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Project Management Enriched by Engineering Design Science during the Design Process of a Technical Product

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Abstract

The aim of this paper is to show a possible method for predicting the properties of technical products already in the design phase. The method is based on the knowledge of Project management (PM) and also uses the methodical basis of Engineering Design Science (EDS). To verify the presented method, this method was used in the context of solving a real design problem.

Keywords: design process, prediction, Project management, EDS

1 Introduction

During the design phase of the technical product the final properties of the product and future costs of its production, transport and disposal etc. are determined. For the prediction of future properties of technical products it is possible to use various methods such as analytical calculation (deformation, tension waveforms etc.), virtual reality, 3D CAD systems, 3D printers etc. The possibility to predict properties of technical products already in the design process (DesP) using a method based on Project management and also enriched with the methodical base of EDS on the basis of the Technical systems theory is demonstrated in this paper. This paper includes also a practical application of such a method on a real scientific and research project.

2 EDS on the basis of Theory of Technical Systems

EDS relies on systematically arranged information: the so-called "map" of findings derived from theory and application used for research and design practice. EDS therefore does not deal with design tasks as such. Instead, it provides a systematic overview of findings on objects, processes and links affecting the design process. The purpose of EDS is to identify (recognize and describe), generalize, verify, systematically process and explain the findings for effective designing of technical products (technical systems) [1].

2.1 Basic structure of EDS

EDS findings are divided into four fields (**Fig. 1**):

- Theory of Technical Systems – TTS
- Methodical Knowledge related to Technical Systems– MTS
- Theory of Engineering Design Process – TDesP
- Methodical Knowledge related to Engineering Design Processes – MDesP

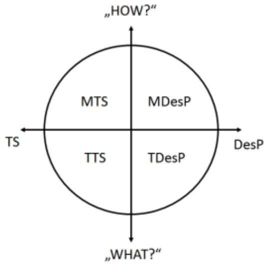

Fig. 1 Basic structure of EDS findings [1]

The method for predicting properties of technical products uses two fields of this structure (**Fig. 1**). The first area is TTS (Theory of Technical Systems) which provides the necessary theoretical knowledge of technical products (technical systems), their properties, classification of these properties and structures. The second area is MPKP (Methodical knowledge related to Engineering Design Science), which contains the methodology of technical products design using the knowledge of Technical systems theory (TTS).

3 Design process and influencing factors

If we base on the EDS/TTS, the design process is the second phase of the product life cycle and can be displayed as a transformation process (**Fig. 2**). These five operators have a significant influence on the design process: human (HuS), technical system/equipment (TS), active and reactive environment (AEnv), (specialized)

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information system (IS) and manager system (MgS). Considering the operators affecting the design process possible risks are detected already in the design phase, which has a positive effect on the final properties of the final product e. g. as in [2] or [3]. The positive effect on the final properties of the products as well as well-chosen approaches of this design strategy have been verified many times on design projects during the course ZKM at the Department of Machine Design (in which the author of this paper actively participated) or by solving science and research tasks at the Research Centre for forming technology FORTECH [4].

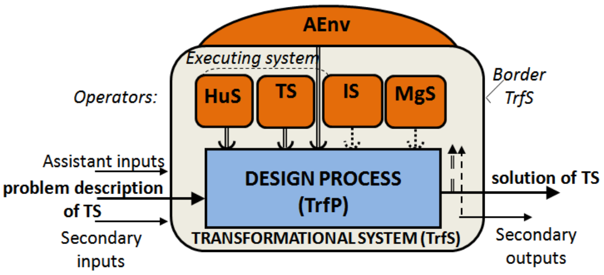


Fig. 2 Model of the design process as a transformation system according to EDS

Some other factors have an effect on the design process. They make up a so called ‘design situation’ [1]. In the design situation (DesS) such factors can be included:

- **Active and reactive environment of the DesS:**
  - **Global factors** (world/national) - e.g. policy, know-how, market,
  - **Business factors** (total/local) - e.g. production programme, strategy, company size, type of production, company's potential,
- **Design system:**
  - **Factors of the design potential** (special and branch) - designers, work equipment, work environment, technical information, management system, design process,
- **Input and output DesS/DesP:**
  - **Custom factors** - e.g. product, design phase, production phase, customer.

4 Project management

Project Management (PM) is according to [5] a discipline including planning, organizing and management that leads to an achievement of planned specific goals. PM is a discipline which is not easy to define because almost every author defines their own way that they will go.

