Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/130512

Expert System for Automatic Configuration of Kinematic Chain of Multi-Spindle Drilling Boxes

Ayoub Fajraoui[1,*] *and Mehdi Kamel*[2]

[1] URMSSDT, Superior School of Sciences and Techniques of Tunis, 5 avenue Taha Hussein B.P. 56 Bab Mnara 1008 Tunis, Tunisia.
[2] Preparatory Institute for Engineering Studies El Manar (IPEIEM), University of Tunis EL Manar (UTM), PB. 24, 2092 Tunis, Tunisia.

Received: 10 Sep. 2018, Revised: 12 Apr. 2019, Accepted: 22 Apr. 2019
Published online: 1 Sep. 2019

Abstract: During the preliminary design of a mechanical system, designers have always needed to test different concepts in order to find a final mechanical architecture that replies to their demands. They change parameter values, re-execute the calculation, add objects, change technological solution, modify or add hypotheses, etc. The different concepts manipulate often components whose interactions are essential for a good functioning of the system and an economic execution of the design process. In fact, most of components do not reply solely to one desired function, but participate also to the behavior of the system and the geometrical definition of the other components. In mechanical design, all of these functionalities have to be taken in consideration by the definition of relationships between objects. This paper proposes a design methodology for automatic configuration of kinematic chain of multi-spindle drilling boxes. This approach is based firstly on an object-oriented architecture for the representation of the various components and assembly of the system and secondly on an expert system for decision making and automatic determination of a possible kinematic chain for a given application. This is done by taking into consideration the design criteria of gearboxes.

Keywords: Mechanism design, conceptual design, design methodology, artificial intelligence, expert system, object-oriented language, multi-spindles drilling boxes

1 Introduction

The design of mechanisms and machines depends on the choice of appropriate technological solutions. These choices are made based on many criteria and conditions that may change during the progress of the project.
Indeed, in the initial phase of the design, the general structure of the mechanism is not considered to be unique and perfect. It depends essentially on the assumptions previously chosen and defined by the experts. These hypotheses lead to solutions allowing designers to study the behavior and feasibility of the mechanism. However, this assessment is often subject to changes due to the evolutionary and dynamic nature of the assumptions. As a result, companies are obliged to optimize their production processes in order to save time and thus reduce costs in order to remain competitive [1]. Moreover, the production capacity of manufacturing industry with less increase in cost is the challenge by the modern production industry [[2],[3]]. Hence, some companies develop new products using software engineering which aims to put the art of the engineer at the service of the rational construction of programs. This software engineering that currently relies on Artificial Intelligence (AI) seeks to satisfy the requirements of users and to model the expert knowledge to solve complex problems that are poorly posed, fuzzy and difficult to represent by algorithmic models. This ability to create conceptual and computer frameworks for the representation of expert knowledge has attracted the interest of many researchers. These aim to implement the fundamental principles of AI in order to design systems for decision-making. Indeed, the use of AI within a design system can be justified by an ability to simulate to a certain extent the reasoning of the expert [5] [4]. This simulation is carried out thanks to the implementation of expert rules related to the design and not only to calculation modules in which any unstructured reasoning is difficult to exploit. Moreover, we note that expert systems, fuzzy logic, neural networks, genetic algorithms and object-oriented languages occupy a prominent place in the field of AI application. Indeed, a considerable number of industrial applications have been realized

* Corresponding author e-mail: ayoub.fajraoui@enit.utm.tn

thanks to these systems in which the process of product design has gone from sequential engineering to concurrent and integrated engineering [6] [7] . In this perspective, our research work consists to develop a decision support system for the design of multi-spindle drilling boxes. These mechanical devices, used for example by automobile manufacturers, make it possible to simultaneously perform various drilling or tapping operations on the casings of the gearboxes, on the engine blocks, etc. A multi-spindle drilling box (Figure 1) is equipped with a single electric motor that transmits its movement and power to the various drilling or tapping spindles. This transmission is generally provided by a number of cylindrical helical gears forming complex kinematic chains of two or more levels. It is widely used to meet the processing needs of the business industry, not only by improving the efficiency of machining, but also saving space and processing costs [8] and its production efficiency increases several times than the common machine tool. The design of an optimized multi-spindle drilling box is a crucial step. Indeed, several parameters must be simultaneously to accomplish this work. Hence, the use of Artificial Intelligent (AI) computer tools is a better solution to help designers in their efforts.

