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APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS IN GEAR TRANSMITTERS CONCEPTUAL DESIGN

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Abstract. *This paper presents artificial intelligence methods and their influence on development of intelligent integrated system for gear power transmitters design. System is based on knowledge. The development of expert and fuzzy expert systems has been made in CLIPS and FUZZY CLIPS program environment. This system supports all the rules of Object Oriented Programming, and enables integration of algorithmic (procedures and methods) as well as non-algorithmic programming techniques (production rules).*

Key words: *CAD, Artificial Intelligence, Expert system, Neural network.*

1. INTRODUCTION

Market demands are more and more complex in aspect of productivity, quality and speed of new products development. Intensive development brings up growth of project-constructional tasks with even higher degree of complexity. Conventional "traditional" design, based on experience and intuition does not allow successful tracking of development of other areas of human activities. Therefore, in engineering practice, automation of the design process is being imposed as an imperative, which is, of course, result of computer application in product development.

CAD technology means and tools are the most widely applied in automation of the design process and they appear as support mechanisms in object embodiment design, engineering analysis and documenting. The use of CAD technology means is limited on engineering analysis (FEM analysis and simulation), while CAPP and CAM tools can be applied in modeling and detailed break of a work process. KE (Knowledge Engineering) and AI means (Artificial Intelligence) are also been applied in automation of the design

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process. Artificial Intelligence gives completely new approach in one's work in the design process, enabling development of intelligent system for automated design-in this case-gear power transmitters design.

Two types of systems for automated design can be set off: Conventional and Intelligent. Characteristic of conventional systems for automated design is that it is based on methods and means of CAD, CAM and CAE technologies. Data organization, which they refer, is a classic one and usually imply structures of special (graphical) data files, or hierarchical or network database models. Software support is procedural. On the other hand, intelligent system for automated design is based on DBMS (Data Base Management Systems) which enables higher degree of software support independence of data structure. As a means of further process rationalization in automated design function, computer aided knowledge engineering is being introduced in form of KBS (Knowledge Based System), where engineering knowledge has been memorized, saved and innovated as facts and rules of conclusion.

Development of intelligent CAD systems, that is expert CAD systems, is possible thanks to knowledge and data bases which connect the design process elements. With automation of the design process, engineer will not be excluded from the process of making decisions, not only because it is not possible, but because it is not necessary. During creative activities, computer should give an intelligent advice, based on analysis and search through knowledge base, but engineer is the one who makes the final decision.

Subject of this paper is development of integrated intelligent system for simultaneous design of the gear power transmitters.

2. GEAR POWER TRANSMITTERS

The design process (Fig. 1) takes time and has all the characteristics of a dynamic process. It represents simultaneous realization of constructional operations and operational decisions. Constructional operations implicate determination of working principle, calculations of stresses and dimensions, shape development, etc., while operational decisions implicate choice of parameters and other starting values.

Power transmitters are component of almost every machine, so reliability of whole machine depends on their reliability. Power transmitters serves for conversion and leading mechanical energy from output shaft of operating machine to place where it is needed-entrance shaft of working machine. The gear power transmitters have the biggest role in this mechanical energy transfer, therefore they represent one of the most important assembly of almost all machine types by it's function and economical value. Structure of needs, system of values and technology capabilities are intensively being changed so that current constructional solutions are relatively fast becoming out-of date.

Gear power transmitters vary in very large range, depending on module, power that they transmit, transmission ratio, etc. Power transmitters must also fulfill demands such as: continual and discrete change of output rotation number, then demands for weight, cost, constructional compactness, resistance on aggressive environment, and demands for noise, vibrations, maintenance, etc.

Gear power transmitters are variant constructional solutions made of same elementary executors. Transmitters have great number of standard machine elements and machine elements with standardized parameters. Crucial decisions are being made on variant structure choice, choice of dimensions, material and standard parts, therefore this construction is suitable for automation of the design process in all it's phases.

