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

METHODOLOGY OF DESIGN OF GEARS' SIZE RANGES

W. CZADER, J. DREWNIAK
Research Development Center of Gear Reduktors – Bielsko-Biała
e-mail: jdrewniak@ath.bielsko.pl

Keywords: mechanical design, gears' size ranges

Abstract: *In the present paper, methodology of design of gears' size ranges has been presented. The proposed methodology incorporates rules of object-oriented programming, rules of design of size ranges and general rules of computer aided-design. Due to this approach, several goals were achieved: design process has been accelerated and simultaneously its costs have been reduced.*

1. INTRODUCTION

A design process, according to the proposed methodology, consists of three fundamental activities: object analysis (theoretical background), object synthesis (implementation) and validation (evaluation, assessment). Furthermore, within these activities more detailed phases or stages can be distinguished i.e. determination of a need, formulation of demands and constraints, object analysis, introductory and final object-oriented design, testing, introducing into the practice or usage and service.
During the activities connected with an object analysis, several tasks have been performed e.g. gathering of an essential information on the considered problem. This should be done in as wide and adequate way as possible and with subjective attitude to the task on the lowest possible level.
Determination of needs is connected primarily with the market research performed by the marketing department aiming for detailed identification of the needs which have to be satisfied. Several tools are used which allow for reasonable assuming of the right direction of the designing process and then for proper determination of the main and less important goals. The hierarchical methodology is utilized which enables for listing the tasks according their priority from the most important or urgent to less and less significant i.e. main and minor (second-rate) tasks. Formulation of demands and constraints consists in preparation of the complete list of demands and constrains as well as criterion of validation – what finally enables unequivocal (interchangeable) formulation of the design problem. After identification of the existed and also forecasted market demands, the detailed set of our demands is prepared and/or rephrased for the purpose of the project procedure.
The goal of object analysis is to describe an object which should be undergone to the further stages of the product creation process. At this phase, the determined needs and formulated demands together with different structural connections and relationships are utilized in a creative way.
Object synthesis is connected with introductory and final object-oriented design. It consists of such action as: search through the solution space for the considered problem as well as the design activities themselves what leads to creation of particular design solutions i.e. embodiment. It consists in implementation of the proposed methodology to an object-oriented shaping of the design solutions of gears' types series.

2. OBJECT ANALYSIS OF SIZE RANGES

The proposed methodology of object-oriented shaping of design solutions of gears' size ranges has been based upon three main groups of quantities (Fig. 1 and 2), which can be considered as inputs to the process [1, 2, 3, 4]:
● properties of object-oriented programming - they consists in decomposition of the complex problem into objects, which can be solved independently using five basic properties of this approach: abstracting, inheriting, making hermetic, polymorphism and dynamical interactivity,
● possibility of application of the graphical editor (LOGOCAD system) which enables parametric technical drawing preparation and performance, variant creation and utilization of object-oriented techniques,

● properties of size ranges design technique which enables for essential savings in designing and manufacturing processes due to: a possibility of single performance of design-research sequence of activities related to the whole size range, usage of geometrical and partial similarity laws as well as usage of the row of so called normal numbers (according to the respectable standards PN).

The design process - which incorporates all above described properties and possibilities in such areas as object-oriented programming, size ranges designing as well as usage of graphical editor – consists in acting according to the worked out methodology. It encloses the following elements:

• phases of the design process i.e. determination of a need, formulation of demands, object analysis and synthesis, testing, introducing into practice/usage and service,

• scenario of acting in consecutive phases which consists in division into classes and objects, determining the attributes and methods assigned to particular classes, creating of block-schemes (diagrams) of data flow among the distinguished classes, models created in phases i.e.: hierarchical model, model item-relationship, model of data flow and object-oriented model,

• methods and tools of linkage between the phases, such as: data bases and user's menu.

The outcome of the utilization of the proposed methodology is the technical documentation created step by step in phases as the result of inserting more and more details (specification, stating the different types of data more and more precisely) about the considered gears' size ranges. This process leads finally to issuing the package of technical drawings of all single elements and sub-systems (engineering documentation). In Fig. 3, the whole range of the elements of the process is presented: inputs for the process as well as resulting methodologies of object-oriented shaping of design model for the gears' size ranges.

