICATION IN PRACTICE

In the summary, the actual level of knowledge and research activities within the EDS field in the world as well as in the Czech Republic can be characterized in such a way, that the emphasis is still put on procedural, less or more "guideline" approaches to engineering design methodics. The original approach by Hubka and Eder, further elaborated by Hosnedl [10], [11], [7], [8], [4] to EDS knowledge is specific because it is built explicitly on integrating theoretical bases, on the principle "subject – theory – method". This approach, which leads to the mentioned "map" of knowledge about and for design engineering, is considerably more compatible with natural intuitive design engineering (Fig. 5), which still predominates in practice. In spite of this not every and each engineering designer is able and willing to accept this approach, and moreover, to change his or her proceedings used up to now and apply EDS knowledge at solution of his or her problems in engineering design.

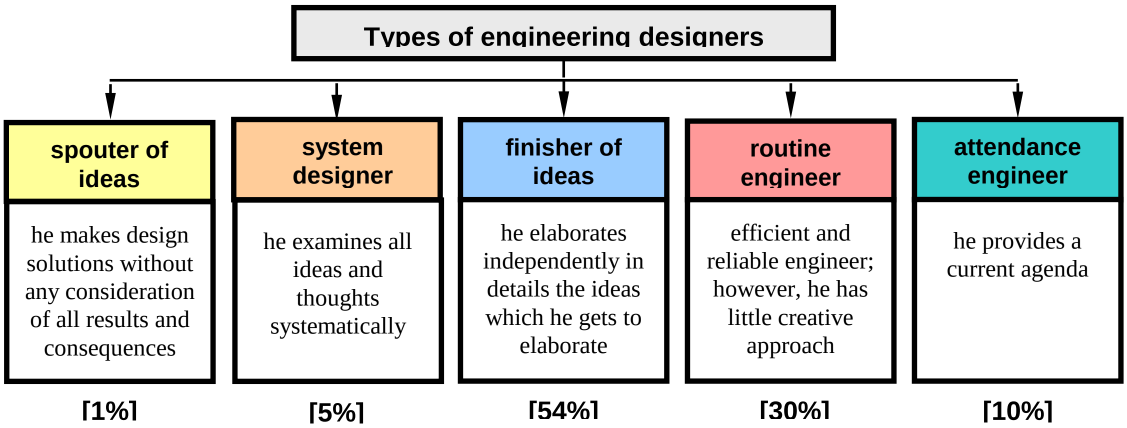

Fig. 6. Characteristic types of engineering designers and their proportion in the engineering design department [12]

Of course, EDS knowledge and methods do not solve engineering design or development problems, but they grant creative people and management dealing in engineering design as well as in cooperative and management sections the systematical overview about objects, processes and relationship, which influence the product engineering design and development process. So, EDS knowledge and methods enable within the particular possible limits:

- to use creatively the rational system of interconnected theoretical and practical knowledge and methods of engineering design,
- to predict and analyse extraordinary situations and risk in time as well as to prepare oneself optimally to be able to solve them.

Therefore, the contributions can be expected [13,14,15] in the particular (even if not trivial) application of the basic principles and elements of well-arranged and interconnected system of well-ordered EDS knowledge and methods (from theory and from practice) which are necessary at engineering design and integrated development of new products [6], [1], including application of CA and IT technologies. Of course, EDS has no sense, if extraordinary situations and risk predominate in the engineering design and development process and if these are caused by chronic management and other failures. However, also in this case EDS can contribute – at least partly – to eliminate them.

5. SUMMARY AND CONCLUSION

We intend to minimalize the traditional "human factor" problem (Section 4) especially by "customization" of the large EDS knowledge complex, which can be still understood in practice only with difficulties, and by "educated" technical management of their implementation within the integrated product development at TOSHULIN company. We plan to solve the objective contradiction between traditional procedural ("guideline") approaches and stimulation of creative engineering design work (Section 1) by utilization of essentially new possibilities granted by the "EDS knowledge "map". This original concept described shortly in e. g. [7] supports interdisciplinary solution of engineering design and development problems not only on the system level.

