UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
ADEKO - ASSOCIATION FOR DESIGN, ELEMENTS AND CONSTRUCTIONS

MACHINE DESIGN

THE EDITOR OF THE MONOGRAPH:
PROF. PHD. SINIŠA KUZMANOVIĆ

ON THE OCCASION OF THE 47TH ANNIVERSARY
OF THE FACULTY OF TECHNICAL SCIENCES

1960 - 2007

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MACHINE DESIGN

DECISIONS MAKING IN DESIGN PROCESS – EXAMPLES OF ARTIFICIAL INTELLIGENCE APPLICATION

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Boban ANĐELKOVIĆ
Miroslav MIJAJLOVIĆ

Abstract: *Main goal of design process is finding optimal solutions for technical systems. Various decisions have to be made during design process in order to choose appropriate parameters, material and other data. Decisions made in design process connect other operations and activities in the structure of process and enable its continuum. Automatism of the design process can be achieved by application of the artificial intelligence methods. Faculty of Mechanical Engineering in Niš is working on development of intelligent integrated system for design of power transmitters. During this work, various expert and fuzzy expert systems, trained neural networks have been developed and this paper will partly describe them.*

Key words: *Decisions, Artificial Intelligence Methods, Expert System, Fuzzy Logics, Neural Network*

1. INTRODUCTION

Market gives all the time more com lex re uirements about roductivity, uality and s eed of new roduct s develo ment. Intensive economical rogress gives increase of roject-constructional tasks with greater com licity. Conventional, “traditional” design, based on em iric and intuitional knowledge, does not allow successful follow u of develo ment in other areas of human work. Com any hat wants to be concurrent on global market must use Com uter Aided CA technologies during rocess of roduct design. Most used technologies for automaton of roduct design are Com uter Aided Design/Com uter Aided Manufacturing/Com uter Aided Engineering CAD/CAM/CAE and they a ear as mechanisms of backu for rocesses of modelling, engineering analysis and develo ment of roduct s develo ment documentation. Goals reached by usage of CA technologies in area of gear design are multi le and can be illustrated as follows:

- Time of the design rocess has shortened for more then one to hundred times com ared to the manual design de ending on object of design and level of automatism of design rocess ,
- Price of the design rocess is lower for 10 to 90 com aring to the manual design. A lication of the CA technologies does not re uest creation of ex ensive rototy es in some cases.
- Quality of design results is much higher concerning about the fact that a lication of Informational Technologies IT largely eliminates subjective sources of errors or mistakes.

During last decades various tolls and techni ues of Artificial Intelligence AI have been develo ed. A lication of the AI technologies gives new oint to work of designer during design rocess. Decision making in design rocess can be ualitatively im roved with a lication of AI it is ossible to automate design rocess and this means more ualitative results, more efficient roblem solving, saves resources and time and Knowledge Engineering KE find its lace in design rocess. Areas of a lication are various: AI in Design AID , Knowledge Based Design System KBDS , Intelligent CAD IntCAD or ICAD or Knowledge Integrated CAD KIC .

2. DESIGN PROCESS AND STRUCTURE OF DECISIONS IN DESIGN PROCESS OF TECHNICAL SYSTEMS

Design is mostly creative rocess, based on a science and ex erience ran thru ste -by-ste hases. It starts from an idea and at the end finishes as design and technological documentation for manufacture of technical system. This is a rocess which transforms idea into the roject, which is, furthermore, basis for the manufacture. Goal of the design rocess is to find o timal solutions for the technical roblems. O timal solutions consider ade uate manufacture, ex loitation and recycling of the concurrent technical system.

Design rocess follows recisely defined ste s and hases Figure 1 .

In order to find an o timal solution, it is im ortant to define, at the very beginning of the design rocess, very recisely, design task. If it s ossible, it should be com letely analysed. As a result of this hase comes check list of re uests that technical system has to fulfil.

Second hase of the rocess is a conce t of an idea-solution. Formulating the structure of functions, global function of the system is decom osed to artial and elementary functions. These functions are mostly concerning about energy transformation forces, moments, movement , trans ortation of energy etc. Definition of elementary functions starts from the mathematical descri tion of the transformation. Transformation can be achieved based on mechanical, hydro, neumatic, electrical, magnetic, thermal, chemical or other rinci le. Most commonly used rinci le is mechanical, which is based on the basic hysical laws. Combination of ade uate rinci le solutions gives grater number of conce tual variants. Grading and com arison of variants gives o timal variant solutions.