It would be better to talk about some kind of list of the best experiences of many important managers, who used PM in practice and then decided to share their acquired experiences. In the PM it is possible to find a set of methods and methodologies that give instructions for problem solving. One of these methods is also used in this paper. This paper shows how methods principally based on PM can be extended and enriched because of their specific focus.

4.1 The method of Project management supported by TTS knowledge

The Ishikawa method, which is also known as a cause and effect diagram was selected because it is suitable for predicting the properties in the design process and can be enriched with EDS knowledge based on TTS. This method is commonly used to find the most likely cause of the problem. The starting point for the implementation of this method is the basic principle that a cause or combination of causes leads to an effect (problem). This diagram is used for a clear graphical display of the effects on a target criterion (error, shortage or property).

The above mentioned model will be extended and enriched in four steps in this paper. The goal is to include as many factors as possible in its methodological description, that influence the design process and that help to set properties and their indicators during the DesP. External factors of the DesS such as market or environmental influences will also be included in the DesP.

4.1.1 Starting point

If we use the generally available Ishikawa model (**Fig. 3**), take account of knowledge based on TTS and if we see the design process as a transformation process (**Fig. 2**) it is possible to supplement the standard Ishikawa model (**Fig. 3**) with other areas of potential problem causes (in this case future properties of a technical product **Fig. 4**) that are partially or completely ignored in the standard Ishikawa model. The result is the discovery of potential factors that influence the observed problem/property or behaviour of the TS.

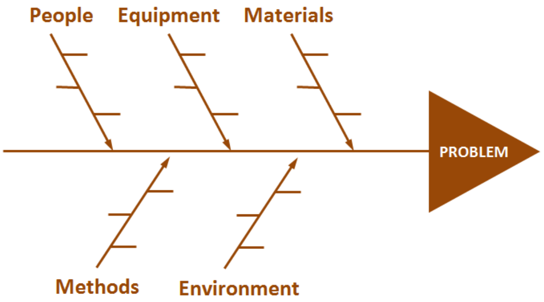


Fig. 3 Standard Ishikawa model

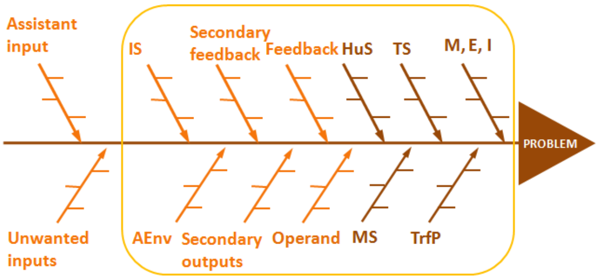


Fig. 4 Ishikawa with support of EDS/TTS [1]

4.1.2 External factors of the design situation

If we use the extended model (**Fig. 4**) and if we enrich it with the factors of the design situation we acquire a further developmental stage of the Ishikawa model that now takes into account not only internal factors but also external factors that also influence the observed DesP. The factors of the DesS can change in individual phases of the life cycle and not all the above described factors will occur here. The reason is that each phase has its specific conditions. These factors will be hereinafter referred to as external factors of the process.

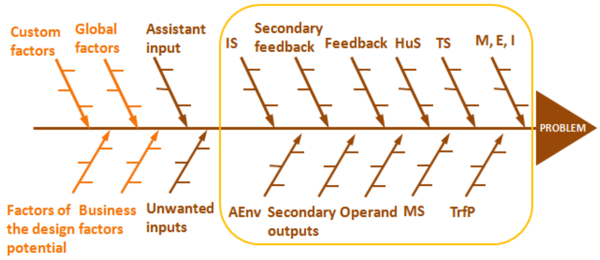


Fig. 5 Ishikawa model with theoretical support of EDS/TTS extended by external factors

4.1.3. Using in the life cycle of the TS

In the next step it is possible to apply the model from **Fig. 5** to the whole TS life cycle by using the theoretical base of TTS. If individual phases of the LC are considered as transformational processes with their internal feedback connections it is possible to use the theoretically based model with external factors (**Fig. 5**) in all seven phases of the LC (**Fig. 6**).