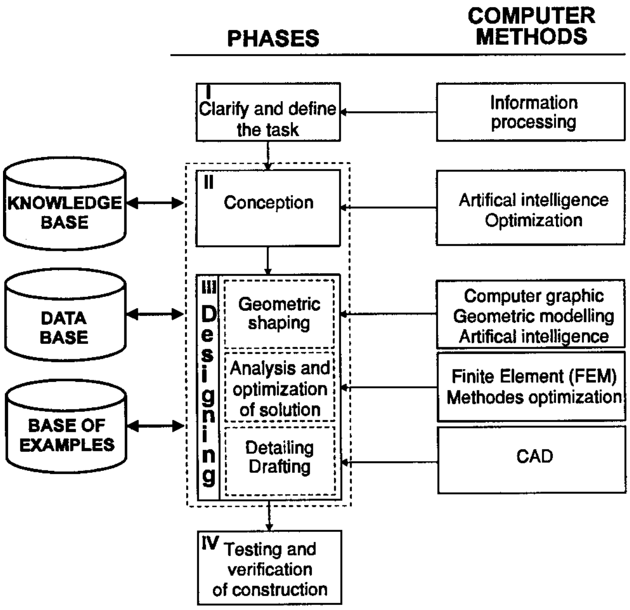

Fig. 1. The design process

3. PROGRAM SYSTEM FOR GEAR POWER TRANSMITTERS DESIGN

For the automation the design process, an integrated intelligent program system for simultaneous design has been developed, whose global structure is shown on Fig. 2.

As it can be seen, program system is consisted of 6 integrated basic program modules:

1. Program module for gear pairs calculation,
2. Program module for rolling and sliding bearings calculation,
3. Program module for hub-gear joint choice and calculation,
4. Program module for calculation and shaft design,
5. Program module for belt transmitters calculation,
6. Program modules for modeling and technical documentation of gear transmitters components (AutoCAD, GENIUS, Pro/ENGINEER).

System for simultaneous gear power transmitters design is characterized with modularity of former program modules. Integrating different program modules is achieved through server control of knowledge bases. For user interface development, MS VISUAL BASIC is being used.

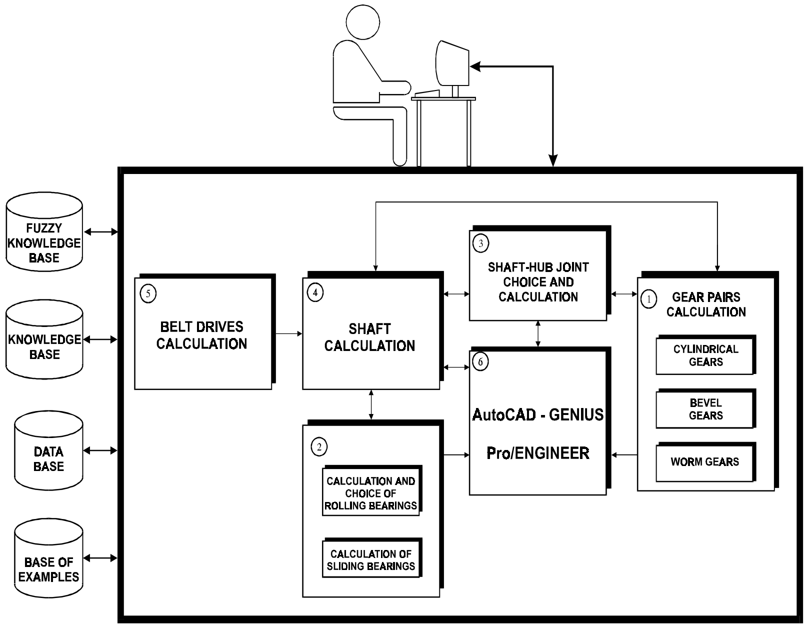

Fig. 2. Global structure of integral system for gear power transmitters design

4. APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS IN GEAR TRANSMITTERS CONCEPTUAL DESIGN

4.1. An Expert module for gear power transmitter variant choice

Starting point in gear power transmitters design is user demands and precise definition of project task. Accordingly, there is a need for correct definition of demands which must be fulfilled, and that is achieved by using following data: position, number and disposition of input and output shafts, shape of gudgeon, coupling, available space for transmitter, starting and ending rotation numbers and directions, rotation moment, type of operating and working machine, power of operating and working machine, lifetime, energy loss and type of cooling, lubricant characteristics, lubrication type, gearing, bearing, etc.

According to precise defined demands, using the expert system [6], one or more possible solutions are defined, based on database of examples. In knowledge database, there are over 70 gear power transmitter variants: cylindrical, bevel, and worm gears, bevel-cylindrical gears and cylindrical-worm gears. If constructor is not satisfied with given solution, he can make concept of a new one. Following elements are available: gears with straight and skew teeth, bevel gears with straight and arc teeth, bevel gears, belt drives, couplings and bearings.

Parameter choice for gear power transmitters is directly related to choice of transmitter conception. In order to define parameters for chosen transmitter variant, it is necessary to resolute power transmitter and to analyze each element. Structure of decisions in transmitter development process is given on Fig. 3.