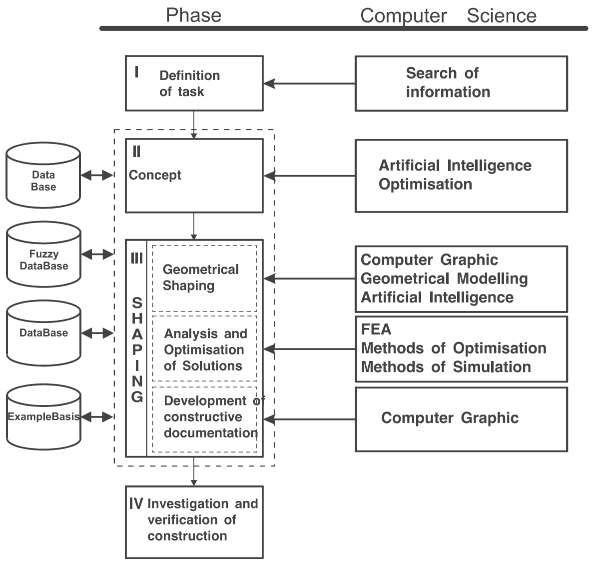

Figure 1: Design Process and Applied Computer Methods

As illustration, Figure 2 shows sim lified structure of basic calculation o erations and decisions making rocess in rocess of design of gear ower transmitter. Com lex connections and mutual conditionality of decisions and results of calculations, shown in this sim lified figure shows com lexity of this structure.

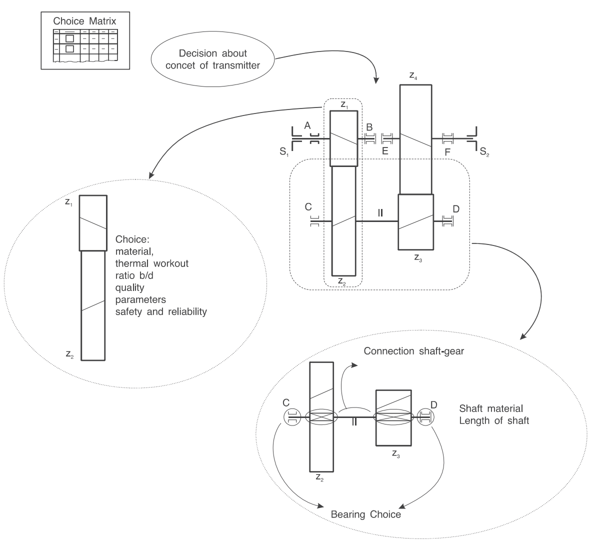

Figure 2: Structure of Decisions in Design Process - Power Transmitter

Third hase is hase of sha ing which defines executors of rinci al solutions. First art of this hase develo ment of the construction includes reliminary calculations, which firstly defines global dimensions and later sha e of the resumed art. Material and manufacturing rocess are determined and basic dimensions are chosen. This hase, beside creativity, re uires several iteration ste s, what gives higher level of defining designing solution. This is very com licated hase since re uires combination of calculation and sha ing and very often re etition of same ste s thru ade uate changes.

Second art of the sha ing hase involves work out of drawings and develo ment of technical, manufacturing documentation. This means, develo ment of assembly drawings, based on drawings, and o timisation of arts sha es, definition of uality of worked surfaces, re uirements about recision etc.

Fourth hase includes develo ment of documentation for arts of the system, finishes technical documentation and checks correctness of data on the drawings.

Every of design hases is realised in com lex structure of o eration and activities. Phases are realised thru ade uate o erations like forming of function structures, choice of dimensions, sha e modelling and stress analysis are.

O erations and activities which show arameter, data, material and other facts choosing in design rocess are called decisions. They connect other o erations and activities in the structure and enable continuing of the rocess. During thoughtful rocess, decisions are made unconscientiously, by inertia, ex erience, logics etc. In models of design rocess, decisions are result of cause-conse uential mutuality and restrictions. This gives several a roaches for this: algorithmic, rinci le of already known variants, o timisation rinci le, non-algorithmic rinci les ex ert systems, fuzzy ex ert systems , fuzzy rinci les, rinci le of neural networks etc.

3. METHODS OF ARTIFICIAL INTELLIGENCE

3.1. Expert System

Ex ert systems are knowledge based systems they use human knowledge, ex erience and behaviour during roblem solving. In short, they use human intelligence. Ex ert systems are results of work in area of AI research. These systems include knowledge of one ore more ex erts and use it for roblem solving. Ex ert system has com etences of ex ert for roblem solving, also.

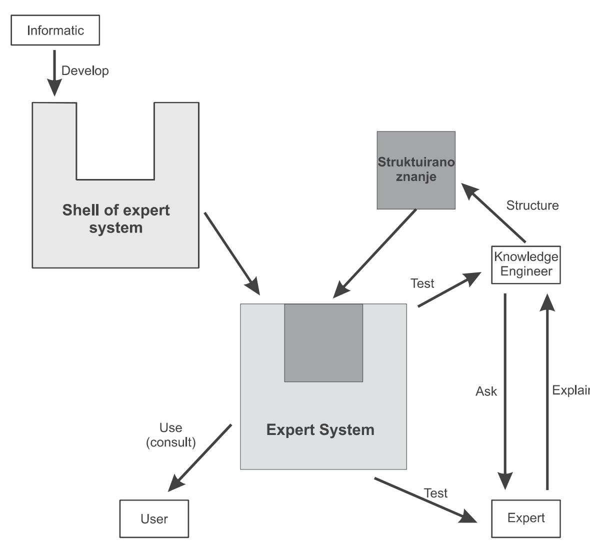

Figure 3 Development of the Expert System

Com etence considers knowledge and ossibilities for solving some of the roblems in the area of ex ertise. Knowledge can be divided to the: basic knowledge gathered from study books, scientific books etc. and individual – ractical knowledge. Practical knowledge is gathered thru the work, during long time eriod. Most of this knowledge considers ex ert rules, which can be titled as heuristics, necessary for roblem solving. Heuristics has large amount of details, which are not available in the books, but re resent s bond between theoretical and ractical knowledge. Mixture of the knowledge and mechanism of deduction heuristic deduction of humans re resents basic ower of ex ert systems.

