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FUNCTIONAL COST ANALYSE BASED ON VIRTUAL PROTOTYPING MODELS IN CAD/CAE ENVIRONMENT

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1. ABSTRACT

New developed approach for Functional Cost Analysis (FCA) based on virtual prototyping (VP) models in CAD/CAE environment, applicable and necessary in developing new products is presented. It is instrument for improving the value of the product while maintaining costs and/or reduce the costs of the product without reducing value. Five broad classes of VP methods are identified. Efficient use of prototypes in FCA is a vital activity that can make the difference between successful and unsuccessful entry of new products into the competitive word market. Successful realization of this approach is illustrated for a specific example using press joint power tool.

Keywords: Functional Cost Analysis (FCA), Virtual prototyping (VP) models, CAD/CAE environment.

2. INTRODUCTION

The current trend forces companies to produce low-cost and high-quality products in order to maintain their competitiveness at the highest possible level, which arises due to rapid technological developments. Customers constantly prefer newer and much more functional products. There is no doubt that, reducing the cost of a product at the design stage is more effective than at the manufacturing stage. Therefore, if the product manufacturing cost can be estimated during the early design stage, designers can modify the design to achieve proper performance as well as a reasonable cost at this stage.

Functional cost analyse (FCA) of Functional value analyse (FVA) is a relatively new cost management technique that incorporates a customer perspective into the cost analysis of a product or service. Consequently, managers better understand the functions of a product or service and the value customers place on each function. The internal and external focus of functional cost analysis provide a means of determining precisely where cost reductions are needed and can be used to stimulate ideas for their reduction. Also, functional cost analysis enables managers to identify proposed cost reductions that erode the value that customers place on a product and, thereby, avoid cost reductions that are counterproductive.

In this respect, physical prototyping can prove to be very lengthy and expensive, especially if modifications resulting from design reviews involve tool redesign. The availability and affordability of advanced computer technology has paved the way for increasing utilization of prototypes that are digital and created in computer-based environments, i.e. they are virtual as opposed to being physical.

The main aim of this paper is to present a new approach which define performance of FCA based on virtual prototypes in CAD/CAE environment, while using all of their advantages and specific techniques. The proposed approach is illustrated with an industrial example.

3. FUNCTIONAL COST ANALYSE

The functional cost analysis is a value engineering method that aims to increase the difference between the cost and the value of a product [Cross, 2008]. The cost is the amount that is incurred in the production and delivery of the product. This expense can include the price of parts, labor, overhead (e.g., building, power), packaging, shipping, and advertising, among others. The value of the product is considered as what customers are willing to pay for it. This definition of value is extremely important when completing a functional cost analysis. Functional cost analysis can be applied to new designs, extensive redesigns or in an evaluation of a competitor's product. Functional cost analysis' primary focus is not on enhancing the value of a product and therefore lends itself well to exercises in reducing high cost items, especially those that provide little value. There are many approaches and formats for creating a functional cost analysis. Generally it is performed in several steps [Ertas, 1993]:

Step 1: Create a list of components

A list the component parts of the product can be prepared based a tangible product (e.g., existing product, competitor's product, prototype). If a tangible product does not exist, exploded diagrams can be used. Parts lists and engineering drawings can also be used but may be of lesser value because they do not offer the same ease of visualization. For each component is necessary to indicate the purpose of function. In some cases, it may be difficult to attribute a function to a single component, therefore grouping a number of components as a sub-assembly may aid the process.

Step 2: Determine the cost of each component

The determination of product costs is often oversimplified and therefore inaccurate, even for relatively simple products. A number of other factors must be considered and included such as cost of parts including the purchase price as well as any associated shipping costs, cost of consumables that are used in the fabrication of the product (e.g., glue, cleaners, finishes), labor costs for assembly as well as for any modification or finishing to parts, equipment or tooling costs, handling and inventory control, packaging and shipping costs.

The total product cost is calculated by summing the totals for all components. This total is then used to calculate the percentage of the total cost that each part represents.

Step 3: Determine the value of each component

This step is one of the most difficult in the functional value analysis because much of it is subjective and it requires an estimate of the value as perceived by the customer. When determining the value of the components and subassemblies, it is important to consider the value of aspects other than those that contribute to function or performance. Although it is preferable to quantify the values of components, it is often difficult for developmental products or when legacy products do not exist.

Step 4: Consider the value of functions

Before looking at ways of reducing the cost of the product or increasing its value, the value of the current functions should be examined. If a certain function is not perceived to be valuable to the customer and the function is determined not to be necessary for reasons such as performance or reliability, then perhaps that function should be simplified or eliminated. Having added functionality in a product that is not perceived valuable by the customer can actually hurt the sale of the product.