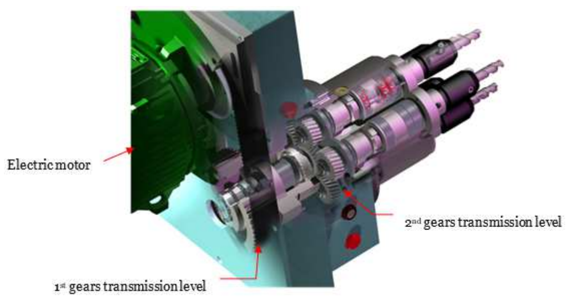


Fig. 1: Example of multi-spindle drilling boxes

The analysis of existing approaches in the literature for the design of preliminary multi-spindle drilling boxes shows the absence of efficient optimization methods to be applied for the choice of a multi-spindle drilling box configuration. This represents a very important gap, as the cost and efficiency of the multi-spindle drilling box designed depend greatly on the quality of the results obtained at this stage. In addition, it should be noted that each type of multi-spindle drilling box brings constraints to take into account, for which different mathematical models are necessary. As a result, it seems unlikely to find a suitable mathematical model and resolution method for any multi-spindle drilling box. The way of developing the methods dedicated to each type of multi-spindle drilling boxes seems more reasonable. So, we opt for the development of a heuristic models and solving methods for the problem of optimizing the configuration of multi-spindle drilling boxes. This choice can be explained by a real industrial need because until now the design of these systems relies essentially on the know-how of the experts. Hence, this paper proposes a design methodology for automatic configuration of kinematic chain of multi-spindle drilling boxes. This approach is based firstly on an object-oriented architecture for the representation of the various components and assembly of the system and secondly on an expert system for decision-making and the automatic determination of a possible kinematic scheme for a given application. This was done by taking into consideration the design criteria of gearboxes.

2 Conceptual analysis of multi-spindle drilling boxes

In order to establish a knowledge database allowing the automatic generation of a kinematic chains of multi-spindle drilling boxes, we have analyzed some existing chains previously established by experts in the field. Figure 2 show one of these chains which corresponds to a multi-spindle drilling box for the realization of 21 bores simultaneously. In each chain, the transmission of power passes from a central gear driven by the main motor ?Motor Input? to the gears rotating the drilling spindles. These gears will be designated in the text by ?D.S.G.?. We distinguish between D.S.G. intended for drilling individually defined by the position of their respective centers. Other D.S.G. will be designed for circumscribed holes in a circle. The latter will be defined by the position of its centre and the value of its radius.