Ex ert systems are not universal. Their ability for roblem solving is limited to s ecific area. They are not all- owerful: even thou they can give better results then ex ert what is not so rare they do not give absolutely best solutions. Ex ert systems are used in large number of scientific areas, but, most they are mostly used in: diagnostics, rediction, lanning, maintenance, design, automatics etc.

Basic difference between ex ert system and conventional software is in se aration of the knowledge base from work out of data and inference modules Figure 3 . Conventional software has both com onents im lemented into the algorithm, unbreakably bonded to each other.

Some advantages of ex ert systems, used in design rocess and decision making rocess, are:

- Mechanism of knowledge based systems creates note about deduction during design rocess,
- Mechanism of deduction enables ex lanations,
- Designer can be focused only on knowledge base,
- Knowledge base can be develo ed in object oriented form, what gives all advantages of database design to the designer,
- Knowledge base is inde endent from inference mechanism,
- In contradiction to the rocedural languages C, FORTRAN etc., knowledge base is not rocedural and this makes irrelevant rules inscri tion and running.
- Knowledge base can be develo ed incrementally.

3.2. Fuzzy Logic

Basic idea of fuzzy logic is based on human ability to, in s ite of various non- recise information can uni uely and correctly decide. Theory of fuzzy assemblage is generalisation of the classic assemblage theory based on the generalisation of term a urtenance. One of basic characteristics of the classic assemblage theory is o osability of a urtenance or not to the only one assembly at the same time. On a contrary, theory of fuzzy assemblages dismounts the rule of exclusion of third and allows belonging or no belonging of elements to the fuzzy assemblage. This is set by degree of belonging to every element of assembly and takes values from interval 0,1 .

Fuzzy logic is also, generalisation of Bulls algebra. Three most im ortant areas of a lication of fuzzy logic are fuzzy controlling, fuzzy ex ert systems and fuzzy analysis. When roduction rules consider fuzzy variables they are called “fuzzy roduction rules”. Classic ex ert systems mani ulate with structured knowledge in sha e of rules on symbolic bases and fuzzy ex ert systems translate structured knowledge to flexible numerical boundaries. This gives larger ada tation and sim ler modifications.

One of the most im ortant characteristic of fuzzy ex ert systems, ex ert systems based on a lication of fuzzy rules is ability of bonding in a roximately human domain. Process of deduction, based on conclusions of fuzzy rules, facts and its meanings in the context is called “a roximate deduction”.

Functions of in ut s belonging are mostly triangle or tra ezoid. Very often they are marked by a endixes for linguistic values:

- Λ for triangle function delta function
- Π for tra ezoid function
- Z for left o en tra ezoid function
- S for fight o en tra ezoid function

Discretisation of s ace, where is defined linguistic variable, can be done by subjective graduation. Psycho-linguistic ex eriments have shown that for this ur ose are mostly used scales of subjective grades 5 or 7 dots Figure 4 .

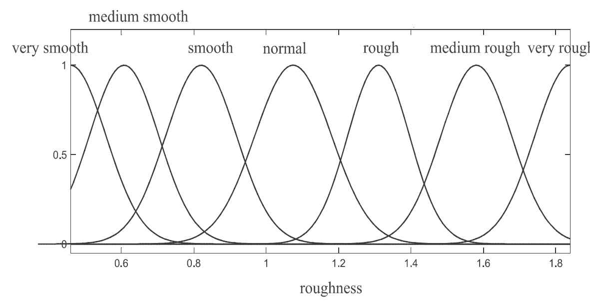

Figure 4 Linguistic Variable of Roughness Defined with 7 Dots

Fuzzyfication is tightly connected to im recision of human s eech. This is subjective valuing that transforms a numeric value to subjective value and can be described as transformation from the in ut s ace in the fuzzy assemblages in a ro riate domains. Fuzzyfication has very im ortant role in work with im recise information, either subjective or objective. Procedure which converts in ut values to ade uate fuzzy values is “fuzzyfication”. Basic architecture of one fuzzy system is shown in Figure 5 .