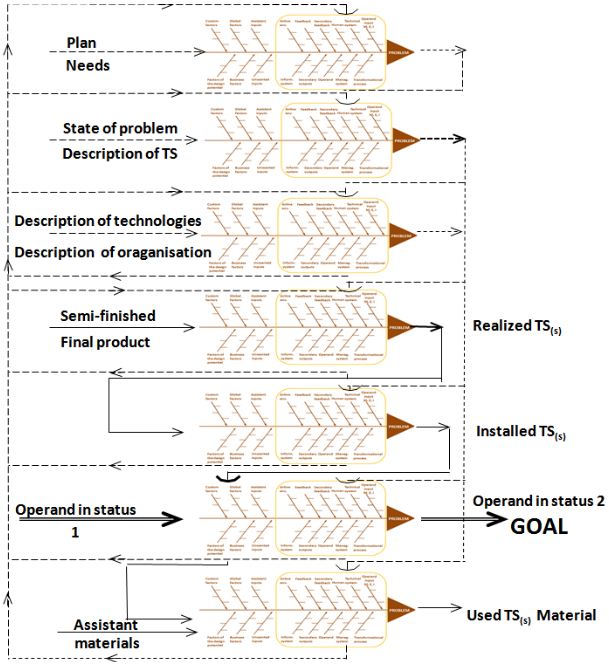


Fig. 6 TS life cycle as a series of Ishikawa models

4.1.4 Phases of the life cycle as factors of the analysis

In the last step it is possible to see individual phases of the TS LC as influencing factors of DesP and to place them on each "arm" of the model. If individual phases are considered as Ishikawa models together with external factors, a complex model occurs (**Fig. 7**) which allows the analysis of both individual phases of the LC, as well as for external and internal factors of the DesP.

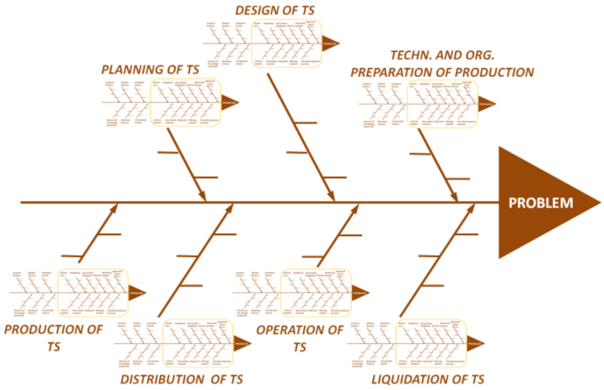


Fig. 7 Phases of the TS life cycle as factors in the Ishikawa diagram

5 Verification of the enriched method in practice

The method of the PM enriched with the theoretical base of EDS based on TTS was used to solve a design problem, the goal of which was to design a test jig which enables implementation of the tensile test of material samples. The material samples were taken from a prototype bottle made of an aluminium alloy (**Fig. 8**) and also from a semi-finished product of this bottle (**Fig. 9**).

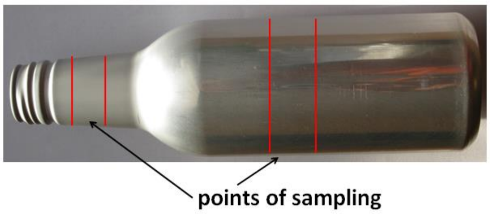


Fig. 8 A prototype bottle with marked points of sampling

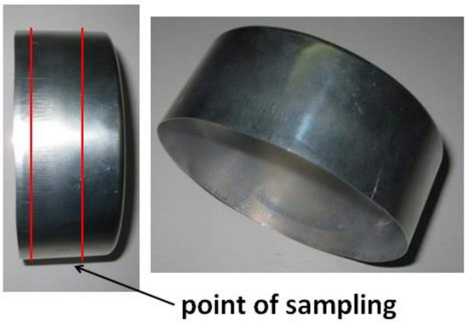


Fig. 9 A semi-finished bottle with a marked point of sampling

The test jig enables implementation of a tensile test. The samples are tensile deformed in order to obtain a tensile curve of the material for the material state of the sample in the form of the semi-finished bottle and for the material state in the form of the finished bottle.

Results of the test should be inferred on the mechanical properties of the used material, such as stress (limit of proportionality, limit of elasticity etc.) and corresponding deformation. Simultaneously, the jig must allow an equalizing of misalignment between the upper and lower jaw of the machine.

It was necessary to produce samples with a notch (**Fig. 10**) from the prototype of the bottle and semi-finished product. The notch was necessary to achieve the targeted concentration of the stress and deformations in the pre-elected area of the sample. After consultation with experts at the Research Centre for forming technology FORTECH at the University of West Bohemia in Pilsen, especially with the head of the research centre three points of sampling were established - two on the prototype bottle (**Fig. 8**) and one on the semi-finished product (**Fig. 9**).