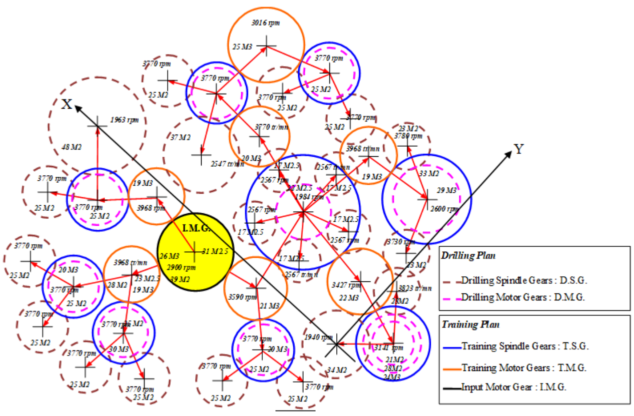


Fig. 2: Example of a kinematic chain of a multi-spindle drilling box

In addition, the observation of these kinematic diagrams reveals some knowledge that can be summed up in the following points: 1. The problem of generation of the kinematic chains of the multi-spindle drilling boxes is considered in parallel plans to (X, Y) plan. Consequently, the position of the center of each pinion in the plan to which it belongs will be determined by two parameters x and y. 2. The multi-spindle drilling box is composed of at least two gears plans levels. These plans are parallel and located at a predefined distance by experts according to the width of the gears and of the others assembly components. In this sense, we distinguish two categories of plans: The first class includes the ?drilling plan? in which the D.S.G. and the ?Drilling Motor Gear? (D.M.G.) centers are located. The second class includes the ?training plans? in which the centers of the ?Training Motor Gears? (T.M.G.) and the ?Input Motor Gear? (I.M.G.) are located. 3. Gears belonging to the same plan have in common the same cutting module. 4. Each of D.S.G. can be meshed with only one ?Drilling Motor Gear? (D.M.G.) The center of each of these gears is located in the drilling plan. 5. Unlike a D.M.G. characterized by the ability to transmit its motion to one, two or three D.S.G., each drilling spindle gear (D.S.G.) is unable to transmit his motion to another gear. 6. Rotational training of a D.M.G. is provided by a ?Training Spindle Gear? (T.S.G.). The center of this gear is located in a training plan and admits the same coordinates (x, y) as those of D.M.G. 7. The motion and the power transmission from an ?Input Motor Gear? (I.M.G.) to a T.S.G. is provided by gear designated by ?Training Motor Gear? (T.M.G.). Each of a T.M.G. meshes with the I.M.G. and with a T.S.G. 8. The I.M.G. or the T.S.G. is able to mesh only with a maximum of three T.M.G. 9. Each of T.M.G. can mesh with one, two or three T.S.G.

In summary, the kinematic chain of a multi-spindle box can be presented according to the conceptual diagram given in Figure 3. In this diagram, only the main components of the kinematic diagram and the principal relationships between them have been presented.

Furthermore: The relationships designed by meshes with show all the objects (gears) that mesh with another wheel of the same plan. For example, a D.M.G. can mesh with a set formed by n D.S.G. of the drilling plan (n = 1 ... 5). The relationships designed by is trained by show all the D.M.G. belonging to the drilling plan that will be trained by the T.S.G. of the training plan. In figure 3, three types of elementary gearbox reducers can be defined as follow: 1. The first type, defined in a training plan, is a set composed of the *?Input Motor Gear?* (I.M.G.) and of one, two or three *?Training Motor Gears?* (T.M.G.). The corresponding gearbox reducer will be a member of the gearbox family designated by *?RedElem1?*, *?RedElem2?* and *?RedElem3?*. 2. The second type, defined also in a training plan, is a set composed of a *?Training Motor Gear?* (T.M.G.) and of one, two or three *?Training Spindle Gears?* (T.S.G.). The corresponding gearbox reducer will be also a member of the family *?RedElem1?*, *?RedElem2?* or *?RedElem3?*. 3. The third type, defined in the drilling plan, is a set composed of a *?Drilling Motor Gear?* (D.M.G.) and one, two, three, four or five *?Drilling Spindle Gears?* (D.S.G.). 4. The corresponding gearbox reducer will be also a member of the family *?RedElem1?*, *?RedElem2?, ?RedElem3?, ?RedElem4? or ?RedElem5?*. In the case of the gearbox family *?RedElem4?* and *?RedElem5?*, the D.S.G. are uniformly distributed around the center of the D.M.G. Figure 4 resumes in a schematic representation the configuration of the five elementary gearbox reducers.

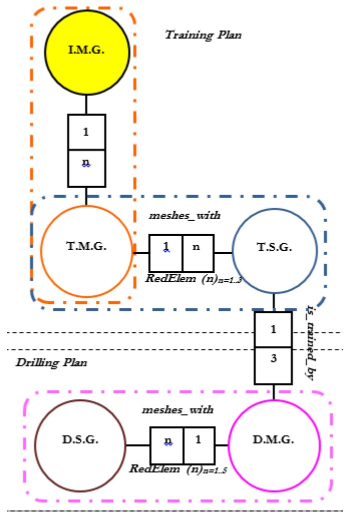


Fig. 3: Conceptual diagram of the kinematic chain of multi-spindle drilling boxes