One of the methods of interpretation and visualization of the proposed methodology is drawing diagrams of objects: hierarchical, item-relationship type and functional. The diagrams of objects enclose classes, for the classes also specification of attributes and methods, hereditary structure among the classes, relationships of association and aggregation, number of elements in these relationships, different constraints and the notation rules. Besides these, the following handy tools can be applied: hierarchical diagrams, diagrams item-relationship and functional diagrams for particular designs which are frequently special mutations of data flow diagrams. The diagrams as visual representations, are made by means of graphs and represent some aspects of the considered problems or their solutions.

Design solutions comprise the formerly formulated demands for both: work duty of the technical products as well as future performance of these work duties via determination of the design solution of the product. Having the decided design solution and the hierarchical structure, the designer can single out the elements of the wanting solution. In the last step, the constructional parts reach the final design form needed for preparation of the technical documentation of the project.

Classes and objects assigned to them are connected in particular with the range of application of the product. Creation of adequate classes and objects, it means identification of them, can be done after precise definition of these notions. Creation of objects depends also on precise definition of data and determination of the processes. For the purpose of decomposition of a problem e.g. designing of gears' size ranges, the detailed data analysis has to be performed. It can be done by means of models described by the particular diagrams.

In the considered projects, it is useful to create two diagrams of hierarchical models i.e. separate diagrams – one for spur gears and the second – for bevel-spur gears (Fig. 4). Creation of these diagrams is the first step in the process of searching and dividing a problem into classes and objects. Another tool for objects searching is a diagram of the data flow system. For every object, it is necessary to establish a procedure of input, processing and creation of data sets. Through consideration of the kit of the data flow diagrams, the process is decomposed into the primal (or primitive) elements. Finding proper (suitable/useful) classes and objects during the design process is a difficult but necessary task; especially in the case when they are repeatedly used. Their names (identity codes) have to be chosen in such a manner that they describe a class or an object themselves and not only the functions performed by this class or its characteristics.

Investigated projects, which refer to size ranges of spur and bevel-spur gears; – in the proposed methodology – consist of three modules. These modules are as follows: sets, subsets and elements, such as: housings, shafts (of low rotational speed), pinions and gear wheels. As the sets, one can consider: spur gears or bevel-spur gears of different number of stages (e.g. 2, 3, 4 or 5) as well as of different layout of axes: linear (or expanded) and compact (or convoluted/arbitrary placed in 3-D space), furthermore box or spur type of housings are taken into account. As the subsets, the following shaft subsets can be considered i.e. bearings, geared wheels, fixing elements and versatile types of shafts: slow-rotational-speed shaft, mediate shafts of third or second stage, mediate of second or first stage and high-rotational-speed shaft, mediate bevel-spur of second or first stage, bevel high-rotational-speed shaft (so called angular countershaft). Whereas, elements can be as follows: housings in the form of rectangle (vertical cross-section) or circle, shafts, spur and bevel pinions, spur and bevel gear wheels, commercial and standardized elements.

In the object-oriented design methodology, structures just determine the relationships between the classes and their objects together with the hereditary rules. Attributes of classes are the data enclosed in a particular class. They have adequate names and they determine requirements according to the storage of the data related to a class or an object. Methods act on objects i.e. attributes. They consist in determination of a routine of sequential tasks i.e. they can be considered as simple procedures. They act in an environment of a class using its information nature and input attributes. The method is utilized to an arbitrary object being direct or indirect appearance (representation) of the class. In the considered and investigated methodology, several methods of a common name exist (i.e. polymorphous nature) as well as there is a possibility of choice of a particular method during its performance (dynamic interconnections). These methods – in case of object-oriented design of gears' types series - are used for determination of definite (set, fixed) values of constructional characteristics (e.g. final geometrical dimensions, precision of manufacturing, roughness of outer surfaces etc.).

One of these methods used in the case of series of types design is the method of constructional (form) similarity. The similarity laws refer to a types series in the case if a ratio of at least one physical quantity between the main design and a second-rate design is constant. Such cases allow for optimization which refers to every member of series of types. It means that having optimally created one gear set, due to geometrical similarity spreading on the whole range of gears, one can find rough initial form of the rest of elements of this series. It was just said "rough initial" form – because sometimes some adjusting is necessary e.g. taking into account standard restrictions.

In the algorithms used in the present paper for calculation of the parameters determining the design form of elements of series of types of gears (spur as well as spur-bevel) – the rule of geometrical similarity of these elements has been utilized. In the parametrical calculation methods which were used in the proposed methodology, especially the similarity of gear wheels is used because these are the basic elements of the considered kind of gears. In utilized algorithms, the gear wheels' parameters determine the overall dimensions of a housing i.e. its width, length and height. Thus, the width of the housing is a function of geared wheels' widths whereas its length and height depend on the addendum circumferences of all geared elements. These dimensions depend also on distances between wheels and shafts as well as inner distances between the walls of a housing.