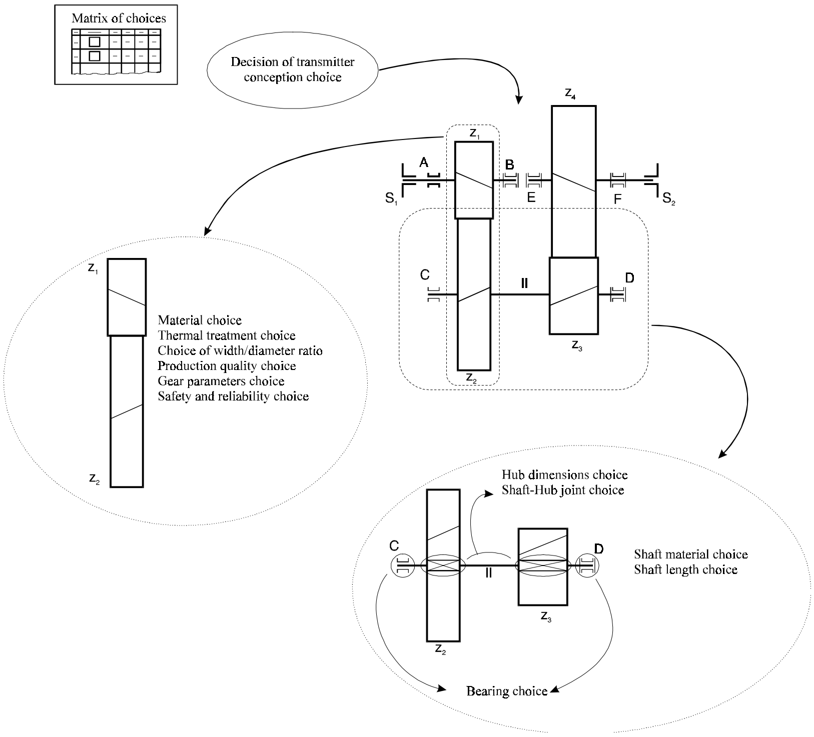

Fig. 3. Structure of decisions in gear development process

For complete gear calculation, it is necessary to make decision on material and thermal treatment, thickness/diameter ratio b/d_1, production quality, working safety and reliability, number of teeth, module, etc. These decisions are closely related, and are also related to decisions made for shaft and bearings. For example, shaft length is determined with gear thickness, bearings and other present parts. Shaft stiffness is related to gear load distribution. Choice of bearing type depends on shaft stiffness. Therefore, order of decisions is essential. This example shows all the complexity of the gear power transmitters design process.

4.2. An Expert module for choice of gear parameters

After choice of variant in conceptual design phase, embodiment design follows. It is an optimization process with large number of iterative steps. In phase of defining executors of basic system functions, constant verification of requirements list is present. In dimensioning and embodiment process, part production, assembling, exploitation, maintenance, and later recycling is considered.

Gear conceptual design (determining number of teeth, module, width, inclination angles) can be executed in two ways.

Conceptual design of gear pairs(determining the number of teeth, module, thickness, inclination angles) in this program system can be made in three ways: an expert system, fuzzy-expert system and neural network.

According to first procedure (Fig. 4), it is necessary to distribute transmission ratio for defined variant on certain number of transmission drives, and after that, program module ZPS1 enables determination of all possible variants of gear pairs (number of teeth z_1 and z_2, module m_n, tooth inclination angle β, gear width b), for the given transmission ratio i, input rotation number n_1, inter axial distance a or input power P. Beside requested parameters (i, n_1, a, P), it is necessary to supply gear material, width-diameter ratio b/d_1, and quality.

The most significant factor in gear material choice is endurance characteristics, that is demands for material quality, cost of material, production method and final thermal and mechanical finish, number of parts in series, as well as noise and vibrations during work, and capability of manufacturer to find requested material.

Considering previously mentioned, it can be concluded that many factors have influence on gear material choice. Therefore, an expert system for gear material choice has been developed-ZPS_MAT/ES [7], which should help constructor in making this important decision, during the process of gear power transmitters design.