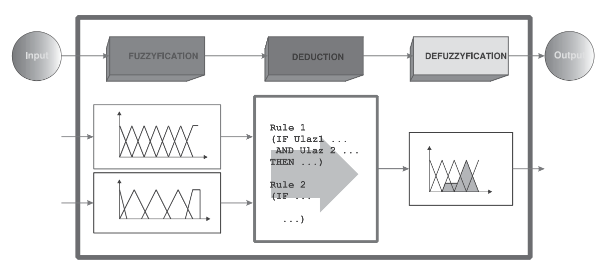

Figure 5 Architecture of Fuzzy System

After finished fuzzyfication, based on an in ut defined as fuzzy variables during next hase is im ortant to deduce according to the a ro riate actions. This can be achieved by a lication of roduction rules, as it is shown in revious, by IF-THEN descri tion.

Classic ex ert systems mani ulate with structured knowledge in sha e of rules on symbolic bases while fuzzy ex ert systems translate structured knowledge to flexible numerical boundaries what gives ada tive and sim le modifications. Most im ortant characteristic of fuzzy ex ert systems is ossibility of a roximate matching, which is an ability of human beings. Process of ade uate deduction based on fuzzy rules, facts and their meaning is fuzzy inferencing.

Linguistic models re resent fuzzy bases of knowledge, one or more of them de ending on com lexity of system they describe. Deduction mechanism uses them and generates a ro riate conclusions and solutions for the roblem. If it is, during that rocedure, used generalised modus onens rule of getting conclusions, rocess is called data guided fuzzy deductions. This is mostly used for greatest number of ex ert systems.

3.3. Neural Networks

Brain of animals and human beings were an analogy from which artificial neuron was built. This means that neural networks are an attem t to simulate biological intelligence on a com uter. Basic of all neural networks make neurons which work on gathered information. Artificial neural networks have arallel distributional architecture with numerous nods and relations. Every relation between two nods is added weight. Structure of one neural network is considered as known if it s known:

- characteristics of network: to ology of network, ty e of relations, level of relations and ratio of weights,
- characteristics of neurons: activation extent and functions of activation,
- dynamics of the system: scheme of weight initialization, formula for calculations of activations and rules of learning.

To ology of neural network Figure 6 concerns about its structure and connections of the network. Structure is determined with number of levels and number of nods er level. There are three levels:

- In ut level – neurons are in uts for network,
- Hidden level – neurons re resent hidden units of network and deliver nonlinearity of network,
- Out ut level – out ut neurons code ossible variants and join them to the exam le after consideration: every out ut unit re resents class of object.

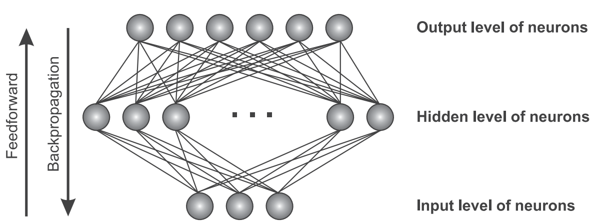

Figure 6 Topology of Neural Network

4. APPLICATION OF ARTIFICIAL INTELLIGENCE METHODS IN PROCESS OF GEAR POWER TRANSMITTERS DESIGN

Based on activities that have to be done during rocess of ower transmitters design, Faculty of Mechanical Engineering in Nis, long time eriod is working on intelligent integrated system for design of gear and worm gear ower transmitters – ZPS.

ZPS is very com lex and heterogenic, develo ed on a modular basis system. Primary aim of ZPS is to enable integrated a lication of various different rogram modules and systems develo ed by different authors or com anies which are involved in automation of activities during gear ower transmitter s design. That is the reason why software latform of develo ed system Figure 7 maximally uses all a licable standards in area of data exchange, communication and com uter science.

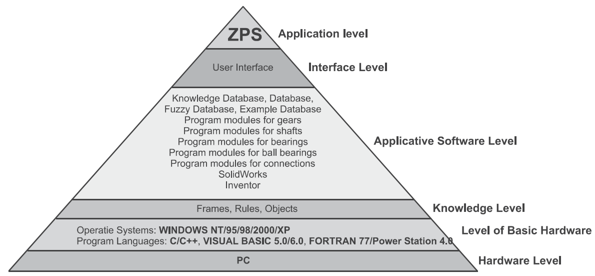

Figure 7: Software Platform of Program System ZPS - for Design of Power Gear Transmitters

Integrated rogram ZPS Figure 4 consists of three arts:

1. Program modules for calculation of elements for ower transmission,
2. Program modules for calculation of elements for rotation movement,
3. Program modules for calculation of mechanical connections.

