An Expert System for Bolt Selection

Araştırma Makalesi/Research Article

Kadir SARI*, Yunus KAYIR, Hakan DİLİPAK

Manufacturing Engineering, Gazi University, Ankara, Türkiye

kadirsarion@gmail.com, ykayir@gazi.edu.tr, hdilipak@gazi.edu.tr

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***Abstract*—** Expert systems are one of the widely used artificial intelligence techniques and their use is increasing day by day. Expert systems are a technique that can use the knowledge and experience of experts, evaluate them at the decision-making stage and make inferences. Bolts are fasteners used to connect various parts and are within the scope of standard machine elements. There are different types of bolts in the industry and choosing the right bolt requires expertise. In this study, an expert system called Exbolt System, which selects bolts according to head types, was developed. Commonly used standard bolt types were based on bolt head types. Relevant rules for bolt types were established by collecting and analysing information about each bolt. While the rules were written, it was aimed to choose the truest bolt type. Criteria such as the need for fine-tuning, use in rotating parts, centring in the hole, flat surface requirement, mounting accuracy, system weight status, high force-holding and use in dirty environments were considered in the creation of the rules. The programme makes the best choice and recommends the bolt that can be used according to the head type to the user. CLIPS expert system programming language was used in the development of the Exbolt System. With the answers to the questions asked to the user by the programme, it was ensured that the truest bolt selection was made. The most accurate result was achieved by making faster, easier and more comprehensive decisions in the bolt selection, which requires expertise, and a more effective and efficient selection process was realised by saving time and labour.

***Keywords*—** bolt head type, selection, design, expert system, artificial intelligence, clips

Cıvata Seçimi için Bir Uzman Sistem

***Özet*—** Uzman sistemler yaygın olarak kullanılan bir yapay zekâ tekniğidir ve kullanımı günden güne artmaktadır. Uzman sistemler, uzmanların bilgi ve tecrübelerini kullanabilen, bunları karar verme aşamasında değerlendirip çıkarım yapabilen bir tekniktir. Cıvatalar çeşitli parçaları birleştirme amaçlı kullanılan bağlantı elemanlarıdır ve standart makine elemanları kapsamındadır. Sektörde farklı tiplerde cıvatalar bulunmaktadır ve en doğru cıvata seçiminin yapılabilmesi uzmanlık gerektirmektedir. Bu çalışmada, baş tiplerine göre cıvata seçimi yapan Exbolt System adlı bir uzman sistem geliştirilmiştir. Cıvata baş tiplerine göre yaygın olarak kullanılan standart cıvata tipleri esas alınmıştır. Her bir cıvata ile ilgili bilgiler toplanıp analiz edilerek cıvata tipleri için ilgili kurallar oluşturulmuştur. Kurallar yazılırken, en doğru cıvata tipinin seçilmesi amaçlanmıştır. Kuralların oluşturulmasında ince ayar gereksinimi, dönen parçalarda kullanım, delikte merkezleme, düz yüzey gereksinimi, montajlama hassasiyeti, sistem ağırlık durumu, yüksek kuvvet tutabilme ve kirli ortamlarda kullanım gibi kriterler göz önüne alınmıştır. Program en iyi seçimi yaparak kullanıcıya baş tipine göre kullanılabilecek cıvatayı önermektedir. Exbolt System'in geliştirilmesinde CLIPS uzman sistem programlama dili kullanılmıştır. Program tarafından kullanıcıya yöneltilen sorulara alınan yanıtlar ile en doğru cıvata seçiminin yapılması sağlanmıştır. Uzmanlık gerektiren cıvata seçiminde daha hızlı, kolay ve kapsamlı bir şekilde karar verilerek en doğru sonuca ulaşılmış, zaman ve işgücünden tasarruf edilerek daha etkili ve verimli bir seçim süreci gerçekleştirilmiştir.