If the system solution is not possible (time) or necessary (simple and routine tasks), "at any time" it is possible to pass Fig. 5 to the "level" of procedural (established and prescribed) and proved intuitive methods, or (at "insoluble tasks") to the "trial – error" approach. After the solution, it is possible to "come back to the EDS map" and here after "orientation" to continue in the system solution of the project as the whole. However, the knowledge "map" is irreplaceable at regular and output inspections and evaluations of the solution which must be a system one. This qualitatively new strategy "Knowledge Integrated Engineering Design – KID" is impossible at procedural or intuitive approaches.

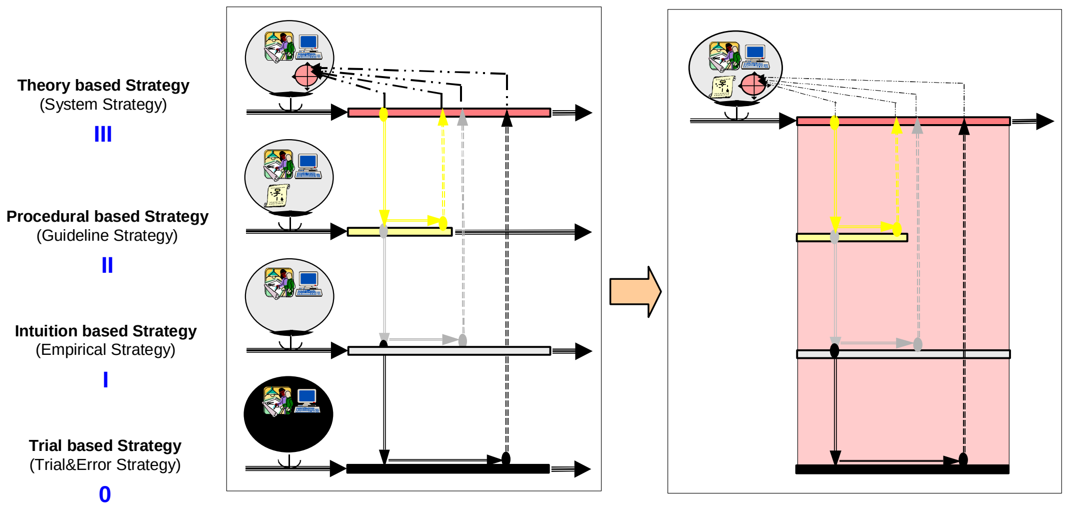

Fig. 7. a) Incompatibility of Procedural based Strategy (II) with the 'lower' strategy levels I – 0 (middle left) versus compatibility of Theory based Strategy (III) with all the 'lower' strategy levels II – 0 (top left)
b) Resulting complex strategy of Knowledge Integrated Design Engineering – KID (right) based on EDS

Since many years, the mentioned principles have been tested in practice and further theoretically developed at University of West Bohemia in Pilsen, i. a. within semestral engineering design projects in tight cooperation with industrial companies. The first projects were represented e. g. by active headrests for cars solved for GRAMMER CZ Tachov and successfully presented and evaluated also in the R&D GRAMMER AG centre in Amberg. Moreover, these the projects were solved for VALUE, CHIRANA DENTAL, FLABEG, ŠKODA and this year for ASTOS, LINET and ŠKODA AUTO. The results at dozens of projects prove that even that even the non-skilled students are able to master the EDS knowledge "map" during one semester and to use it effectively for purposeful formulation of key requirements as well as of "hidden" requirements and for creative solutions of an engineering design task. Students of Institute of Art and Design (UUD) were also included to teams during the last two years. EDS has proved also here the ability to integrate professions which seem to be so contradictory and to support their creative abilities [9]. This can be demonstrated also by extraordinarily positive reactions by companies which set these tasks, as well as by the request by Autodesk company (USA) for cooperation at the next development of project concepts; this cooperation has been already started.

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