At the stage of object analysis, the final outcome of the engineering calculations process is a set text files gathered in databases. In the work, the following quantities were assumed as the basic parameters: distances between the shafts' axles. So, these determine the particular design (design form) and its place in the built series of types of gears. For the particular gear ratio, the axles' distances on the first gear stage is determined by the high-rotational-speed pair of gear wheels and on the last gear stage by low-rotational-speed pair, respectively. Similarity of gear wheels in the considered gears' types series is a fundamental assumption. Their dimensions do determine the dimensions of housings and shafts on the particular stages.

The calculations methods have been prepared based upon the acquired experience, inner factory recommendations, domestic and international standards as well as utilizing relevant mathematical and geometrical analyses. These methods are used for determination of numerical values of parameters needed for determination of design form of gear constructional elements. The elements are as follows: housings (boxes and covers), bevel and spur gear wheels, low-rotational-speed shafts, pinions and angular countershafts. Especially in the relations between the relationships in the hierarchy of systematic structure of three-stage spur-bevel gears (Fig. 4) – three levels of relationships were distinguished. The particular design forms are assigned to these levels. As can be stated upon the hitherto practice, the hierarchical model has some drawbacks namely it impedes representation of the semantic connections many-to-many and it forces to (frequently artificial) surfing through intermediate notations. Nevertheless, it is frequently used because it univocally (adequately) describes the hierarchy levels, to which particular machine constructional elements can be assigned (i.e. sets, subsets and elements of gears' types series).

3. OBJECT SYNTHESIS OF GEARS' SIZE RANGES

In the previous chapter, the original methodology for shaping constructional design form of gears' types series has been presented. The essence of this methodology consists in creating – for a particular models' superclass – consecutive classes, subclasses and objects. It is typical object analysis, in which the rule "from an overall view to the details" (known also in design theory [5]) has been utilized. An example of an application of this rule is division of a superclass of (cspur and spur-bevel) gears' types series into classes depending of number of stages (two-, three- or four-stage ones), as it is shown in Fig. 5 and 6.

Implementation of the methodology consists in creation, more precisely shaping a design form of gears' elements in such a way that they belong to a series of types. The input data are: geometrical parameters of the gear i.e. axles' distances, circumferences of geared elements, dimensions of shafts, angles of teeth deflection, basic housings' dimensions and codes of standardized elements (e.g. bearings numbers according to particular catalogues). The process of shaping of design form starts from conversion of the objects into the (actual) definite elements through inserting to the objects the actual numeric values of adequate quantities. As an example, let's consider the spur and bevel geared wheels, low-rotational-speed, high-rotational-speed and mediate shafts (Fig. 5, 6). Some of them have global importance (e.g. geared wheels and shafts) other have local importance (e.g. housings, bevel geared wheels and shafts).

The definite forms of gears' housings (boxes, covers) are obtained in a different way. These are assigned to the adequate attributes i.e. number of stages of a gear (two, three, four etc.), layout of axles (expanded – linear or arbitrary) and shape of the housing (the form of housing vertical cross-section i.e. rectangular or circular). In this case, the base objects are kinds of series of types of gears (i.e. two- three- or four-stage, spur or spur-bevel, respectively). From these objects, the second-rate (derived) objects are created for particular shapes, number of stages and axles layouts. These objects are less universal or general than for e.g. shafts and they are prepared as views or cross-sections of boxes and covers. They restrict the range of designer's abstraction (creativity) in forming a gear housing however they have an impact on the properties of a dedicated similarity of gears and they assure homogenization of the created ones.

From the spur and spur-bevel housings' objects, the definite constructional design forms of housings are obtained as views and cross-sections (Fig. 5 and 6):

- rectangular spur and spur-bevel gear of linear-expanded axles' layout;
- rectangular spur and spur-bevel gear of convoluted (arbitrary) axles' layout;
- circular spur gear of convoluted (arbitrary) axles' layout.

In a similar way, the definite forms of sets and subsets are created, obviously based upon the respectable their objects (Fig. 5 and 6).

The succession of shaping of gears (implementation) from e.g. geared wheels and shafts through subsets till sets ("compound/assembly technical drawing") is consistent with the most frequently used principle "from an overall view to the details" [5]. Therefore, the method implementation is not an object analysis but just object synthesis.