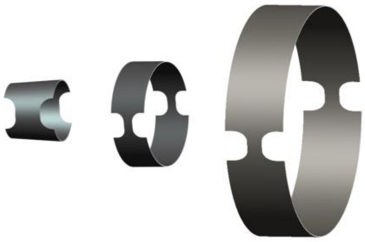


Fig. 10 Final shape of the samples in the form of virtual models

5.1 Design of the test jig

To verify the theoretical assumption that the Ishikawa method enriched with the knowledge of TTS can be successfully used during the design process this method was applied as the second step of the design process. This method is displayed in graphical form in the following figure (**Fig. 11**). Not only traditional influences on the design process (human, machine, customer requirements etc.), but also global or custom effects are considered in this model.

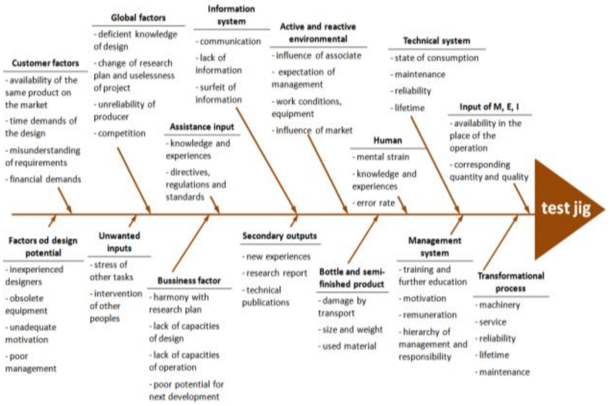


Fig. 11 Use of the Ishikawa diagram enriched with TTS

5.2 Determination of sub-goals

The next step in the design process of the test jig was to determine the sub-goals and the repetition of the main goals. After a thorough analysis of problems using the above-described methods and techniques, it was found that it is necessary to extend the requirements and also goals (sub-goals) with the design of a device for the treatment of the test samples. The reason is that the currently available technical devices were not able to ensure their required form with the appropriate quality. The device for the treatment of the samples must enable creation of notches on the samples with a repeatable accuracy and always in the same position so as not to be negatively influenced by the tensile test e.g. with a different size of notch and thereby a reduction of effective cross-sectional dimensions.

5.3 Interdependence of the life cycles

Individual designed technical systems during the tensile test are interdependent and can be represented by their life cycles. In the figure (**Fig. 12**) an integration of the life cycle (LC) of the test jig TS_{TP} and LC of the sample TS_{VZ} and also an integration of LC of the device for the treatment of the samples TS_{UVZ} are shown. When adapting the first one it was necessary to correspondingly adapt the second one - e.g. if the point of sampling on the bottleneck was changed, the diameter of the sample would be changed and then it would be necessary to adapt the device for the treatment of the samples because of the new diameter, too.

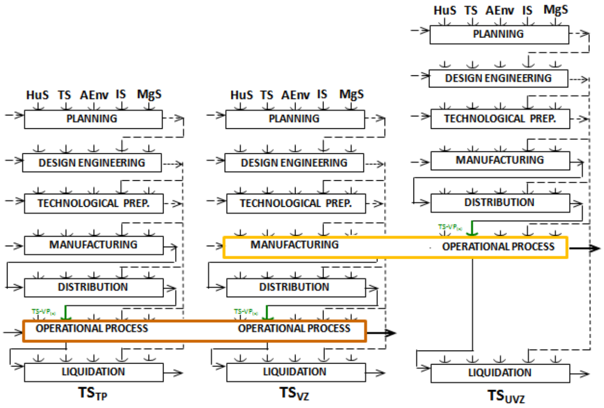


Fig. 12 Integration of the LC of the test jig TS_{TP}, of the sample TS_{VZ} and of the device for the treatment of the samples TS_{UVZ}

5.4 Analysis of the operational phase of the sample

For a detailed analysis of the tasks associated with the implementation of the tensile test from the perspective of a future sample this sample was analyzed by the EDS knowledge with use of TrfP (**Fig. 13**).

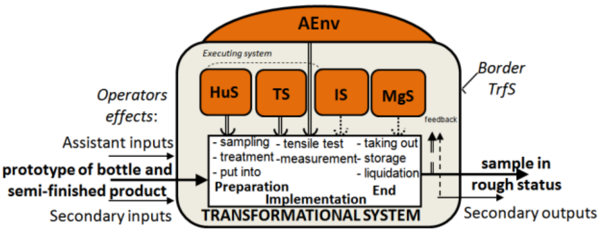


Fig. 13 Operational scenario of the main phases and operations of the LC sample

After analyzing the operation of the sample (**Fig. 13**) you can see that individual operations intertwine with not only the test jig but also the device for the treatment of the samples. The input of the operational phase of the sample (left) is the prototype of the bottle, respectively of the semi-finished bottle. The output from this phase (right) is the sample after the tensile test.