Step 5: Generate alternatives that lead to reduced costs and/or increased value

Once the existing product has been assessed, the next step is to find design or component alternatives that serve to reduce costs without risking value or increase value without adding cost. The most ideal situation is to find alternatives that reduce costs while adding value. Cost can be reduced by reducing the number of components, combining components, reducing specifications (e.g., material strength requirements), eliminating redundant or unnecessary components, simplification of design, simplifying the assembly process or sequence, using of less expensive materials and finishes, using standardized or bought-out rather than specialized components.

The value of the product can be enhanced by utility (increase capacity, power, accuracy, flexibility), human factors (Increase ease of use, intuitiveness), reliability & maintainability (limited or no maintenance, reduce susceptibility to environmental conditions, reduce risk and severity of malfunction, increased lifetime), safety (risk free operation, protection from injury), environment (little or no undesirable by-products, recyclability or reusability), aesthetics (enhanced appearance, improved visual and tactile finish).

Step 6: Evaluate alternatives

Not all alternatives suggested to improve costs or increase value will be feasible or compatible therefore a careful evaluation should be made before any implementations are made.

4. VIRTUAL PROTOTYPES

Virtual prototyping is an aspect of information technology that permits analysts to examine, manipulate, and test the form, fit, motion, logistics, and human factors of conceptual designs on a computer monitor. It facilitates communication between different engineering disciplines during the early design process, and also provides quality illustrations that help "sell" the design or program. Thus, based on the modeling objectives and purposes, five broad classes of VP methods are identified. These classes consist of prototypes for:

- Visualization,
- Fit and interference of mechanical assemblies,
- Testing and verification of functions and performance,
- Evaluation of manufacturing and assembly operation,
- Human factor analysis.

4.1 Visualization models

Visualization models are used for examination of form as well as appearance. These models play a crucial role in communication of product information between a variety of users including marketing people, customers, managers, product development teams and engineering and even repair and maintenance personnel. Visual appearance also serves as an attraction factor. Modern visualization software can simulate interactive navigation capabilities (such as variable-speed walking and flying) through complex assemblies of any size (whether microscopic or macroscopic) to enable effective and accurate visual inspection.

4.2 Fit and interference

Fit and interference assessment is generally an iterative, time consuming and errorprone process that would benefit from being replaced with VP using three dimensional models. Using VP, the product can be evaluated automatically with great accuracy and speed, resulting in a listing of all the interference's. It is also possible visually to inspect the virtual prototypes, where clearances and interfering areas of the CAD model can be highlighted with different colors. Visual inspection of a digital three-dimensional increasing the power of VR with new haptic applications and interfaces may provide a solution through simulating sense of touch.

4.3 Testing and verification of functions and performance

Prototypes are used frequently to verify the functionality and performance of various features of a new product during its development phase. Virtual prototyping relies on three-dimensional solid models to create accurate models that are complete and comprehensive in terms of both detailed geometrical (e.g. center of gravity, surface, volume) and non-geometrical (e.g. properties such as density, stiffness, etc.) data. The resulting wealth of information satisfies the data needs of advanced CAE tools for carrying out extensive and specialized tests and analysis. As for the test data, they may be either simulated or collected from previous physical testing of finished products. The latter option can provide more confidence regarding the relevance of testing data but cannot always be comprehensive enough to include all the operating conditions.

4.3.1 Structural and physical phenomena analysis: Finite element analysis is the most accepted and widely used VP tool. It calculates the relations between material properties and structural performance to predict the behavior of a structure with respect to virtually all physical phenomena [Hughes, 2000]. Using sophisticated FEA software packages, engineers can design complex structural systems and perform detailed analysis of complexities with either none or only very few physical prototypes prior to production.

Computational fluid dynamics (CFD) originating from automotive, aerospace and nuclear industries, CFD is a VP tool that is used to simulate flow and/or heat transfer for fluids (liquid and gaseous) and solids (homogenous or porous). CFD provides increasingly more reliable prediction of movement and velocity, shear, temperature and pressure contours and distribution patterns inside the systems under study. This is achieved by solving the Navier Stokes transport equations using the conservation of mass, energy and momentum. In general, using CFD allows the design to be functionally correct in more aspects than merely the mechanical domain.