4. FINAL REMARKS AND CONCLUSIONS

Based upon the successful utilization of the methodology proposed in the paper, the following main conclusions can be drawn:

- object-oriented computer system which enables for shaping the constructional design forms of gears (after entire introducing into the practice) accelerates the design process so called embodiment phase,
- object methods integrated with the rules of design of gears' series of types allow for gathering the knowledge and experience of designers acquired during designing of other drives and upon the results obtained from the performed test stands experiments – the knowledge is stored in defined classes and objects,
- the objects and classes - determined within the phase of analyses and design – maintain their validity throughout the full cycle of usage of a particular model and they increase the level of detailed description. It allows for improvement of the objects – taking into account uniqueness of the problem,
- simultaneously, a possibility of making essential analyses of the problem by the designers is greater and greater due to an essential reduction of time and monotony of design process,
- the investigated methodology enables performance of process analysis in a reasonable and unified manner – what allows for improvement in organization and management and in consequence it allows for preparation almost fully precise time and financial balances for the involved group of workers/designers,
- the methodology conduces to improvement of computer-aided design and manufacturing,
- the proposed methodology has an essential influence on enlargement of technological homogenization of the range of manufactured products.

References

[1]. Beitz W., Pahl G., Nauka konstruowania. WNT, Warszawa 1984

[2]. Drewniak J. (red.), Wspomagane komputerowo projektowanie typoszeregów przekładni zębatych. Wyd. Filii PŁ, Bielsko-Biała, 2000

[3]. Gendarz P., Metodologia tworzenia uporządkowanych zbiorów konstrukcji maszyn. Zeszyty Naukowe Politechniki Śląskiej, 1548, Gliwice

[4]. Czader W., Metodyka obiektowo zorientowanego kształtowania postaci konstrukcyjnej typoszeregów przekładni zębatych. Praca doktorska, ATH – Bielsko-Biała 2004