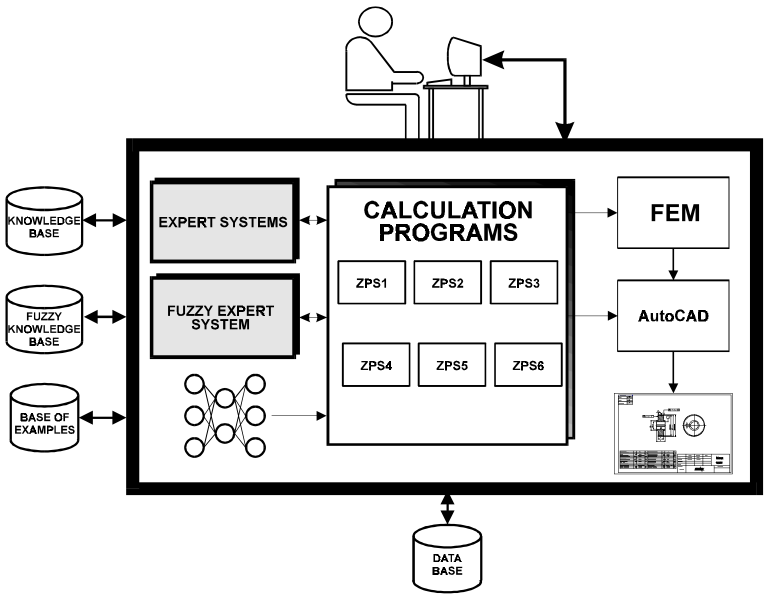

Fig. 4. Relations between modules based on artifficial intelligence methods and calculation program modules.

Development of Expert system, which is incorporated in integrated system for the gear power transmitters design, is executed in CLIPS program environment. CLIPS (C Language Integrated Production System) is an expert shell. Version CLIPS 6.0, developed by NASA Johnson Space Center [11], used for expert system development, is adapted for working on PC, MAC and UNIX platforms. This system supports application of all the rules of object oriented programming, and offers integration of algorithm (procedures and methods) and non-algorithm way of programming (production rules).

Knowledge base is formed based on recommendations from [2], and [3] for gear material choice, which are used for existing transmitters examples, where combination of operating and working machine is defined (for example turbine/pump, turbine/ compressor, steam turbine/ generator, electric-motor/compressor, electric-motor/elevator in casting factory, electric-motor/mill, electric-motor/rotor dredge working wheel etc.). Experiences in gear material choice in existing transmitters of our power transmitters manufacturers are also included in knowledge base. Besides, knowledge base includes common recommendations for gear material choice, depending on transmitter function, demands, and production conditions. On basis of defined transmitter function expert system gives the recommendation for material, thermal and mechanical finish and gear tooth flank hardness.

Gear material, mechanical and thermal finish directly influence the tolerance quality of gear pair, so expert system recommends gear quality in fact.

For defined gear material, expert system offers constructor possible limits of width/diameter ratio for small gear (b/d_1).

In next step, for given teeth numbers z_1, z_2, width b, module m_n, tooth inclination angle β, attuning of gear material, thermal finish, production number, gear diameter, module and width has been made. Determination of these values is being made in program module ZPS1, on basis of the first approach. This means that the teeth number for the drive gear z_1 can take the values limited by literature recommendations for the given gear material, and the teeth number for the driven gear z_2 is being determined from transmission ratio, which can not differ more than 2%. Constructor should choose one of the variants given by the program. Chosen data are directed into program module ZPS2, where gear geometry and hardness calculation takes place.

4.3. Fuzzy-expert module for gear parameters choice

In the gear power transmitters design, constructional parameters have characteristics that can be classified into two categories, based on their description method: qualitative and quantitative. Their values are given as numbers and descriptions. However, these values are mostly intervals, approximate or inexact, or they create interval, approximate, or inexact value of some other constructional parameter. That is the case with length tolerances where the tolerance field is given as an interval, thermal material finish that is also given as an interval, etc. For modeling of these values, a concept of fuzzy sets is being applied. Fuzzy sets, therefore, represents a generalization of classic sets, where the element belonging to specific set is determined with belonging degree that can take values from continual interval [0, 1].

Let X represent point (object) space. Fuzzy set A from X is determined by belonging function $\mu_A(x)$ that allocates an real number from interval [0, 1] to each point (object) from X based on function value $\mu_A(x)$ for x, that represents "degree of belonging" of a point (object) to set A. Therefore, fuzzy set can be represented by ordered pairs of elements

$$A = \{x, \mu_A(x) \mid x \in X\} \text{ , } \qquad \text{where}$$
$$\mu_A : \quad X \to [0,1]$$

Considering this definition it can be concluded that the disperse sets are generalization of common ("crisp") sets, whose belonging function can have only two values - {0, 1}.

Theory of disperse sets can be used for development of fuzzy-expert system that can be used for making decisions in areas where the precise solution forms are not present [4, 5].