4.3.2 Motion analysis: The motion of any mechanical assembly may be modeled, evaluated and optimized in two or three dimensions. The results can be recorded using powerful animation tools and can be replayed at any time later. The two main types of motion simulation are:

Kinematics performance. Velocity, acceleration, position, displacement and rotation are determined without considering the mass or force properties. The main objective is to verify proper geometry of motion as intended for the design. Traces (as two dimensional objects) and envelopes (as three-dimensional volumes) are used to show the path of the outline or center of gravity of a body at various intervals during its motion. This information is useful in identifying possible interference and collisions between various parts of an assembly. It can also be used during tolerance analysis to provide integration and space requirement tests, which otherwise can only be achieved through expensive physical prototypes.

Dynamic motion. The main difference from kinematics simulation is that dynamic analysis considers additionally both the mass and the forces (e.g. gravity, drag and electrostatic forces) associated with the constituent elements of an assembly. Thus, detailed design information such as the power required to drive a mechanism, stiffness, safe loads, etc., can be obtained. The method for calculation of the dynamics of forces and motion is the 'numerical method' which is used to approximate the motion of mechanical systems by solving differential equations [Golub & Ortega, 1992].

4.4 Manufacturing evaluation

Ideally, virtual prototyping should comply with the requirements of concurrent engineering (CE), as opposed to sequential engineering, and must therefore allow simultaneous product exploration and collaboration by various engineering teams. Prototype evaluation should include prediction and simulation of manufacturing processes and production planning both during the conceptual design when design data are incomplete and during the later stages when the design has matured after several design iterations. The risks of transition to full production can be reduced by integrating virtual design and testing with manufacturing simulation.

4.4.1 Manufacturability: It is a condition that must be satisfied before a design can be considered valid. Lack of any prototyping of the manufacturing stage heightens the risks of having to carry out design changes shortly after commissioning expensive dies, tools and other production equipment. Process planning involves selection of the type and sequence of the manufacturing operations that are needed to create a component efficiently. Once a design is expressed as a two- or three-dimensional engineering drawing, production process planning is needed to identify the optimum configuration of manufacturing processes using the most appropriate materials and running at the lowest possible cost.

4.4.2 Assembly analysis: The main capabilities of existing VP tools for assembly analysis include [DPM Assembly, 2002]:

1. Assembly plans generation. Rules of the assembly method for feeding, grasping, orientation and insertion of all the elements are applied to evaluate assemblability and the reliability of an intended assembly system.

2. Assembly system design. Ease of maintenance, quality control checks, reconfiguring, workplace layout and station design for all the various stages of assembly are evaluated following the generation of an assembly plan. This will include the creation and configuring of assembly stations, and operations and resources such as tooling, and fixture can be assigned to each process on the basis of a bill-of-material structure.

4.4.3 Manufacturing management: Financial (e.g. the costs of implementing various manufacturing and assembly plans) and logistics and production control requirements (e.g. resource scheduling and bottleneck identification through simulation of queuing events) are the direct result of design decisions. Manufacturing management needs to evaluate the implications of these requirements prior to commissioning new products into actual manufacture.

One of the goals during the design and development stage is to achieve low-cost production. Manufacturing management simulation tools can identify all the costs associated with a new product to allow design teams to identify and improve inefficient design features.

4.5 Human factor analysis

The manufacture of a product may involve handling, assembling, packaging and maintenance by human operators. Traditionally, expensive full-size mock-ups of the product, together with either life-size human models or real users, are used to evaluate safety, ergonomics, visibility, maneuverability, etc.

Although virtual prototyping has many advantages compared to physical prototypes on cost, complexity and time, the presence of a physical prototype is still required in many different applications. This requirement combined with the requirement of creating physical prototypes in a short time, led to the emerging of Rapid tooling, which is described as the third phase of prototyping. With this technology, physical prototypes of complex parts can be produced from a wide variation of materials in a relatively short time.

5. FUNCTIONAL COST ANALYSE BASED ON VIRTUAL PROTOTYPES

Features of the FCA and virtual prototyping can become a significant advantage in development of new products. The approach for making FCA based on virtual prototype emerged as one of the most effective means to generate an adequate assessment of functionality and value of the product (Fig.1).