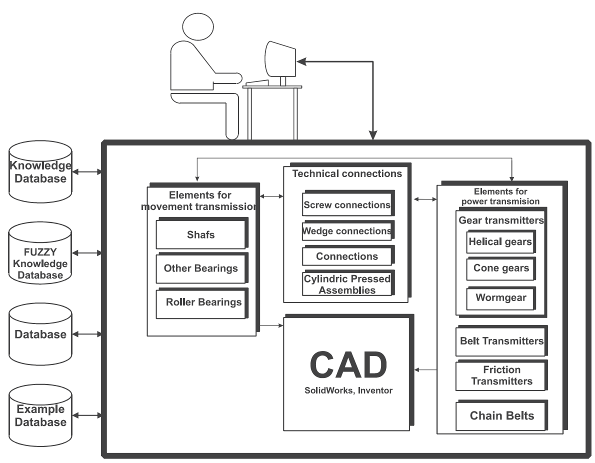

Figure 8: Architecture of Intelligent Integrated System for Gear Power Transmitters Design

All rogram modules are develo ed in FORTRAN and Visual Basic and develo ment of ex ert and fuzzy ex ert systems is used CLIPS or FuzzyCLIPS. Technical documentation is develo ed in SolidWorks and Autodesk Inventor.

Model of ower transmitter is internal com uter resentation of all characteristics necessary for its full defining. Model of transmitter can be realised as numerical model and as symbolic model.

Numerical model is shown with structure of data and mostly is realised in sha e of matrix end vector mutually connected over ointers.

Symbolic model re resents larger and more understandable model com aring to the numerical. This model is acce ted and all characteristics, relevant for the descri tion, are shown as a ro riate descri tive symbols, similar or identical to the real characteristics. These symbols are grou ed in assemblages, and they describe s ecific characteristics – re resent one object.

4.1. Expert Systems in Intelligent Integrated System for Power Transmitter

Based on the defined in uts: in ut ower P, in ut number of rotations n_{ul}, out ut number of rotations n_{izl}, or transmitters ratio i, osition of in ut/out ut shaft etc., from the menu of ossible conce ts in ex ert system , one or more then one variants are chosen Figure 9 .
If number of acce table conce ts is greater then one, designer has right to decide and choose one of them. Choice of arameters is in direct connection with decision making rocess about the conce t.
In order to make ade uate choice of arameters, designer has to decom ose transmitter and analyse every art of the system.

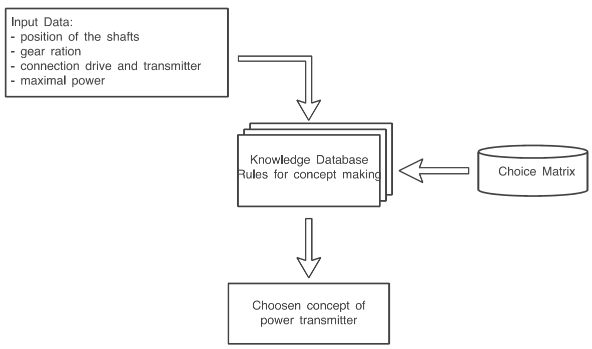

Figure 9: Choice of Acceptable Concept - Application of Expert System

After choosing conce t of ower transmitter, ower transmitter s gear ratio has to be s lit. This is very im ortant decision that constructor has to make during design rocess. Almost all dimensions of gear air de end of this ratio and dimensions of transmitter, also. Gear ratio influences the stress carrying ca acity of gears. Pinion is es ecially loaded in case of bigger gear ratios and erimeter velocities. Numerous recommendations for gear ratio choosing can be found in literature. Choice of number of gear ower transmitters shifting and gear ratios is done based on the recommendations for minimal mass and volume of ower gear transmitter.
These recommendations are for helical, cone and helical-cone one, two or three ste ower gear transmitters.
All of these recommendations are used in the ex ert system for definition of the mentioned arameters. Distribution of the gear ratio in case of worm gear transmitters and helical-worm gear transmitters is achieved by catalogues of famous manufacturers of these transmitters FLENDER THYSSEN .
For calculations of gears, several crucial decisions have to be done: concerning about material of gears, thermal and chemical work out, ratio of width and diameter b/d, uality of manufacture, safety and reliability in work, number of teeth, module etc. these decisions are bonded to each other and tightly connected to the decisions concerning about shafts and bearings. For exam le, shaft s length is determined by widths of gears, bearings and other arts.
Stiffness of shaft and distribution of loads in gear contact are correlated. Ty e of bearings de ends of stiffness of shafts. This makes decisions giving order very im ortant.

From this, all com licity of the design rocess can be seen. ZPS system conce ts ower gear transmitter in several ways. By first, conce t is done by ZPS1 module, which is connected to the ZPS MAT/ES ex ert system. Goal of the ex ert system ZPS MAT.ES reflects in choice of gears materials.
For this decision, has to be known that gears can be manufactured from several various materials: constructive steel, cast iron etc. Non steel materials are a lied, also: titanium, aluminium, some ty es of lastics.
Factor influencing the choice of materials are characteristics of strength and uality of material, rice, manufacturing rocess and finishing thermal and mechanical work out, number of roducts etc.
Already mentioned facts have to be considered during material choosing. Because this ZPS MAT/ES was develo ed: to hel designer to get ade uate decision, which is very im ortant for design rocess of gears. Ex ert system gives recommendations about uality of manufacture and tolerances of gears, also.
For defined material, ex ert system ZPS MAT/ES gives boundaries for ratio width/diameter b/d for inion. Data about material, thermal work out, ratio b/d of gear air are saved in databases faziz1.dat, z sulaz.dat and ret r.dat. They are in ut for further calculations and connection to the ZPS1 module and fuzzy ex ert system Figure 10 .
After first calculation, ZPS1 for reviously defined arameters gear ratio i, material, ratio b/d, uality, defined tools for manufacture etc. gives designer several variants and he has to choose one.
Chosen variant is being written in the database and module ZPS2 uses it, in the next ste , to finalise reliminary calculation checks geometry and strength of chosen gear air .