Second approach in power transmitters gear pairs design uses a fuzzy-expert system (Fig. 4). It is a combination of an expert system for gear material choice and fuzzy logic in choice of teeth number of small gear. Fuzzy-expert system FUZZY_ZPS/ES is realized by using Fuzzy CLIPS shell [12].

Table 1. Recommended teeth numbers for small gear z_1

Gear material	Transmission ratio u			
	1…2	2…3	3…4	> 4
Hardened steel with flank hardness ≤ 230HB	32…60	29…55	25…50	22…45
Hardened steel with flank hardness ≥ 300HB	30…50	27…45	23…40	20…35
Cast iron	26…45	23…40	21…35	18…30
Nitrated steel	24…40	21…35	19…31	16…26
Carbonized steel	21…32	19…29	16…25	14…22

Lower bounds should be used for $n_1 < 1000\ min^{-1}$,
and upper for $n_1 > 3000\ min^{-1}$
$z_{1min} = 12$ – for the power transmitters
$z_{1min} = 7$ – for the motion transmitters

From the table 1, it can be concluded that variables: teeth number z_1 and rotation number n_1 are disperse numbers. Disperse numbers concept is closely connected to linguistic variables. Linguistic variable is determined by:

- linguistic variable name;
- set of variable linguistic values;
- disperse number domain that determines linguistic value for the variable;
- syntax rule for generating the linguistic values and
- semantics rule used to allocate the meaning to every linguistic variable.

Linguistic variable dispersion can be subjectively determined. Researches show that it is best to use subjective scale value with 5 to 7 points. Figures 5 and 6 represents belonging functions for linguistic variables z_1 and n_1.