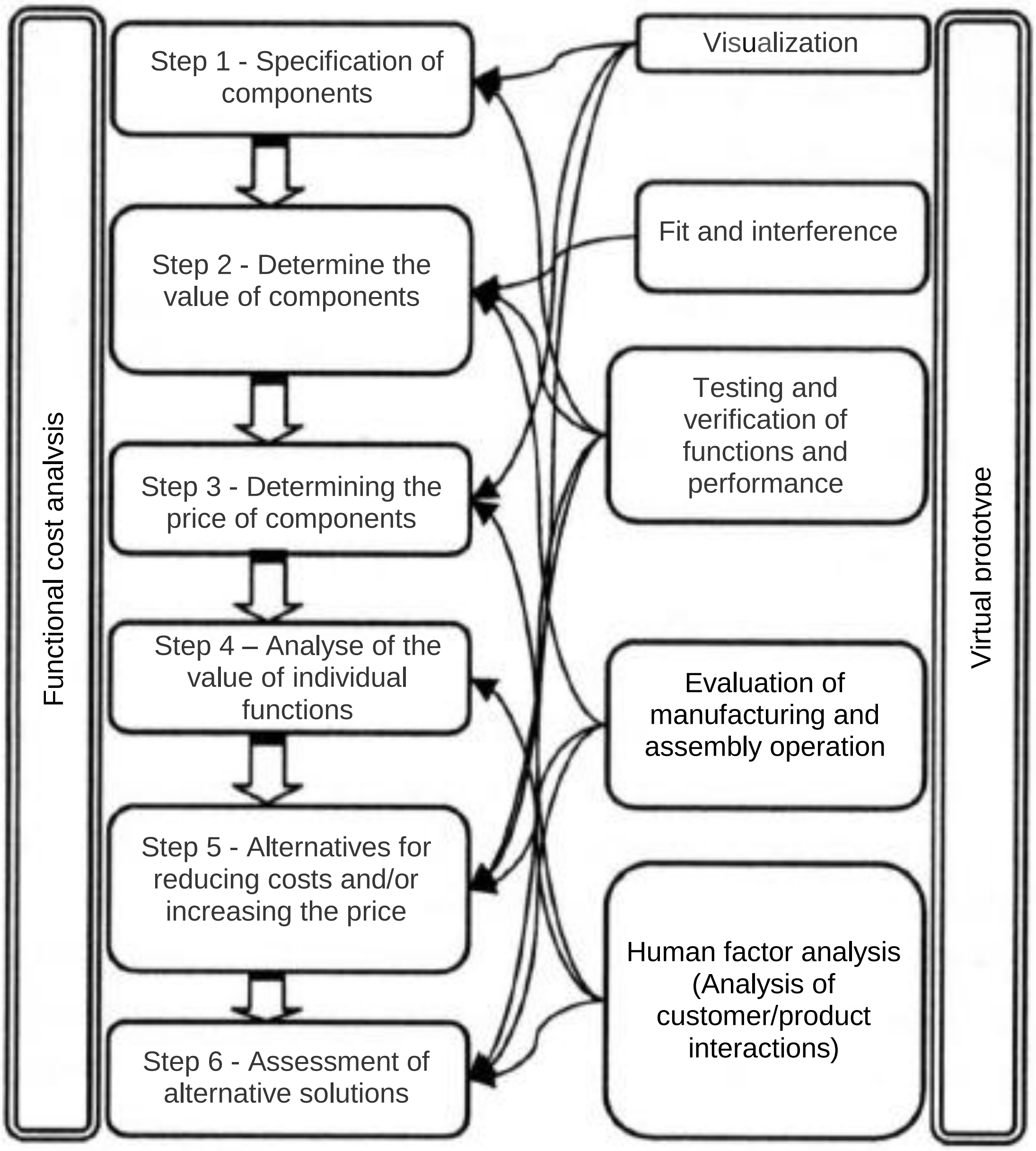


Figure 1. Applicability of the properties of virtual prototype in the course of FCA

The main goal of this approach is to define performance of FCA based on virtual prototypes while using all of their advantages and specific techniques.

Step 1 - Specification of components

Virtual prototype that is available at the earliest design stage contains all the necessary information to compile a list of individual components. In this case falls need of analyzing similar products and data mining of drawings and other documentation of competitive solutions.

Step 2 - Determine the value of components

This step can be regarded as the most important in terms of accuracy at the time of implementation of analysis, and but also represents the core of FCA. This step determines how close a product is to the expected characteristics.

There are several approaches to realize this step:

- Assessment based on similar existing components - this approach works with a various number of approximations and provides not very precise and reliable results.

- Expert evaluation - this approach is more imprecise and carries greater risk to differences between experts and the actual assessment.

- Evaluation based on virtual prototype - this is the right approach, since the virtual prototype contains all the necessary information to produce an accurate value evaluation. Geometric information (volume, specification of material) gives a required volume of used material, while tolerances and precision requirements along with geometric information allow to estimate the cost of production.