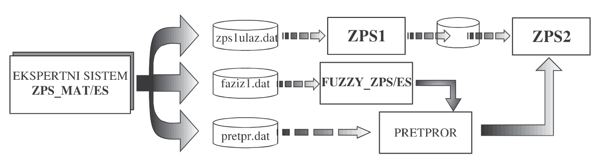

Figure 10: Knowledge Base Modules for Calculations of Power Transmitters – Connections, Calculations of Strength

After this, final conce t of gear air is evaluated over ZPS MAT/ES, fuzzy ex ert system FUZZY ZPS/ES and rogram module for revious calculations PRETPROR. Number of inion s teeth z_1 is determined by fuzzy logics. Since there is a great number of recommendations in literature, choice is delicate and very im ortant art of calculation. For exam le, for same geometry, change of module gives some other number of teeth and at the same time strength changes, safety of gear air and rice, also. Increase of number of teeth decreases carrying strength concerning base of teeth, it remains almost the same for the side of teeth and working safety increases.
For determination of teeth number, influence give gear ratio and round number, meaning, diametric velocity. Choice of teeth number z_1 is in function of diametric velocity:

$z_1 \approx 20 ... 25$ for velocity v_t 5 m/s
$z_1 \approx 18 ... 22$ for velocity v_t 1 ... 5 m/s
$z_1 \approx 15 ... 20$ for velocity v_t 1 m/s.

According to the 4 , choice of teeth number z_1 in relation of the gear ratio i, material and finishing thermal work out is given in Table 1.

Table 1: Recommendations for teeth number of pinion z_1

Material of Gears	Gear ratio *i*			
	1...2	2...3	3...4	4
Im roved steel with hardened sides 230 HB	32...60	29...55	25...50	22...45
Im roved steel with hardened sides 300 HB	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
Carbonic steel	21...32	19...29	16...25	14...22
Lower values for za n_1 1000 min^{-1}, u er for n_1 3000 min^{-1} z_{1min} 12 – for transmission of ower z_2 23 z_{1min} 7 – for transmission of movement				

- Mentioned recommendations give variables: number of teeth z_1, round fre uency n_1 and erimeter velocity v_t and resent fuzzy numbers.

In exam le of determination of teeth number fuzzy ex ert system has been used. Since fuzzy logic is im lemented to the ex ert shell CLIPS, and shell Fuzzy CLIPS is develo ed, it was not so difficult to make connection: fuzzy ex ert system FUZZY ZPS/ES and ex ert system ZPS MAT/ES.

This connection of ZPS MAT/ES and FUZZY ZPS/ES with rogram for reliminary calculation of the gears and for further calculation of geometry and strength, by module ZPS2 is given in Figure 11.

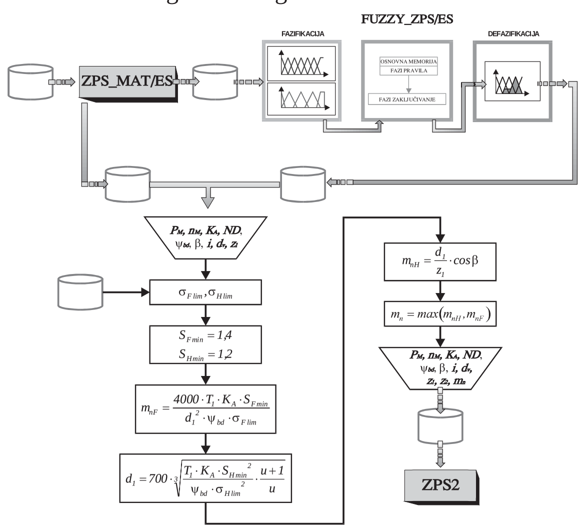

Figure 11: Connection of expert, fuzzy expert and program module for preliminary calculation of gears

Researches about a lication of neural network to design of gear ower transmitter were done.

Based on existing transmitters GOSA-Eickhoff , base of exam les for neural network training has been made. Neural network is a lied to the conce t of two-ste cone-helical ower gear ower transmitters. This exam le is shown Figure 12.

In ut arameters are necessary gear ratio *i*, nominal ower of transmitter P_M and rotating fre uency of in ut shaft n_M. Out ut arameters are standard gear modules m_{et1-2} i m_{n3-4}, numbers of teeth z_1, z_2, z_3, z_4, declination angles of gear teeth β_{1-2} i β_{3-4}, width of gears b_{1-2} i b_{3-4}. Number of in ut /out ut neurons is defined by in ut/out ut arameters of transmitter. There is a uestion about hidden neurons and hidden layers with neurons. First neural shell – Neural Planner, which has been used for ex eriments, had only one hidden layer allowed. Since this network gave no acce table results, new neural shell EasyNN, with three hidden layers was used. Acce ted to ology of neural network was with three hidden layers and 86 hidden neurons.