Description linguistic variable z_1 in FuzzyCLIPS is given with:

```
(deftemplate z1_1
     21 32
(
(VM (21 0) (21 1) (22 0))
(M (PI 2 23))
(S (PI 2 26))
(V (PI 2 29))
(VV (30 0) (31 1) (32 1) (32 0))
))
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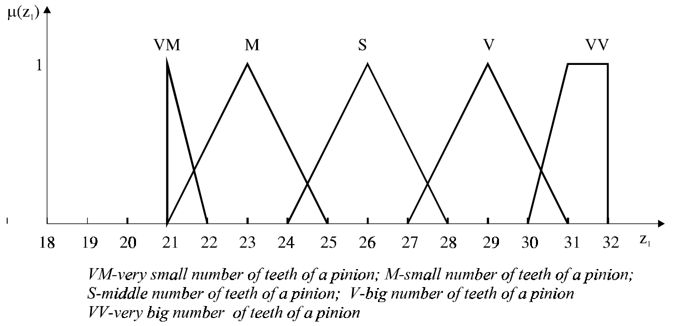

Fig. 5. Belonging function for the linguistic variable z_1

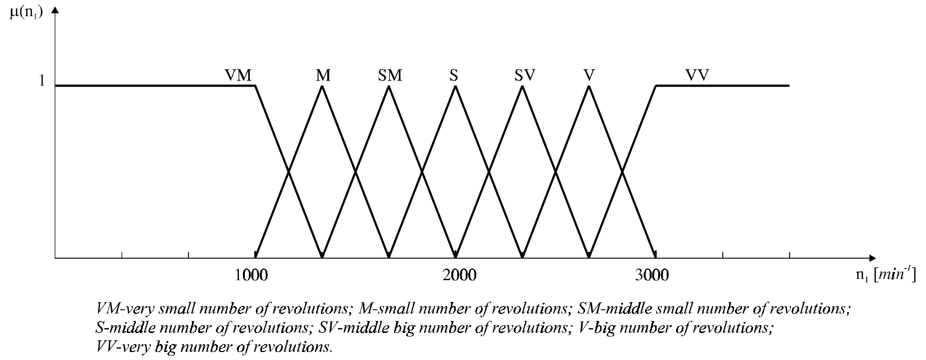

Fig. 6. Belonging function for the linguistic variable n_1

Expert systems are program systems that support expert way of thinking in solving the professional problems. Core of these systems is knowledge base, conclusion mechanism and operating memory. Depending on method of presenting the relevant knowledge, there are several types of expert systems. General technique for presenting knowledge is based on usage of: objects, production rules, semantic networks, frames and statement logic. In area of gear power transmitters design, the most of expert systems are based on usage of "IF-THEN" production rules. When production rules include the disperse variables, they are called dispersion rules ("fuzzy production rules"). Classic expert systems manipulate with structured knowledge in form of rules based on symbolic, while fuzzy expert systems translate structured knowledge into flexible numeric areas, that enables greater accommodation and easy modifications. One of the most important characteristics of fuzzy expert systems, that is expert systems based on usage of disperse rules is the ability of working in approximate domain, which is a human characteristic. Process of making decisions based on disperse rules, facts and their meaning in given context is called approximate reasoning.

Following example represents usage of conclusion rules in FuzzyCLIPS environment:

Process of generating appropriate solutions shows that disperse input values are transformed onto another disperse values. However, in the design process, all values must have discreet values. Choice of such values from the disperse set interval is made by defuzzyfication. In FuzzyCLIPS it is possible to choose MOM (Mean Of Maxima) algorithm or COG (Center Of Gravity) algorithm of defuzzyfication. This example uses the COG algorithm, which is most common. Concept of this method is that for the discreet output value, one of the values of belonging function of output disperse set is being chosen, so that the figure of disperse set is divided in two equal areas.

Architecture of fuzzy expert system FUZZY_ZPS/ES is given on Fig. 7.

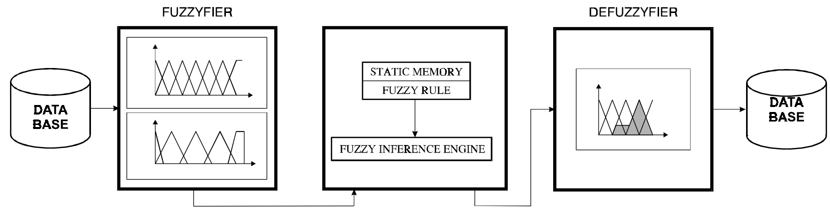

Fig. 7. Architecture of fuzzy expert system FUZZY_ZPS/ES

4.4. Gear power transmitter parameters definition by using the neural network

Man uses a complex "device" for adaptation – his brain. Average brain contains about 10^{11} neurons – cells connected in a very complex manner. Man and animal brain was a model for artificial neural network development. Therefore, neural network are attempt of computer simulation of biological intelligence. Neurons are basic elements of all neural networks, and they are used for data processing. Artificial neuron model (Fig. 8,b) is similar to some biological neurons (Fig. 8,a) that can be found in a man's brain [4]. However, single artificial neurons are far less complex than brain neurons, their number is significantly smaller and organization far simpler.