- Assessment based on information from suppliers

This is possible when virtual prototype and its attributes exist such as visualization, geometric information and more. Virtual prototype allows fully comprehensive information, based on which suppliers can define value of individual components.

Step 3 - Determining the price of individual components and

Step 4 – Analyse of the value of individual functions

These steps are combined as value of the functions defined in the previous steps of FCA. Both steps in general represent attributes of virtual prototypes related to the analysis of interaction between product and customer.

Virtual prototypes combined with the means of virtual reality may be used to obtain feedback from customers or simply to analyze the values of individual functions. Opportunity to review the functionality in near real conditions provides comprehensive information on how a product is perceived by the customer.

Step 5 - Alternatives for reducing costs and/or increasing the price

This is another important step in FCA in which virtual prototype has successful application. Virtual prototype of a conceptual model can be easily modified to create different variations. Furthermore, modern VP can be fully parameterized, allowing individual parameters to be changed, with purpose to define a variant with the best functionality. All five attributes of the virtual prototype are related to this step - visualize new solutions, geometric verification of their implementation, functional analysis – main subject of FCA, manufacturing simulation - mostly related with the next step 6 - the price of alternative solutions and analysis of the human factor - which is an important element in making final decision.

Step 6 - Assessment of alternative solutions

Application of VP in this step is similar to that in step 1. Here the information that VP has is used to assess newly developed alternative solutions. VP also allows parallel storing of all generated variants until final decision, which variant will be use. This enables generating of multiple solutions that can be offered together at the market, which helps greater flexibility to be achieved.

6. EXAMPLE OF USING VIRTUAL PROTOTYPE IN FCA

Successful realization of previously mentioned approach regarding implementation of functional value analysis based on virtual prototype is illustrated for a specific example using press joint power tool. This type of instrument is characterized by a specific design as they require transforming rotary movement of electric motors in translational movement of working instrument. There are additional requirements such as compact and ergonomic design and cost-effective realization.

A comprehensive function cost analyse of existing solution is realized. The analyse is based on a virtual prototype which has relatively high accuracy of the results.

The accomplish analyze focuses on press joint power tool value reduction while maintaining the their existing functionality. A detailed review of the value of each component also is performed. For this purpose the components are grouped in seven basic groups: Completed shaft I, Complete shaft II, Screw nut gear, Reduction gear housing, Working instrument, Electro motor, and other, (Fig.2). The value of each group is evaluated and illustrated graphically in Fig.3. Final calculated cost of existing solution is 105.79 lev. Based on the studies, following conclusions are made:

- The main cost element is electric motor. This component also is used in other existing products and its value can be hardly reduced.