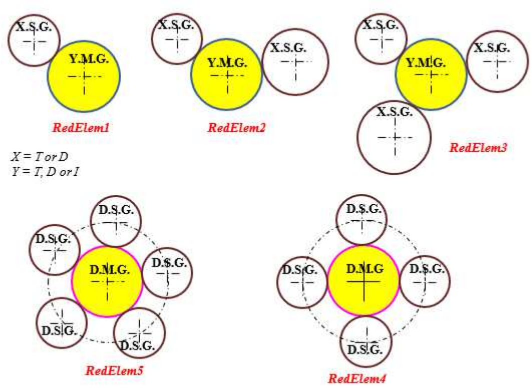


Fig. 4: Schematic representation of the five elementary gearbox reducers

3 Modeling expert knowledge

3.1 Modeling components and assemblies

The process of modeling and representation of mechanisms is made easy thanks to object-oriented programming. Indeed, these languages have been very successful in defining the components and assemblies of machines [9] [10] . Thus, based on the concept of assembly of a mechanism and on the different knowledge identified in the conceptual analysis, we considered that the kinematic chain of a multi-spindle drilling box is obtained following an assembly of the different elementary gearbox reducers. Each gearbox is located in a worktop and it consists of some numbers of gears. Our interest will then focus on the design of gear wheels (components) and the design of elementary gearboxes (assemblies). In addition, in our approach, gear wheels, elementary gearboxes as well as materials, holes and drilling tools are modeled by object instances. Each object is an element of a class or subclass of objects defined by attributes and methods. The attributes represent the static part of the object presenting all the data or the variables of instances. Methods form the dynamic part of the object. They present the procedures that manage the operation of objects and the manipulation of their attributes. These methods and attributes are not visible outside objects (Figure 5). In addition, objects can communicate with each other by sending messages. These messages constitute the public interface of each object. Indeed, each message known by an object corresponds to a method that executes this message. Figure 6 illustrates the tree structure of the classification

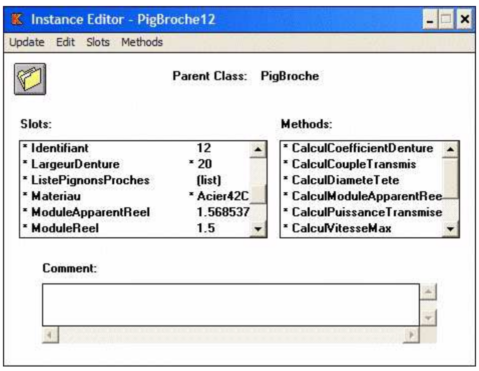


Fig. 5: Wheel Gear object class definition

of the various constituents of multi-spindle drilling box in classes and subclasses. We can note here that a mechanical object is characterized not only by its geometric or dimensional attributes, but also by other types of attributes. These are directly related to the functionality of the object throughout the mechanical system. For this reason, we have proposed three types of attributes necessary for the definition of an object contained in the piercing cases: 1. Geometric or dimensional attributes: The values of these attributes can be caught from the user at the screen, or can be defined from a data base or coming from specific calculation procedures. 2. Functional attributes: These are the variables that characterize the functional state of the object (power, torque, speed, force, pressure, life, etc.). 3. Relational attributes: These attributes define the possible relationship between an object and one or more objects from other types of classes or sub classes of objects. The evolution of objects in the system will be therefore by: 1. The definition of relationships between the objects. These relationships have to be maintained consistent during all the design process. There will be an increase in the accuracy of the attribute values which define the parent links. Examples:

DSG 1 is instance of Gearwheel
DMG 2 is instance of Gearwheel
TSG 2 is instance of Gearwheel
RedEem2 2 is instance of RedEem2
RedEem3 1 is instance of RedEem3
DSG 1 meshes with DMG 2
DMG 2 is Trained ByTSG 2
DSG 1 is part of RedEem2 2
DMG 2 is part of RedEem2 2
TSG 2 is part of RedEem3 1

2. The sending of messages to the different methods applied on each type of objects that release procedures of calculation, choice, checking, etc. In the next example, the message is sent to the object instance RedElem2 2 in order to calculate its dimensional characteristics by executing the method Compute Characteristics. This method is defined in the subclass RedElem2 and the calculation of the gear wheels dimensions is based on the ISO calculation methods presented in Mehdi [11] . SendMessage(RedEem2 2,Compute Characteristics);

3. The application of numerical constraints to insure the geometrical and mechanical functional compatibility on attributes of objects. These types of constraints allow maintaining the coherence between attributes of objects in relationships. Example:

If (Self:D1 $\leq$ WheelGear 2:D2)