***Anahtar Kelimeler*— c**ıvata baş tipi, seçim, tasarım, uzman sistem, yapay zeka, clips

1. INTRODUCTION

The increase in the speed of technology development day by day has led to the widespread use of its applications in various fields. With the developments experienced, it is seen that these technologies are used by enterprises for purposes such as planning, selection, control, analysis, diagnosis and maintenance in areas such as design, supply and mass production when the engineering sector is considered. Efficiency and efficiency are increased by reducing time, cost and labour. In this way, targets can be reached more easily and quickly. With the acceleration of development and the transformation of needs into a necessity, systems called artificial intelligence (AI) that act, think, decide, learn and act like human beings are increasingly used in many fields for various purposes over time. Artificial Intelligence is defined as the branch of computer science that deals with equipping computers or machines with human mental states, such as acquiring information, perceiving, reacting, making decisions and thinking [1]. Computers greatly simplify and speed up some aspects of human thinking processes. Artificial intelligence technology applications allow complex manual operations to be performed automatically and quickly. Additionally, artificial intelligence technologies are rapidly increasing the capabilities and applicability of computers by integrating with other computer-based information systems [2]. These various applications can be realised by using artificial intelligence techniques. One of these artificial intelligence techniques is expert systems. Expert systems are computer systems that generally act as experts. Expert systems facilitate decision-making with their reasoning abilities. The most notable advantage of expert systems is that expert information is stored and made permanent so that information is not lost in any adverse situation. Other benefits are given below:

- *Productivity growth;* less labour and less cost,
- *Quality improvement;* produce consistent and appropriate results,
- *Consistency;* examining all the subject details together,
- *Flexibility;* updating knowledge bases,
- *Sophistication;* combining multiple expert knowledge,
- *Speed;* short decision-making time,
- *Reliability;* reach reliable results in a short time using the knowledge base. [3]

There are many studies on the subject in the literature. A user-interactive computer program was prepared in GW-Basic programming language in order to select and analyse standard bolts, washers, nuts, and some bolted connections under various loads using an IBM-XT compatible microcomputer [4]. An interactive online expert system was designed using the expert system development tool PC-PLUS for the selection of machine screws for the design of industrial products. The knowledge base for this system includes rules on type classification, mounting techniques and material properties of machine screws. In addition, fixing strength, corrosion resistance, magnetic properties, electrical conductivity, thermal conductivity, thermal expansion, safety, cost and appearance factors were also taken into account to improve the quality of the selection. [5]. An intelligent software was developed that can automatically classify and select machines and machine elements, develop and implement classification algorithms using the current knowledge base [6]. By taking the expert system approach, bolt and gear wheel selections were made according to their usage areas, and the selection rules were analysed in the prepared program [7]. A study was conducted in which the application of internet technologies was discussed during the optimal selection of typical or standard machine elements in the design process, computer tools for creating engineering databases and internet applications were discussed, and optimization criteria were discussed [8]. A method was developed for the selection of the nominal diameter of ISO metric screws that can be used in high-duty bolted connections [9]. For ease of disassembly, a multi-criteria decision-making model was developed that can assist in the selection of fasteners with the PROMETHEE method within the scope of the Design for Disassembly (DfD) concept [10]. A model based on the DfD concept and Analytical Network Process (ANP) was developed for the selection of fasteners, which is one of the most influential points in the disassembly of products, among various alternatives [11]. Using the KAPPA-PC expert system package program, an expert system was developed that enables a non-expert in drilling operations to easily, quickly and accurately select insert drills and cutting parameters. [12]. An expert system called ExpertTS was developed to enable the selection of inserts for external diameter and internal threading operations [13]. An expert system was developed that can select bearings for the required features [14].

In general, expert systems were used in the development of computer applications involving other machine elements such as bolts, washers, nuts or gear wheels and their classification, selection and analysis. Additionally, computer tools for the development of applications on such subjects in the internet environment and the creation of databases were examined and optimization issues were discussed. Additionally, studies were carried out to make the most accurate selection of fasteners at the design stage to make the disassembly process based on various concepts and methods more effective and efficient.

As a result, there are very few studies with an expert system approach on the selection of bolts that can be classified under various headings such as head, body, screw and material types. Based on this, this study, unlike other studies, it is aimed to make the most accurate selection of commonly used bolt head types by considering various criteria such as the purpose of use of bolts, places of use and working conditions. In this way, a more effective and efficient selection process experience is aimed by making selections more easily, comprehensively and in a short time.

2. ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) is the engineering or science of making intelligent machines, especially intelligent

computer programmes, performing behaviours that are called intelligent when done by humans [15,16].

Computer programmes work with algorithms. The algorithm is the step-by-step planning of the solution path to reach the result. Intelligence is the ability to produce algorithms. AI, on the other hand, is an automatic system that can produce algorithms [17].

Artificial intelligence is a science associated with computer science and statistics. It includes topics such as expert systems, artificial neural networks, fuzzy logic, genetic algorithms, voice recognition, image processing, robotics and learning. Expert systems are one of the artificial intelligence techniques that can be applied and widely used in every field where the concept of expertise is mentioned (Figure 1).