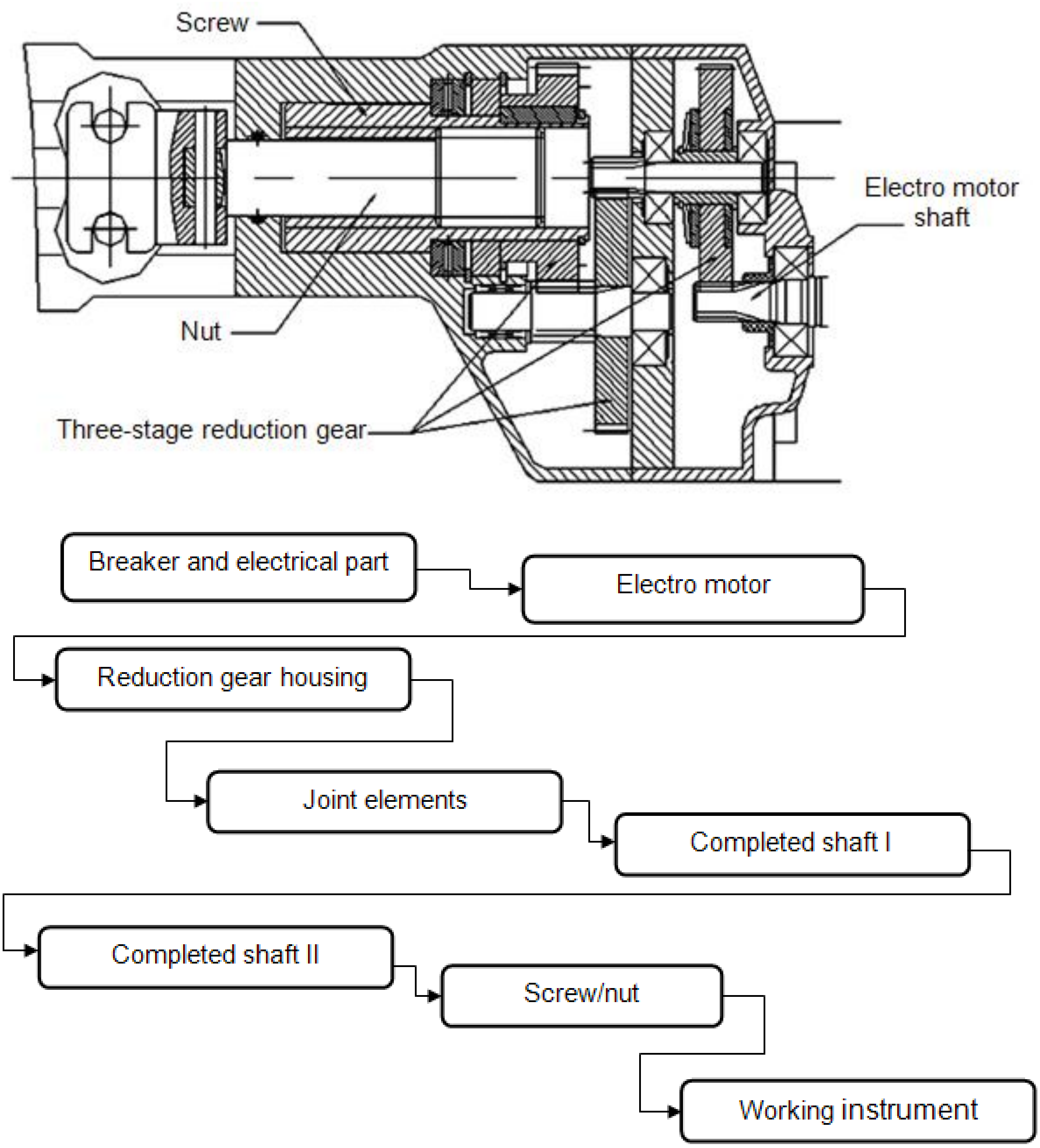


Figure 2. Original design of considered press joint power tool

- The next element is reduction gear housing, whose geometry can be optimize with the reduction gear simplification.
- The third element is screw nut gear, whose value reduction can also be difficult to obtain.
- Working instrument and other components constitute a small part of total costs and his reduction will lead to non significantly reducing of total value of product.
- Three-stage reduction gear has a value close to screw nut gear and his simplifying as well as reducing the number of elements would significantly reduce the whole product value.

- Finally we can summarize that the three-stage reduction gear which was used can be optimized by choosing an alternative mechanism for transmitting movement while maintaining the required torque/pressure force. This is the main goal of the accomplish optimization.