Biological neuron acquires outer signals from Dendrites. Cell body sums these signals. When the existing signal is strong enough, neuron "fires" the signal through axons and synapses to other neurons in chain.

Artificial neuron is simple element of processing, that executes simple mathematical function. Input neuron values are given with x_1, x_2, …, x_n, where n represents overall neuron input number. Every input value is being multiplied with coefficient w_j, $j=1,\dots n$, where j is the neuron ordinal in neural network.

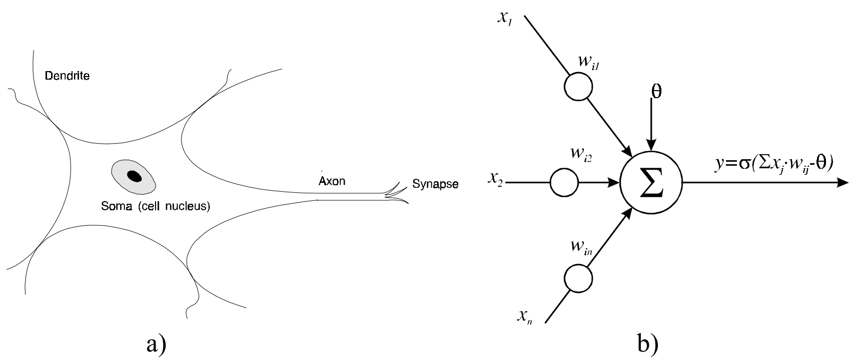

Fig. 8. Neurons: a) Biological neurons, b) Artificial neurons

Value p_i is obtained as a sum of these multiplied values:

$$p_i = \sum_{j=1}^{n} w_{ij} \cdot x_j \tag{1}$$

Further, this value is used as a input for non-linear function σ, that depends on parameter θ - activation level. This dependence is often given by difference of p_i and θ, which is used as an input in non-linear function σ. Result is output value for *i* - neuron:

$$y_i = \sigma(p_i - \theta) = \sigma\left(\sum_{j=1}^{n} w_{ij} \cdot x_j - \theta\right) \tag{2}$$

Artificial neural networks (neural networks) have parallel distributed architecture with large number of nodes and connections. Each connection between two nodes has it's own significant factor (Fig. 9). Multi-Layer-Netze neural network is the most commonly used in practice. Neural network topology is related to it's structure and connectivity.

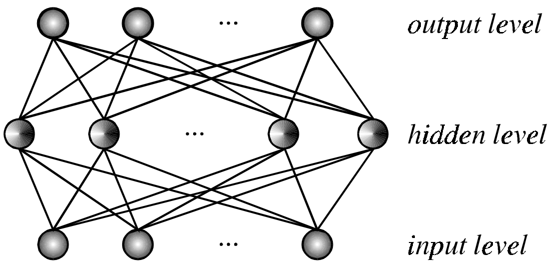

Fig. 9. Neural network

Network structure is determined with number of levels and number of nodes on each level. There are three levels:

1. Input level, with neurons that represent network input units and they adapts the sample for network processing.
2. Hidden level, with nodes that represent hidden network units and they ensure network non-linearity.
3. Output level, with output neurons, that code possible values and join them in sample after analyzing it.

Opposite to it's biological counterpart, artificial neural network is not capable to react on unknown problem. Neural network must be "trained". Network training is based on some number of known relations between input and output values. Neural network is completely trained when it's response on input sample is in expectable error tolerances of expected output.

For determination of power transmitters parameters, neural network with "Back Propagation" algorithm (backward network) is being used. Networks based on this algorithm are known by learning surveillance and multiple level structure. Backward error tracking means that error correction signal is carried backwards through network during learning process. On it's way, significant coefficients are being changed, so the error is reduced in next pass.

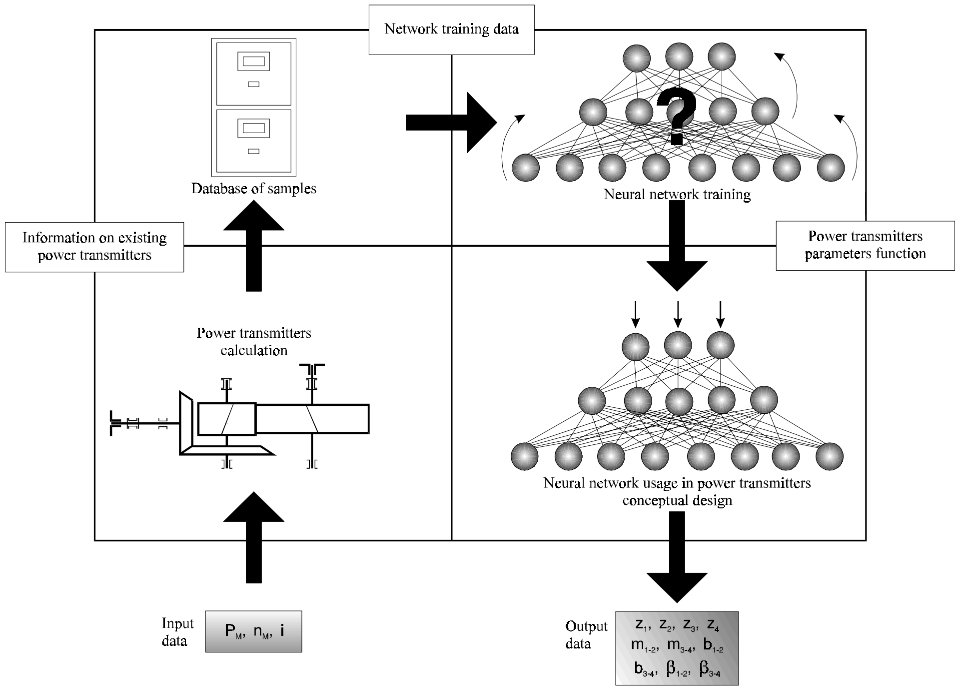

Fig. 10. Neural network application