Then

$$\text{Post Message} : \textit{There is a collision of matter between , Self , Wheel Gear 2}$$

$$Self : CollisionMater = TRUE;$$

$$SendMessage : (\textit{ Global:Select Reducer, Suppression Reducer });$$

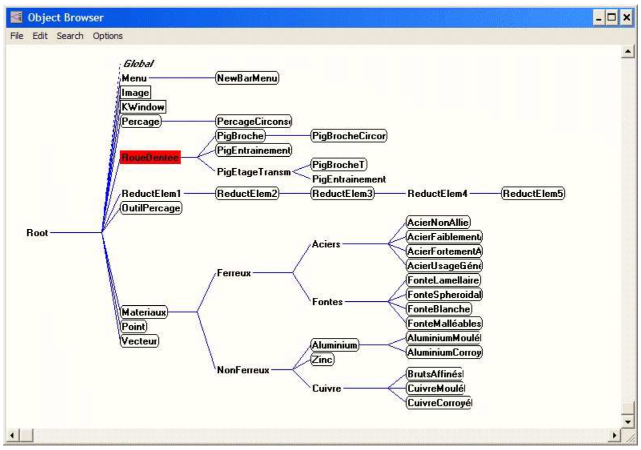


Fig. 6: Wheel Gear object class definition

3.2 Modeling of heuristic knowledge

The heuristic knowledge, allowing the creation and the verification of the coherence of a kinematic chain of a multi-spindle drilling box, are defined in the knowledge base of the system as rules in form of *If Antecedents Then Conclusions*. Thus, several types of rules have been be defined. We give here some examples:
1. The rules established for the choice of the candidate gears for the formation of a reducer. Example: Spindle MakeRule(PignonCandidat, [P1—Drilling Spindle Gear , P2— Drilling Spindle Gear],

if (Distance2Spindles (P1,P2) $\leq$ Global:A-max

And Distance2Spindles(P1,P2) $\geq$ Global:A-min) then TRUE)

2. The rules for creating elementary gearbox reducers ?RedElem1?, ?RedElem2? and ?RedElem3?. As example:

MakeRule(Regoupement2T, [P— TrainingMotorGear],
if Not(KnownValue?(P, ElementOfReducer)) And
LengthList(Global:All TrainingMotorGear) $\geq$ 2
And Not(KnownValue?(
GetNthElem(P:ListOfCandidateGears, 1
),ElementOfReducer))
And DistanceMinMax(P, GetNthElem(P:
ListOfCandidateGears, 1));
then Regroupement2T(P));

3. The rules to minimize the number of the ?Drilling Motor Gears? (D.M.G.) and the ?Training Motor Gears? (T.M.G.) by giving the privilege to the rule of creation of the reducer of type ?RedElem3? then to the rule of creation of the reducer of the type ?RedElem2? and finally to the rule of creation of the reducer of the type ?RedElem1?.

4.The rules for suppressing non-coherent elementary reducers. As example:

MakeRule(SupressionTraininінGear,
[P—TrainingMotorGear], if KnownValue?(P,
ElementOfReducer) And Member?(
Global:AllTrainingMotorGear, P); then
RemoveFromList(Global: AllTrainingMotorGear, P));

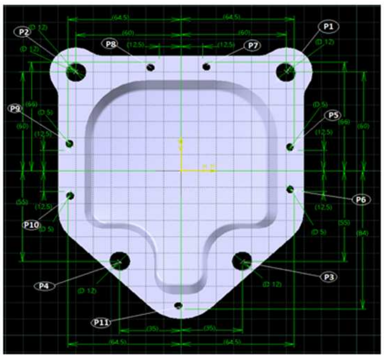
Note that in an expert system these previously defined rules can always be modified. We can also enrich the knowledge base by other rules without any modification of the other parts of the system.

4 Kinematic chain configuration process: Illustrative example

To appreciate the effectiveness of the developed system for the automatic configuration of the kinematic chain of a multi-spindle box, an illustrative example is considered. The multi-spindle box will be intended for drilling holes in an aluminum alloy oil pan (AlCu4MgTi). This pan contains 4 holes Pi1-4 .with a diameter of 12 mm and 7 holes Pi 5-11 with a diameter of 5 mm. The drilling centers of these holes are supposed to be in the same plane (Figure 7).

Figure 8 illustrates the general principle of the kinematic chain configuration process for the design of a novel multi-spindle drilling box. This process is based on a modular approach. Each module responds to a specific function and manipulates instances of objects forming its inputs. The data of a module is manipulated and controlled by methods defined in the corresponding object classes. The entire design process is managed by a control system defined by rules which constitute the knowledge base of the system. The forward chaining of rules is ensured by the inference engine of the KAPPA-PC system.