[5]. Dietrych J., Projektowanie i konstruowanie. WNT, Warszawa 1987

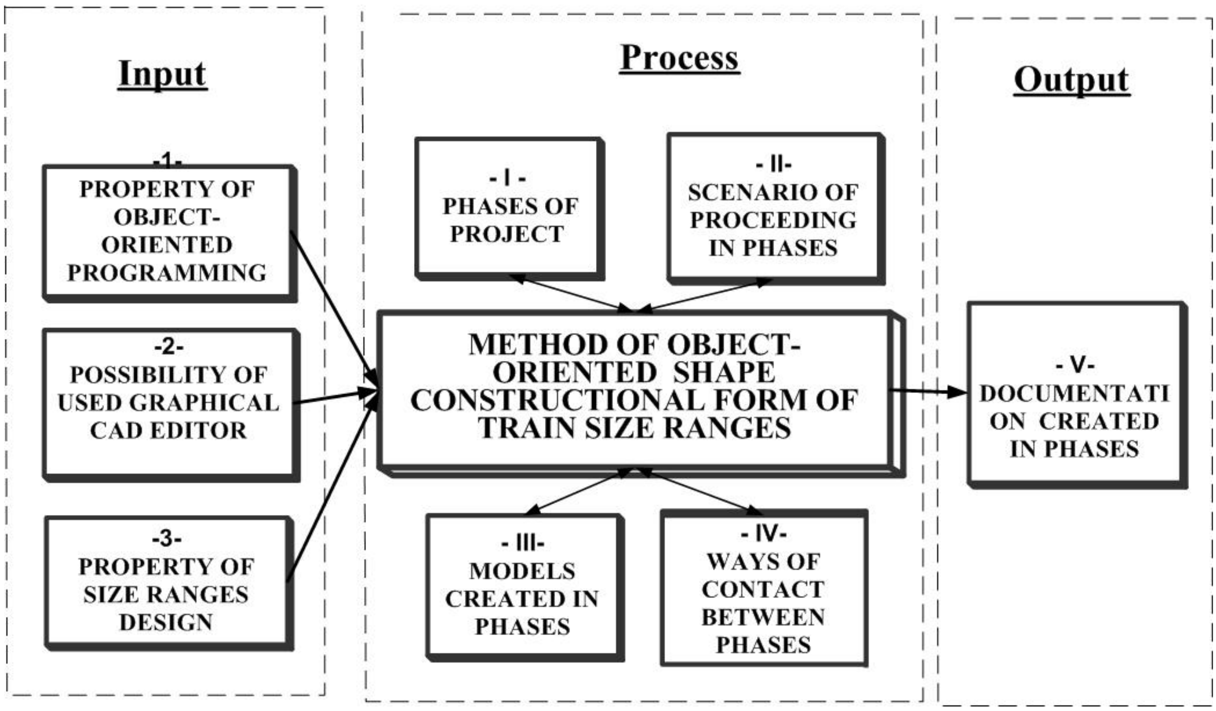

Fig. 1. *Process approach of offered method*

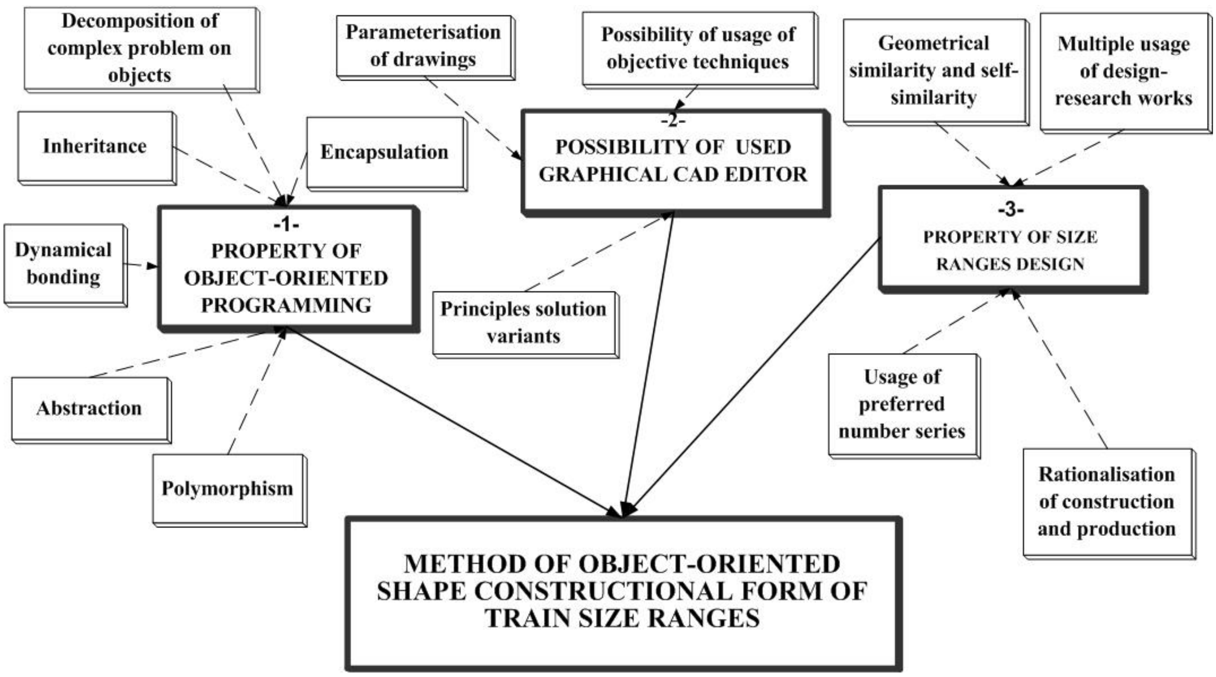