Bevel-Spur gear is being used for neural network research in gear power transmitters conceptual design. Input values are: needed transmission ratio i_Σ, nominal power P_M, and input rotation number n_M. Output parameters are: standard module $m_{1\text{-}2}$ and $m_{3\text{-}4}$, number of teeth z_1, z_2, z_3, z_4, inclination angles $\beta_{1\text{-}2}$ and $\beta_{3\text{-}4}$, common tooth width $b_{1\text{-}2}$ and $b_{3\text{-}4}$. Figure 10 shows neural network preparing for gear power transmitters parameters determination and this must be done in order to successfully train network.

Database of samples must be formed from existing gear transmitters, so that network training can be accomplished.

Data flow in neural cycle of data determination is given on Fig. 11. Neural networks have two data flow types: data flow used for network training and data flow used for network usage.

Normally, this simplifies network usage. Neural network shell EASY NN 4.0, used for neural network development, enables easy database of samples forming. Output data are directed to datafile, so that neural network can be implemented in program system for gear power transmitters design. Neural network topology is presented on Fig. 12. It has three hidden levels with 85 neurons. Over a 1000 existing samples of bevel-spur gear transmitters are used for network training. Network training is carried out for transmitters with transmission ratio from 6,5 to 20 and nominal power of 11-690 kW.

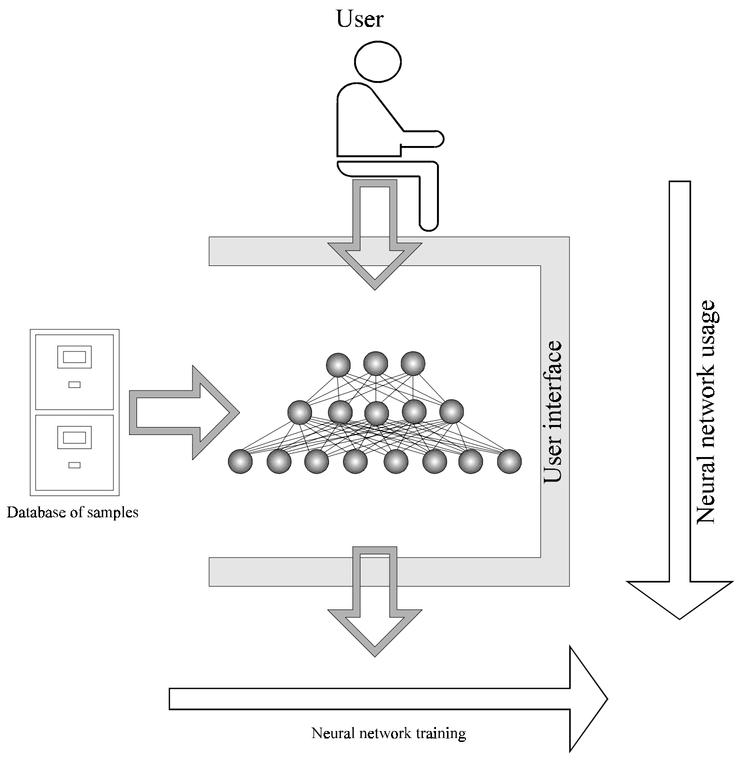

Fig. 11. Data flow in neural cycles of gear transmitters parameters determination

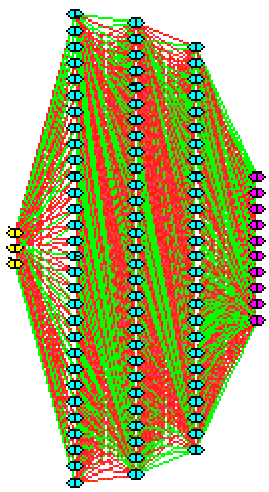

Fig. 12. Neural network topology

5. Conclusion

Considering previously said, it can be concluded that:

1. Considering the gear power transmitters reliability, costs, shorter delivery terms, etc., primer tendency in development of the design process is in automation of the gear power transmitters design process.
2. For the automation of the gear power transmitters design process, an integration of CAD modules and modules based on artificial intelligence has been made. It is enabled by knowledge server which connects and integrates conventional and expert modules and fuzzy-expert modules in concurrent engineering environment.
3. Modules based on artificial intelligence are consisted of several expert systems, fuzzy expert systems and neural network, helps constructor in making decisions related to gear parameter choice.
4. System has an open structure which enables improvements and further revisions of knowledge bases.

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PRIMENA METODA VEŠTAČKE INTELIGENCIJE U KONCIPIRANJU ZUPČASTIH PRENOSNIKA SNAGE

Dragan Milčić, Vojislav Miltenović

U ovom radu su prikazane metode veštačke inteligencije i njihovo mesto u razvoju inteligentnog integrisanog sistema za konstruisanje zupčastih prenosnika snage. Sistem je baziran na znanju. Razvoj ekspertnih odnosno fazi ekspertnih sistema je izvršen u CLIPS odnosno Fuzzy CLIPS programskom okruženju. Ovaj sistem podržava primenu svih pravila objektno orijentisanog programiranja, a omogućava i integraciju algoritamskog (tj. procedura i metoda) i nealgoritamskog načina programiranja (produkciona pravila).