The hole creation module allows the user of the program, in a first phase, to enter the preliminary characteristics of the different gears (helix angle, pressure angle, material, quality of surface, etc.) as well as to acquire the cutting parameters corresponding to the tool and the material to be pierced (cutting speed, specific cutting pressure, feed rate per revolution). Note that the wheels of gears are considered to be designed by the same type of material, the same pressure angle and the same helix angle. However, these wheels may have different cutting modules. The values of these modules will be imposed by the project designer. In addition, the creation of the holes entities represents the second phase of the module. Note that a hole is previously defined by its unique identifier, its diameter and its coordinates (x, y). At the same time, each hole created by the user will be viewed in a screen window (Figure 9) and the system



Id.	X (mm)	Y (mm)	D (mm)
P_1	60	60	12
P_2	-60	60	12
P_3	35	-55	12
P_4	-35	-55	12
P_5	64.5	12.5	5
P_6	64.5	-12.5	5
P_7	12.5	66	5
P_8	-12.5	66	5
P_9	-64.5	12.5	5
P_{10}	-64.5	-12.5	5
P_{11}	0	-84	5

Fig. 7: Scheme of the oil pan and holes to be drilled

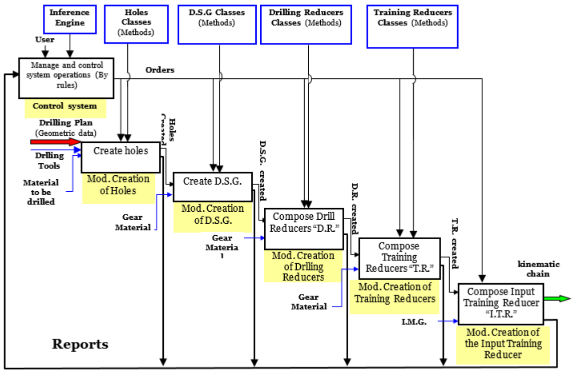


Fig. 8: Kinematic chain configuration process of a multi-spindle drilling box

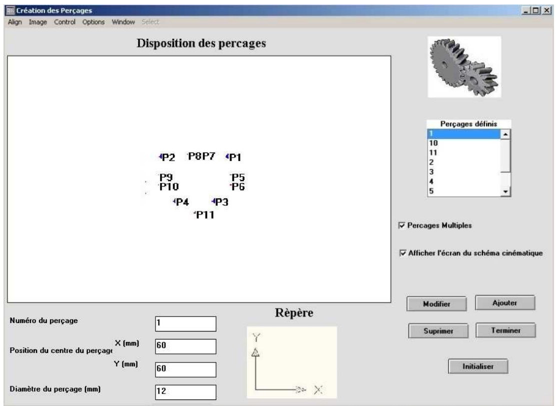


Fig. 9: Data entry and creation of holes instances

automatically associates to each created holes a *gearwheel* instance of the Drilling Spindle Gears *D.S.G* subclass. Thus, thanks to the dynamic links defined between the attributes of an object and its methods, the program calculates the power required for cutting and the frequency of rotation at each D.S.G. instance. The calculated values will then be automatically transmitted to the D.S.G. instance by a simple message sent by the system. Therefore, the instances of D.S.G. associated with the holes instances provide the system with the initial facts for creating the kinematic chain.