Fig. 2. *Elements constituting input of investigated method*

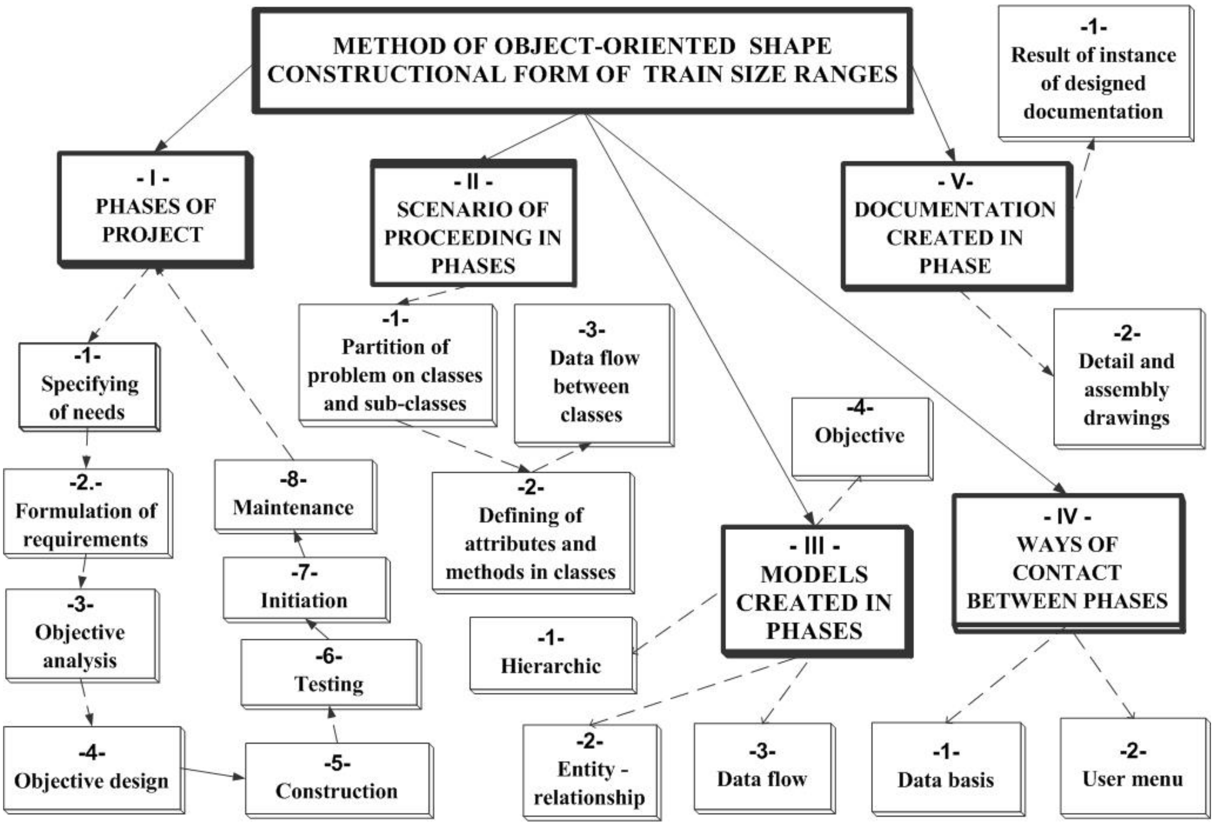

Fig. 3. *Elements of design process and output of offered method*

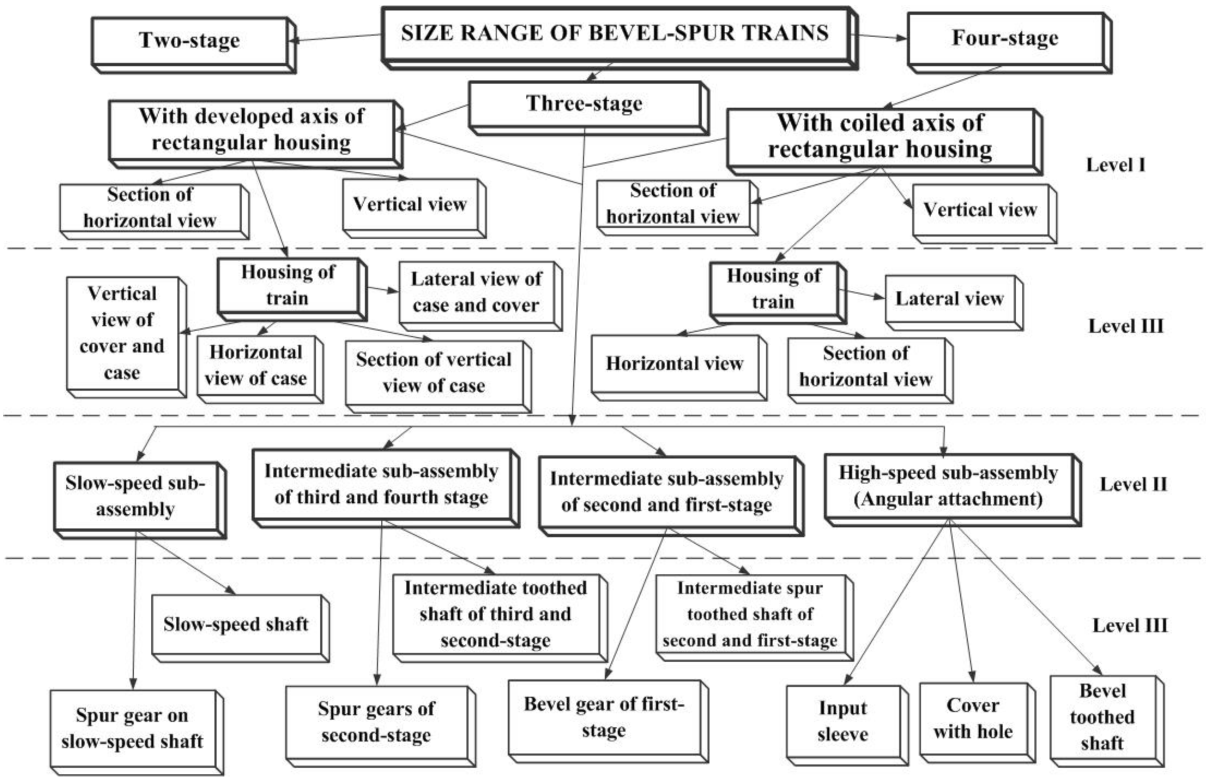