5.5 Design of a functional and organic structure of the test jig

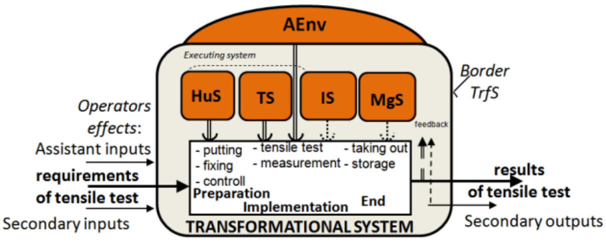
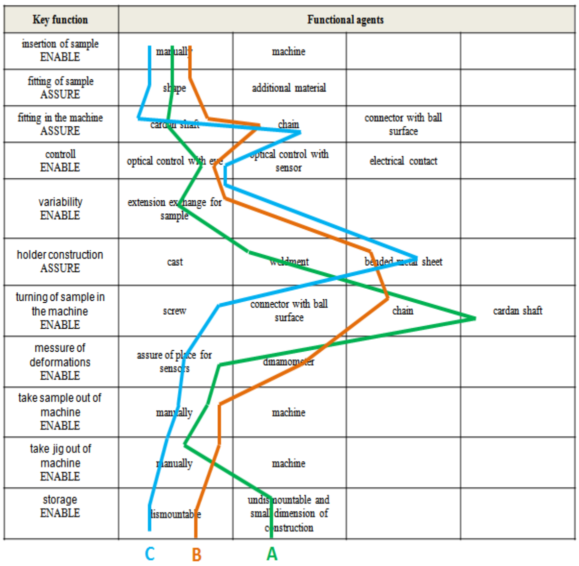


Fig. 14 Operational scenario of the main phases and operations of the test jig in the operational phase of the LC

The figure (**Fig. 14**) shows the operating scenario of the test jig. The input (left) is a sample of the bottle ready for the tensile test. Results of the tensile test are at the output (right). The operational phase is divided into three phases that are characterized in the figure (**Fig. 14**).



Key function	Functional agents			
insertion of sample ENABLE	manually	machine		
fitting of sample ASSURE	shape	additional material		
fitting in the machine ASSURE	cardan shaft	chain	connector with ball surface	
controll ENABLE	optical control with eye	optical control with sensor	electrical contact	
variability ENABLE	extension exchange for sample			
holder construction ASSURE	cast	weldment	bended metal sheet	
turning of sample in the machine ENABLE	screw	connector with ball surface	chain	cardan shaft
messure of deformations ENABLE	assure of place for sensors	dinamometer		
take sample out of machine ENABLE	manually	machine		
take jig out of machine ENABLE	manually	machine		
storage ENABLE	dismountable	undismountable and small dimension of construction		

Fig. 15 Morphological matrix of elements

The next step of the design of the test jig was to create a morphological matrix of elements (**Fig. 15**). In this matrix in the left column the main functions are shown. These functions must be ensured by designing the product to provide effects of the set operations in the operating process of the designed product. The column to the right of the first column contains so called ‘functional agents’ that enable relevant functions to be realized. By joining the selected functional agents (one from each row) available design variants of conceptual structures of the jig (A, B and C) occurred. These could be adapted and improved in the next step of the design.

After creating the morphological matrix it was possible to make a rough design of 3D models of the test jig. Many variants were designed. Then some of them were elaborated in various forms. After their evaluation one variant which best met the given requirements was selected (**Fig. 16**).

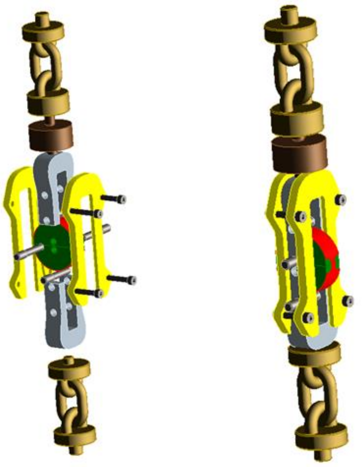


Fig. 16 Designed variant of the test jig with two samples

5.6 Design of the device for a treatment of the samples

When designing the device for the treatment of the samples, the same procedure was used as when designing the test jig. The only difference was that the requirements given on the device were listed in detail at the beginning of the design because the device was not considered in the assignment of the design of the test jig and was solved only in its course. Influences and relations to the test jig and to the sample made from a bottle and vice versa were considered.