Once all instances of holes instances are created, the inference engine of the program starts the step of chaining rules. This step allows, in two different and successive phases, the creation of the elementary gearboxes reducers corresponding to the *Drilling Reducers* (D.R.), the *Training Reducers* (T.R.) and the *Input Training Reducer* (I.T.R.) to finally lead to the creation of the entire kinematic chain of the multi-spindle drilling box. In this creation phase of the D.R., the system starts by associating with each D.S.G. instance a list made up of the other D.S.G. instances. This list is organized in ascending order of their distance from the considered D.S.G. instance. This list will be useful for the rule that allows choosing instances of D.S.G. to group together to form an elementary D.R. instance. As a result of this operation, the inference engine triggers one of the candidate rules for the creation of elementary reducers such as *RedElem1*, *RedElem2* or *RedElem3*. During chaining, the inference engine favors the creation of *RedElem3* reducers then *RedElem2* and then *RedElem1* reducers. The creation of a reducer requires, in parallel, the creation of two *gearwheels* instances of D.M.G. and T.S.G. sub classes. Verification of the consistency of the elementary reducers is accomplished through other rules. Similarly, a non-coherent gearbox will be removed by triggering the rules established for this purpose. Finally, the functional, geometric and dimensional characteristics of a gearbox created in a coherent manner are obtained by calculation procedures defined as methods in their object classes. As a result of this calculation operation, a non-interference material verification rule between the different gears will be automatically triggered by the inference engine. It should be noted that each gear wheel or elementary reducer created by the system represent new facts to the system. These will be considered by the inference engine during its new chaining operation. Once all the D.R. and T.S.G. instances are established, the system passes, in a first step, to the creation of the T.R. and then in a second step to the creation of the I.T.R. In the first step, the system starts by associating with each instances of T.S.G. a list made up of the other T.S.G. instances. This list is organized according to the increasing order of their distances from the considered T.S.G. instance. This list will be useful for the rule that allows choosing the T.S.G. instances to group together to form a Training Reducer (T.R.). As a result of this operation, the inference engine triggers one of the candidate rules for the creation of elementary reducers such as *RedElem*1, *RedElem2* or ?RedElem3?, while favoring the creation of *RedElem3* then *RedElem2* and then *RedElem1*. The creation of a reducer requires, in parallel, the creation of a *gearwheel* instance of T.M.G. subclass. This wheel has the function of a *Motor Pinion* which transmits its movement and power to the T.S.G. instances. Figure 14 illustrates the results of the formation of the elementary training reducers (T.R.). The second step is to transmit the movement of the I.M.G. instance to the elementary reducers previously created. Thus, assuming that the I.M.G. instance can transmit its movement at most three T.M.G. instances, the system starts by identifying the T.M.G. instances closest to I.M.G. to ensure their consolidation and to form together a new elementary training gearbox reducer (I.T.R.). Finally, the results after each chaining step for the determination of the different elementary reducers will be automatically displayed to the user in a graphic screen. Figure 10 is a screen shot taken after completing the various steps of chaining. This figure represents one of the solutions found by our system. A specially created procedure, allows the transfer into a file of all necessary data for automatic visualization in 3D of the kinematic chain by CATIA V5 (Figure 11). It is perfectly possible that after a number n of chaining (iterations) we will have a second or third solution.

The results of this simulation are illustrated in the following figure (12).

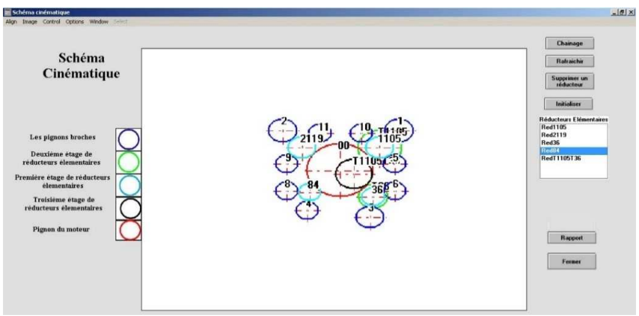


Fig. 10: Graphical representation of the created kinematic chain

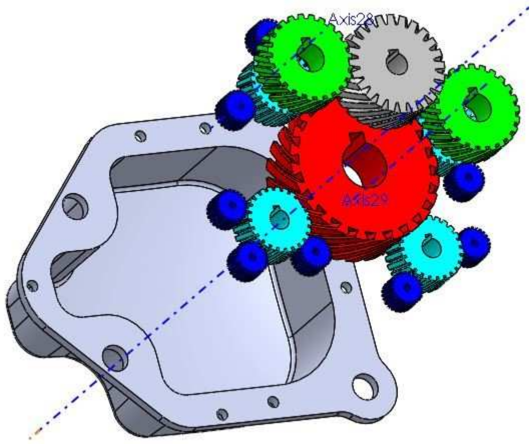


Fig. 11: 3D visualization of the kinematic chain created by the system by CATIA V5 3D kinematic scheme for the result obtained

Fig. 12: Results of calculation of the gears of pinion transmission pin in the kinematic scheme (In the same plane)

The results show that after setting the same modulus and the same pressure angle and for a reduction ratio required, the rotational speeds and torques in this example are appropriate. It is perfectly possible that after a number n of chaining (iterations) we will have a second or third solution.