Fig. 4. *Scheme of hierarchical model of size ranges of three-stage bevel-spur trains*

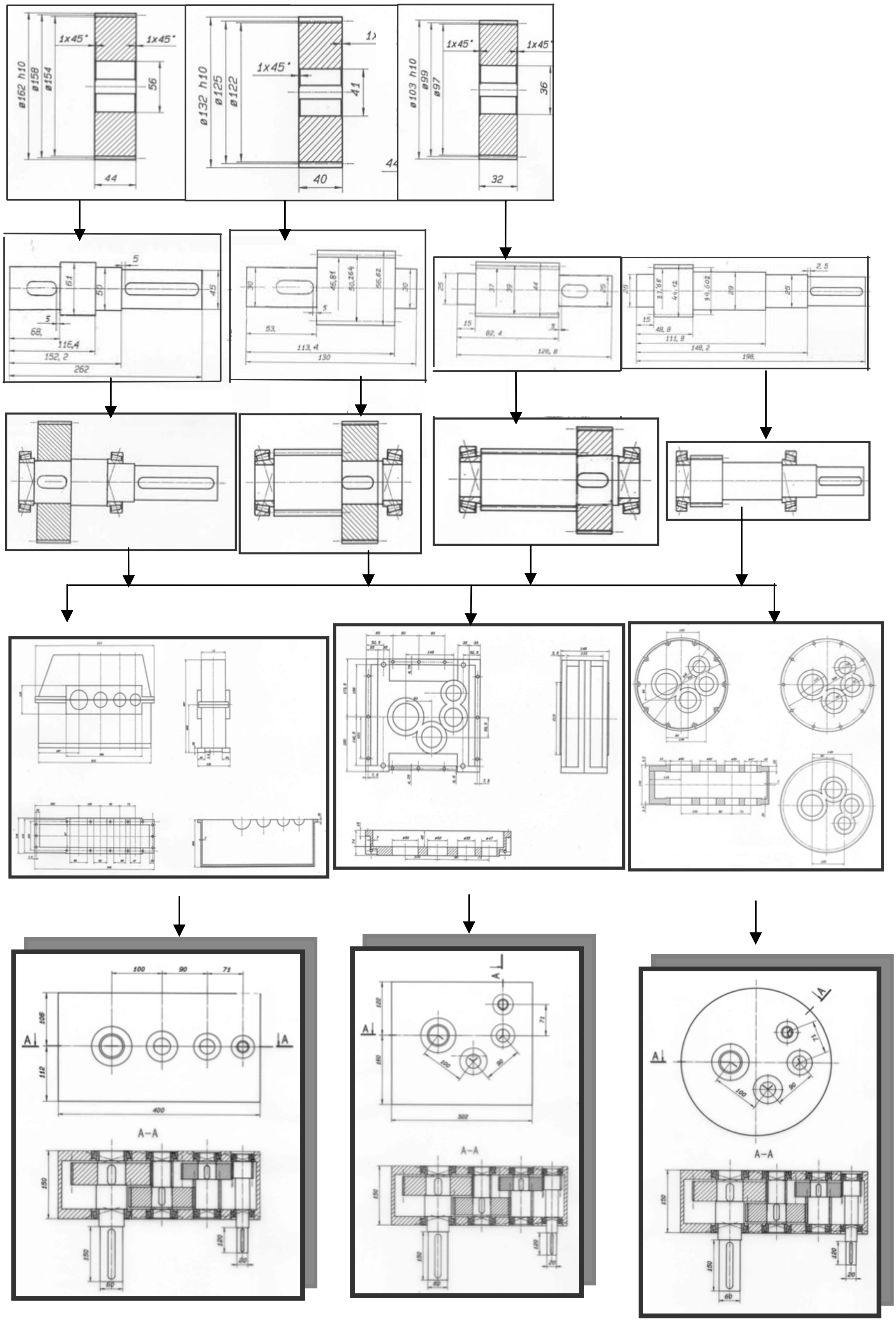

Fig. 5. *Scheme of objects of three-stage spur train according principle "from an overall view to the details"*