For network training was used more then 1000 existing exam les for cone-helical gear transmitters. Material of all gears was steel EN 16MnCr5 Č4320 . Network training was on transmitters with gear ratio from 6.5 to 20 and ower range of 11 to 690 kW.

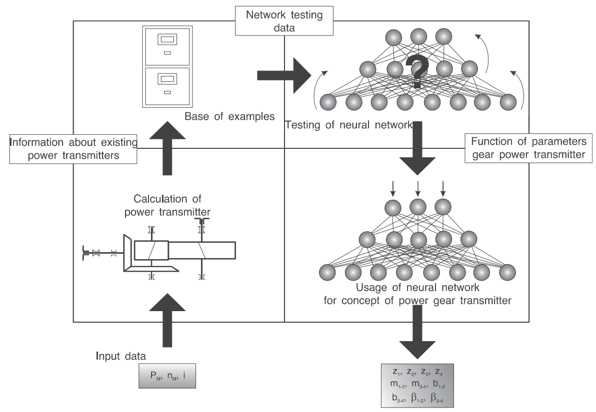

Figure 12: Data flow in neural cycles

For determination of transmitter s arameters is used neural network with algorithm of learning Back Pro agation – back a roaching network. Networks with this algorithm are based on multilevel structure and diagnosis of learning. Guidance of error backwards means that correction signal is being guided to the network again for correction of signal. All involved coefficients are being changed again and error is getting smaller. A criterion for neural network training is average error of 0.05 5 .

5. NEURAL - FUZZY SYSTEM FOR DETERMINATION OF FRICTION COEFFICIENT OF PRESSED ASSMEBLIES

Carrying strength of ressed assembly is determined by friction force that o oses to movement – disassembly of elements under loads. For calculations of carrying strength F_μ for ressed assembly - diameter *d*, length *L*, friction coefficient μ, used relation is:

$$F_\mu = \mu F_N = \mu p \pi d L \qquad 1$$

Realistic carrying strength can be determined only during ex eriment by loading assembly until elements disassembly by force. This value is far different from calculated values. Difference exists since it is hard to determine real values of friction coefficients, realistic values of folding and contact ressure.

Mathematical model, resently used for calculations, is develo ed with various assum tions and sim lifications. Real model is different because the no homogeneity of materials, internal stresses differences from ideal sha e, differences between contact ressure and calculated, distribution of ressure on material and erimeter of contact.

Static friction coefficient is very com lex value, de endable from multi le arameters: existence or not of lubrication fluid between ressed elements, value of contour ressure, value of folds, mechanical characteristics of materials, roughness of surfaces, hardness of surfaces, s eed of montage.

5.1. Friction Coefficient

Value of friction coefficient is determined ex erimentally by measuring the force of ressing during montage, force of disassembly and force of sliding. This is very un ractical method since assembly has to be destroyed in order to get results.

During design hase of ressed assemblies, for carrying ca acity calculations, values of friction coefficients are taken from recommendations, manuals and standards. These values are determined according to the ty e of material, connection method and lubrication during connection rocess. Value of friction coefficient varies from 0.04 to 0.6 and in some cases u to 0.7.

On contact of internal and external elements, when elements do not have the same surface hardens, harder element enetrates into the surface of softer element. During that rocess deformations of the harder element are smaller then deformations of the softer. For calculations and analysis of surface roughness, harder element is considered as measurable. Result of ex eriments show that harder elements have greater friction coefficient.

Theoretical researches show that hardening of softer element decreases value of molecular μ_m and deformational com onent μ_d of friction coefficient 8,9

$$\mu = \mu_m + \mu_d \quad (2)$$

Ex erimental result gives conclusion that increase of difference between harnesses of elements increases static friction coefficient. This is true in cases when analysed elements are worked on mills. Friction coefficient decreases with increase of hardness difference, for elements with smaller roughness.

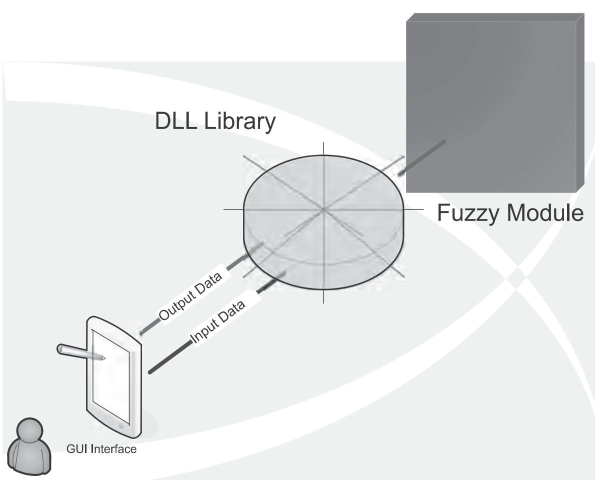

Figure 13: Organization of program interface and fuzzy inference system

5.2. Determination of Friction Coefficient Values by Usage of Hybrid Neural - Fuzzy Inference Systems

Based on ast analysis and ex erimental data, gathered after disassembling ressed elements various materials, carrying strengths etc. , hybrid neural - fuzzy inference system was built. Practical usage of this system for determination of friction coefficients is thru gra hical user interface GUI and a lication Figure 13 able to:

- Use formed neural - fuzzy inference system without extra rogram,
- Enable modularity of whole system,
- Enable sim le extension, ex and and change of inference system, without change of rogram code,
- Enable other similar rograms to use the same neural - fuzzy inference system and make system universal,
- Programmer has unified a roach to fuzzy system s files over dynamic libraries dll

Programming is, ractically, writing a GUI for communication of user and neural - fuzzy inference system. Exam le of interface is shown in Figure 14 . Com lexity of interface de ends of com lexity if the roblem.

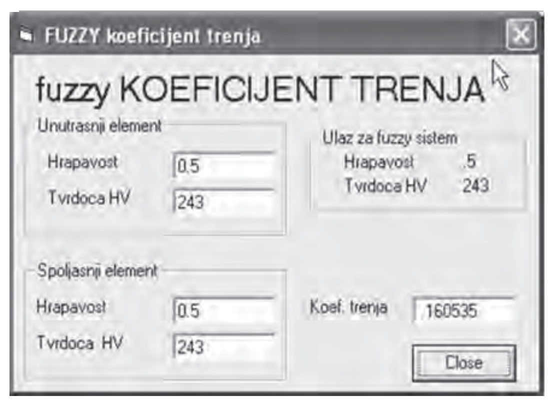

Figure 14: Application for friction coefficient values determination

5.3. Structure of the Program

Structure of the rogram is uite sim le. Sim licity is a follow u of the fact that is necessary to in ut only values of hardness and neural - fuzzy system does all the calculations and deduction. Basic algorithm is shown in Figure 15 .

Decrease of in ut arameters, based on scientific facts and ex ert knowledge is done in the rogramme Figure 15 – Aggregation of the in ut . Result of this action is shown in the rogram itself, since can be significant for similar analysis and further ex eriments.

Then follows exchange of significant arameters with neural - fuzzy system Figure 15 – transmission of arameters FIS and rece tion of results and resentation of results.

Modularity of the rogram gives flexibility and eases maintenance and ex ands.

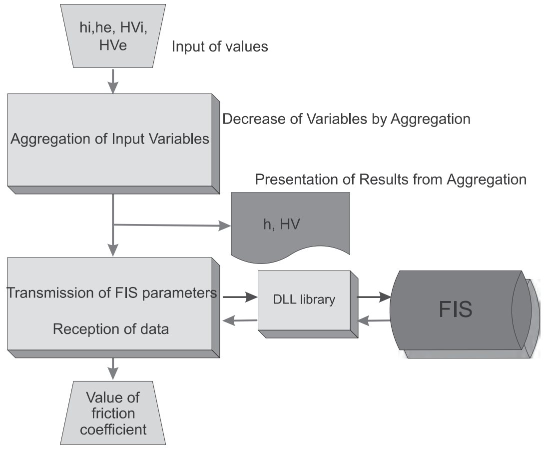

Figure 15: Block diagram of realized program application

6. CONCLUSIONS

Presented material concludes following:

- Systems for design of gear and worm gear ower transmitters ossesses modularity, integration, interactivity, intelligence, o enness, it is concurrent and effective
- ZPS system shortness time for design,
- A lication of the ex ert systems and fuzzy ex ert systems delivers o timal constructions, since time for conce t is maximally literature based and uses recommendations of famous manufacturers,
- Usage of neural network on exam le of two ste transmitter showed reasons for a lication of the system, since all arameters satisfy conce t,
- Fuzzy logics is effective and sim le method to use, built on ex erience and ex erimental results much more often then on mathematical models, linguistic formulation of some terms is much easier,
- Mass roduction costs decrease when use fuzzy systems,
- In theory, many technical roblems can be solved by forming a ro riate mechanical models differential e uations . In ractise, com lexity of this a roach and circumstances of realistic working lace give various difficulties for this method.
- Fuzzy logic forms fuzzy intelligent inference system with only few rules. Extra rules only hel the system to ada t to more realistic roblem and ex erimental data.
- Classic ex ert systems re uire only one rule for only one relation. Fuzzy systems do not need them. Fuzzy If-Then rules combine values on a similar way the humans do,
- Fuzzy logic is nonlinear and multi- arametric. That is the reason why com lex technical roblems successfully overcome.

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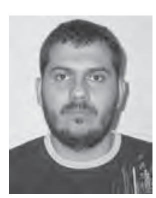

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