5 Perspective

A design methodology for automatic configuration of kinematic chain of multi-spindle drilling boxes was presented. The approach is based firstly on an object-oriented architecture for the representation of the various components and assembly of the system and secondly on an expert system for decision-making and automatic configuration of a possible kinematic chain for a given application by modeling the heuristic knowledge by generic rules understandable by the user of the system. These skills favor the speed, the coherence of the system designed as well as the accuracy and reliability of the calculations. So, the importance of the presented work is to highlight the contribution of object-oriented languages and that of expert systems in the determination of the kinematic chains of multi-spindle drilling boxes. Indeed, these computer resources contribute considerably to the resolution of the problems that can meet the engineers during the modeling and the design of a mechanical system. However, the presented system is still limited since it only uses the forward chaining in its reasoning mechanism. For this reason, we will consider, as part of our research perspectives, using the second type of chaining (back chaining) in the automatic configuration of the kinematic chains of multi-spindle drilling boxes. We will focus on the application of the principles of fuzzy logic and neural networks in the choice and optimization of elementary gear design.

Acknowledgement

The first author acknowledges that he didn't received financial support for the research
The authors are grateful to the anonymous referee for a careful checking of the details and for helpful comments that improved this paper.

References

[1] Martinez, L., Ruan, D. and Herrera, F. Computing with words in decision support systems: an overview on models and applications. Int. J. of Computational Intelligence Systems, 2010; 3(4): 382-395

[2] Peroni, M., Vergnano, A., Leali, F., Brentegani A. Design Archetype of Gears for Knowledge Based Engineering. In: Eynard B., Nigrelli V., Oliveri S., Peris-Fajarnes G., Rizzuti S. (eds) Advances on Mechanics, Design Engineering and Manufacturing. Lecture Notes in Mechanical Engineering, 2017;. Springer, Cham: pp 1131-1140

[3] Mehrabi, MG., Ulsoy, AG. and Koren, Y. Reconfigurable manufacturing systems: Key to future manufacturing. J Intell Manuf, 2000; 11: 403-419

[4] Choudhary, AK., Harding, JA. and Tiwari, MK. Data mining in manufacturing: a review based on the kind of knowledge. J Intell Manuf, 2009; 20: 501 https://doi.org/10.1007/s10845-008-0145-x

[5] Pham, DT. and Pham, PTN. Expert systems in mechanical and manufacturing engineering Int J Adv Manuf Technol, 1988; 3: 3-21 https://doi.org/10.1007/BF02601587

[6] Aziz, ES. and Chassapis, C. A decision-making framework model for design and manufacturing of mechanical transmission system development. Engineering with Computers, 2005; 21(2): 164-176

[7] Gologlu, C. and Zeyveli, M. A genetic approach to automate preliminary design of gear drives. Computers & Industrial Engineering, 2009; 57(3): 1043-1051

[8] Chankeshwara, S., Patil, N., Anklkar, A., Deshmukh, B. and Mistry, R. Development of an Adjustable Gang Drilling Attachment for Radial Drilling Machine. International Conference on Research into Design for Communities, Proceedings of ICoRD, 2017; Springer: 351-359

[9] Hamta, N., Akbarpour Shirazi, M., Behdad, S. et al. Modeling and measuring the structural complexity in assembly supply chain networks. J Intell Manuf, 2018; 29: 259. https://doi.org/10.1007/s10845-015-1106-9

[10] Mehdi, K. and Play, D. An Integrated Process for Gearbox Design. Proc. of the Computers in Engineering Conference and the Database Symposium ASME?95, Boston, Massachusetts 1995;Sept. 17-20: 841-850

[11] Mehdi, K. Integrated gearbox design system, PhD thesis, Insa Lyon, 1995: 315p.

Ayoub Fajraoui Ayoub Fajraoui is PhD student in Mechanical Engineering at Engineering National School of Tunis (ENIT), University of Tunis El Manar and member of URMSSDT of ENSIT?Tunisia. His research interests concern the application of Artificial Intelligence in Mechanical Concurrent Engineering.

Mehdi Kamel was graduated as a Mechanical Engineer from ENIS - Tunisia in 1989. He received his doctor's degree in Mechanical Engineering in 1995 from INSA of Lyon ? France and his HDR diploma in 2008 from ENIS - Tunisia. He is currently Associated Professor in Mechanical Engineering at the IPEI El Manar - Tunis and he is a researcher at the Mechanical Laboratory of Solids, Structures and Technological Development of the ENSIT - Tunisia. His research interests concern Machining and Manufacturing process, Concurrent engineering and Computer Integrated Design of Mechanical Systems.