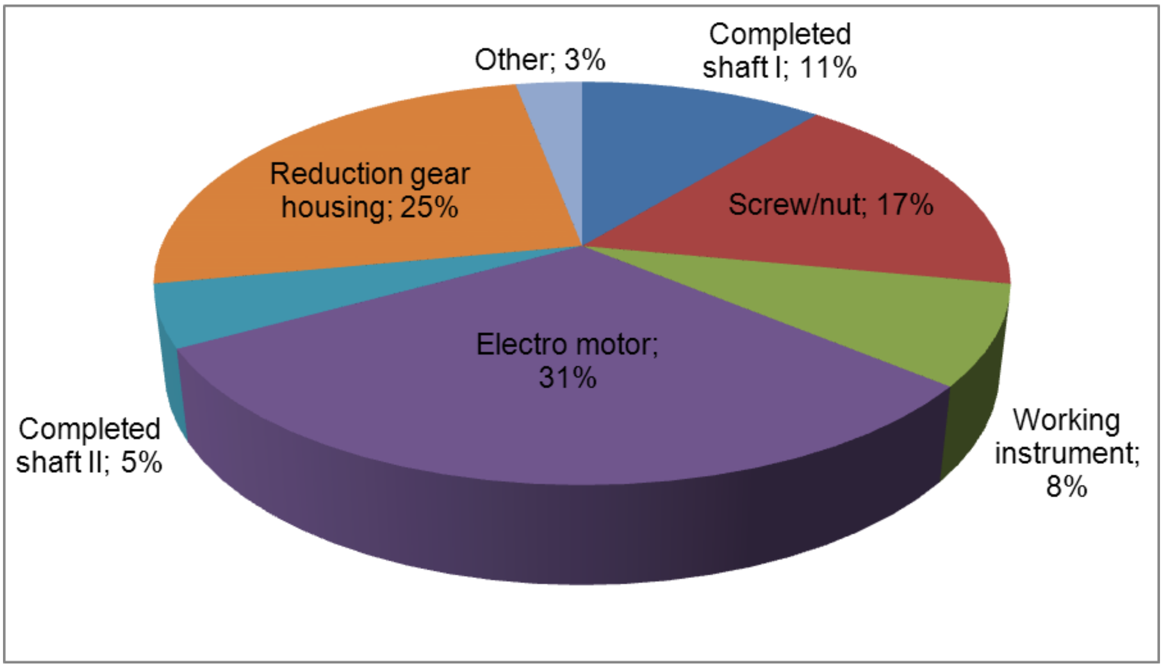
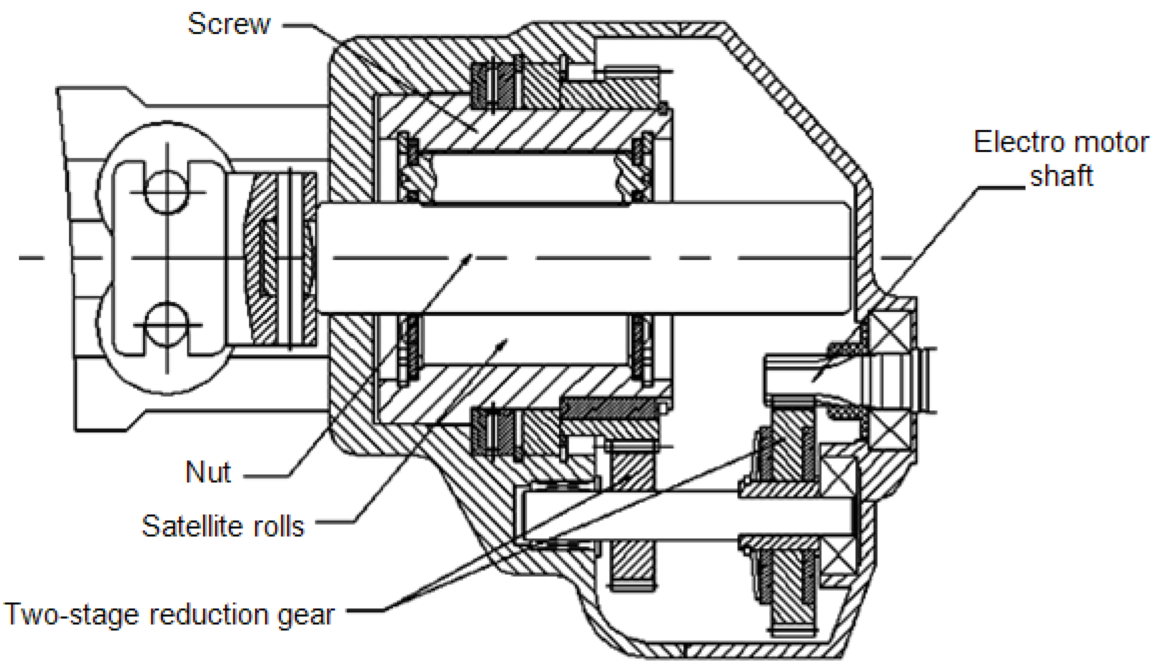


Figure 3. Distribution of expenditure by basics groups of the existed solution

A new alternative construction of gear mechanism, illustrated in Fig.4 is developed. The presented mechanism has the following components:

- Two-stage reduction gear with gear ratio I = 18.43.