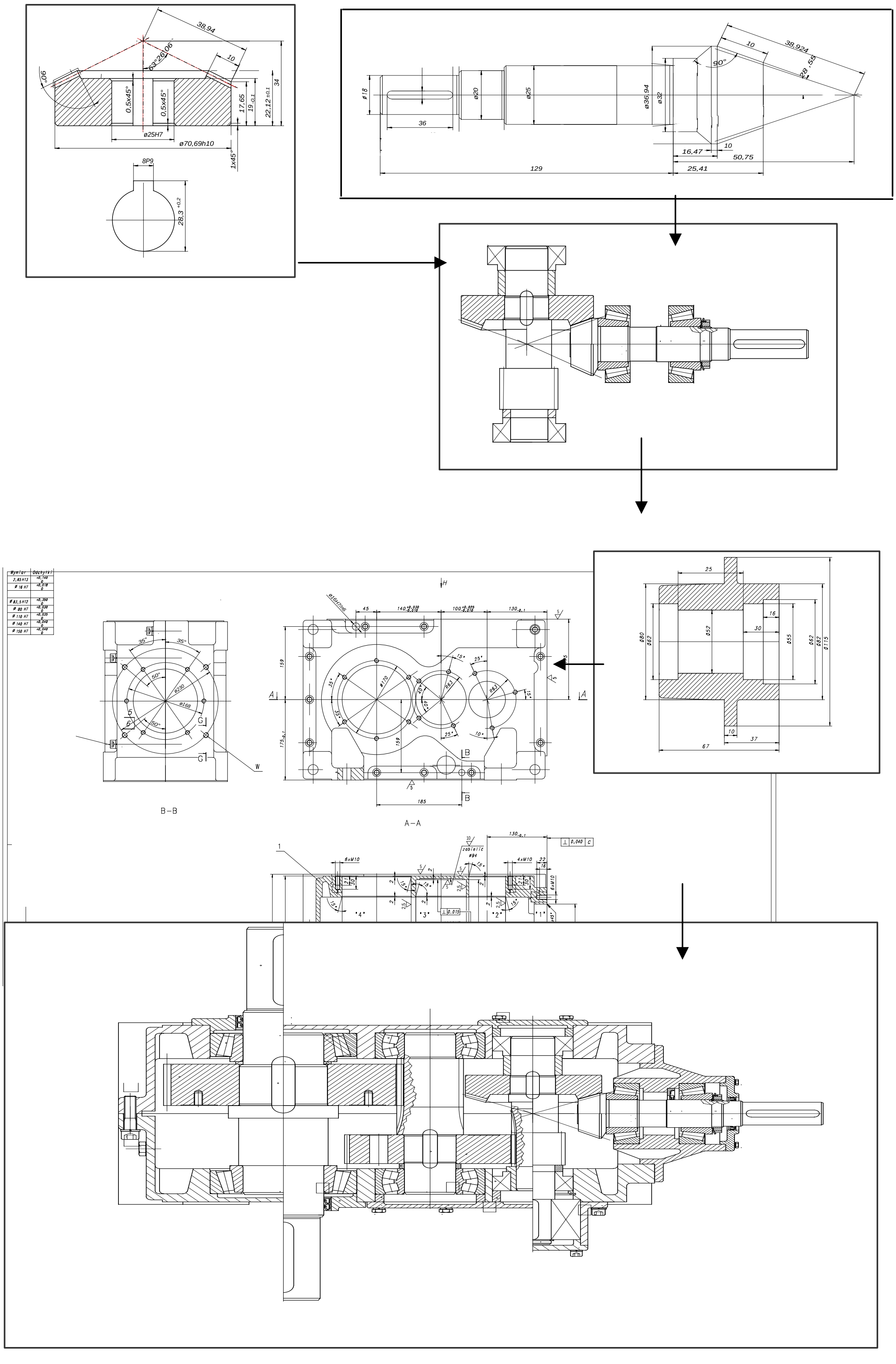

Fig. 6. *Scheme of objects of bevel-spur train according principle "from an overall view to the details"*