5.7 Requirements given on the device for the treatment of the samples

- creation of the notch on the sample - samples of different diameters, conical samples,
- notches of the same size and in the same position on the sample - repeatability,
- easy use - easy handling, easy use, easy storage, safety.

The following process steps were consistent with the previous mentioned design process of the test jig.

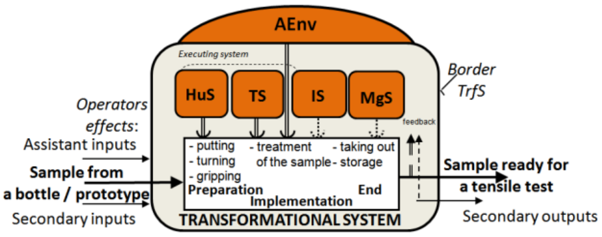
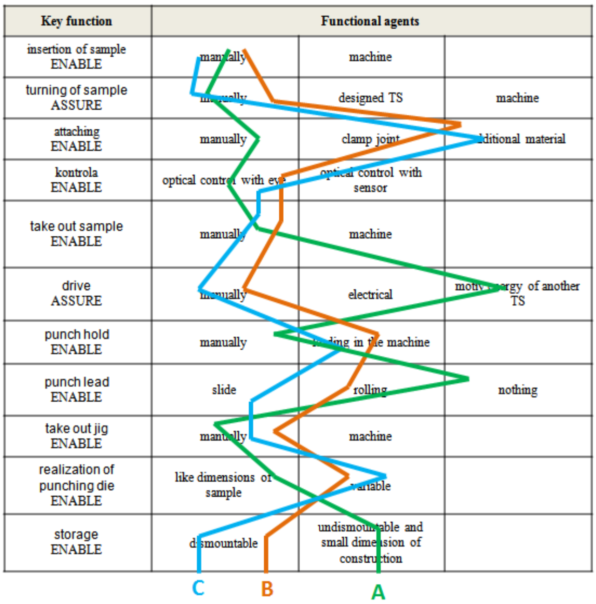


Fig. 17 Operational scenario of the main phases and operations of the device for the treatment of the samples in the operational phase of the LC

The input in the operation of the device for the treatment of the samples (**Fig. 17**) is a rough sample. The output is already a sample with a notch ready for the tensile test. The operational phase is divided into three phases that are characterized in the figure (**Fig. 17**).

Again a morphological matrix of elements was used to find a possible building structure of the device for the treatment of the samples.

Thanks to joining the agents of functions in the morphological matrix (**Fig. 18**) different design variants occurred.



Key function	Functional agents		
insertion of sample ENABLE	manually	machine	
turning of sample ASSURE	manually	designed TS	machine
attaching ENABLE	manually	clamp joint	additional material
kontrola ENABLE	optical control with eye	optical control with sensor	
take out sample ENABLE	manually	machine	
drive ASSURE	manually	electrical	motive energy of another TS
punch hold ENABLE	manually	holding in the machine	
punch lead ENABLE	slide	rolling	nothing
take out jig ENABLE	manually	machine	
realization of punching die ENABLE	like dimensions of sample	variable	
storage ENABLE	dismountable	undismountable and small dimension of construction	

Fig. 18 Morphological matrix of elements

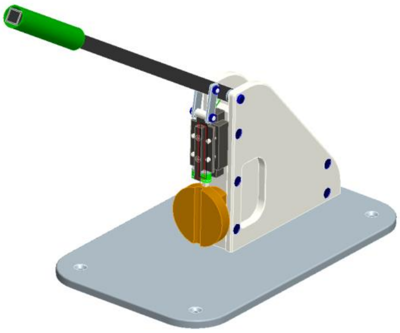


Fig. 19 Designed variant of the device for the treatment of the samples

After the design of several variants resulting from the organ structure of the morphological matrix (**Fig. 18**) variants were evaluated. The variant which best matched all requirements was selected (**Fig. 19**).

6 Conclusion

The test jig and the device for the treatment of the samples were, besides other things, designed to verify and validate the method for the prediction of the properties that was introduced in this paper. After their design we can say that the designed method is usable in the design practice and thanks to its simple system and graphic display in the form of a matrix the method can be used without specific knowledge.

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