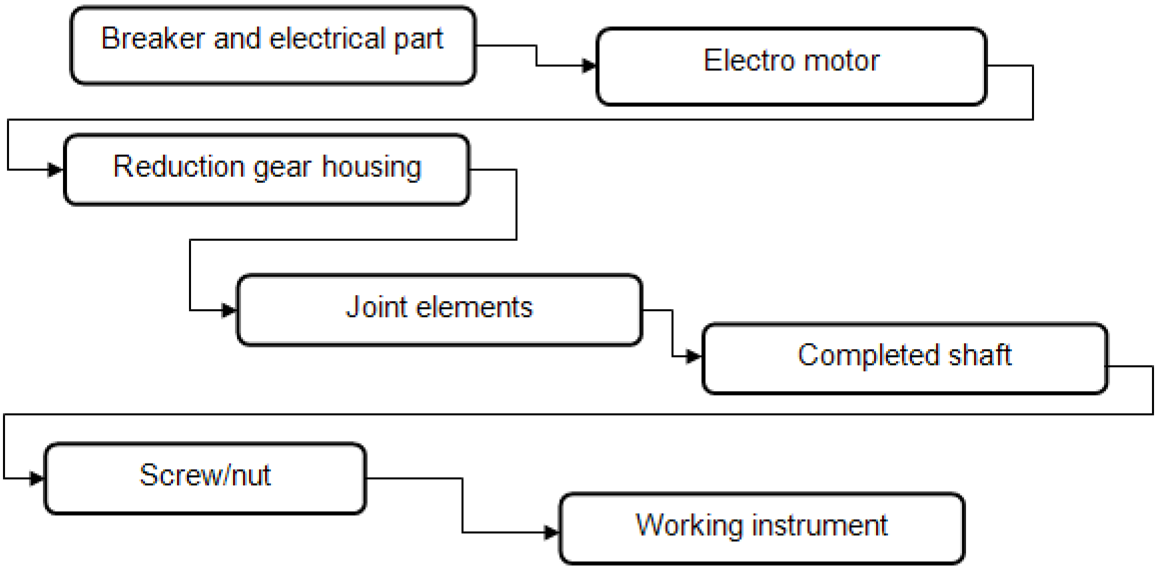


Figure 4. New design of the gear mechanism

- Differential screw nut gear with satellite rolls to move linearly screws of 0,66 mm per revolution of the nut.
- A virtual prototype of presented mechanism is developed. Based on information generated from it, functional value analysis of new solution is performed, again dividing it into separate functional groups. The value of each group is presented in Fig.5.

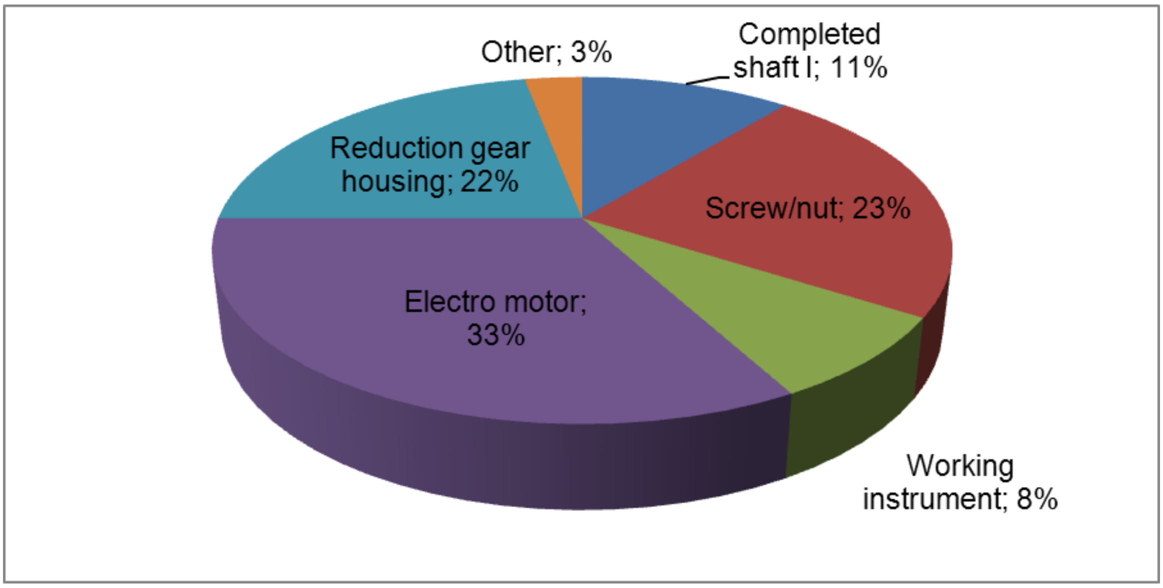


Figure 5. Distribution of expenditure by basics groups of the new solution

Final calculated cost of new solution is 103.85 lev. It seen that with the new solution reduction of the product value for 1.94 lev is achieved. Applying this in series production will lead to significant costs reduction.

7. CONCLUSION

A new developed approach about performing Functional cost analysis with application of virtual prototypes in CAD/CAE environment is applicable and necessary in developing new products. It enables improving the value of the product while maintaining cost and/or reducing the cost of the product without reducing value at early stage of the design. This approach lead to improved product designs and lower costs by identifying or eliminating high cost functions in accordance with customers. Also, it is not necessary to analyze similar products and data mining of drawings and other documentation of competitive solutions, because a list of individual components is based on virtual prototypes. The cost of production can be estimate based on geometric information, tolerances and precision requirements of the prototypes.

8. ACKNOWLEDGEMENT:

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