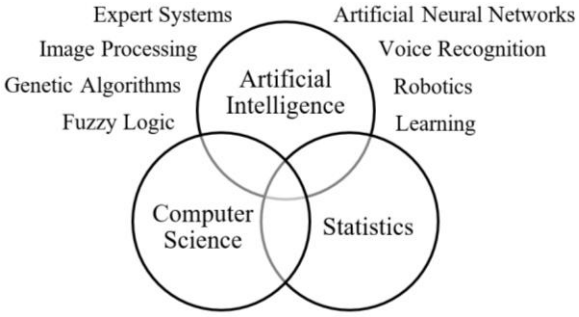

Figure 1. Artificial intelligence approach

2.1. Expert Systems

Expert systems (ES) are one of the artificial intelligence techniques that make the knowledge and experience of an expert permanent, make inferences using this data, solve problems and produce results. Expert systems are knowledge-based systems. Evaluates problems comprehensively and imitate human intelligence in solving them. In this context, it works by using algorithms and inference mechanisms interactively with each other. While establishing the US structure, the information engineer collects the necessary information from the relevant field expert and stores it by adapting it to the knowledge base. While solving problems, ES chooses rules related to content knowledge, processes them in an inference engine, and performs thinking and analysis like an expert. It learns the solved problem and adds it to the knowledge store. ES uses can be listed as interpretation, estimation, selection, diagnosis, design, planning, imaging, debugging, repair, training and control [18].

2.1.1. General Structure of Expert Systems

Expert systems consist of three main modules as knowledge base, inference engine and user interface. During the creation and use of the expert system, it also interacts with the user and the experts (Figure 2).

- *User:* The person who uses the expert system.
- *Expert:* It is the person who forms the basis of the system and has the most knowledge and experience in the field of work.
- *Knowledge Base:* It is a structure of expert knowledge and consists of rules, facts, networks and frameworks.
- *Inference Engine:* It is the mechanism that can reach conclusions with the rules, facts and all other information in the knowledge base.
- *User Interface:* It is a component that uses the expert system and constantly interacts with it. [19,20].

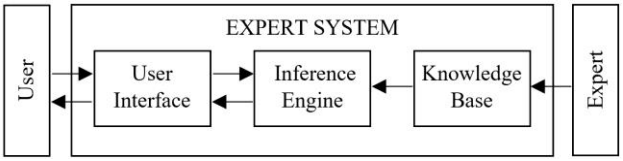

Figure 2. The general structure of expert systems [21]

The reasoning of knowledge and rules in expert systems is carried out by two different inference methods. These methods are classified as forward (data-based) and backward (goal-based).

In the forward chaining method, the reasoning unit starts from the beginning and reaches the conclusion. In this type, the "if" refers to starting over, and the "then" part refers to the result. In backward chaining, it starts from the "after" part of the result and reaches the solution by processing the "if" conditions (Figure 3). A mixture of both forward and backward reasoning can also be used.

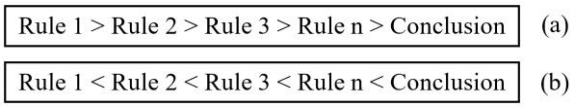

Figure 3. a) Forward chaining, b) Backward chaining

The expert system development process consists of 6 basic stages given in Figure 4.

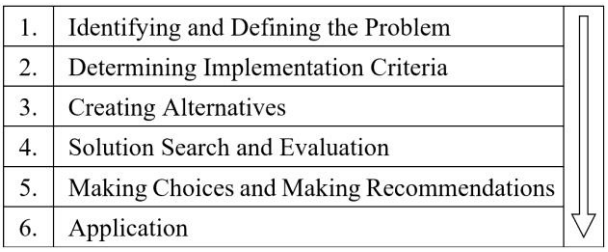

Figure 4. Expert system development process [22]

3. BOLTS AND CRITERIA FOR BOLT SELECTION

Bolts are mainly used to connect parts detachably together. They are standard machine elements with a screw profile drilled according to certain rules on a cylindrical body and the heads of which are shaped in different ways. The part of the bolt or screw that is connected to the head of the screw and partially or completely threaded on it is called a screw. The body end is shaped as dished or conical for easy

threading of screw threads. The conically shaped screw tip is called the chamfer. Bolts are used as fastening and movement elements in the technique. Bolts are made in standard sizes based on their nominal diameters and head shapes according to their intended use [23-26]. For example, in Figure 5, the standard sections of the Hexagon head bolt are given.

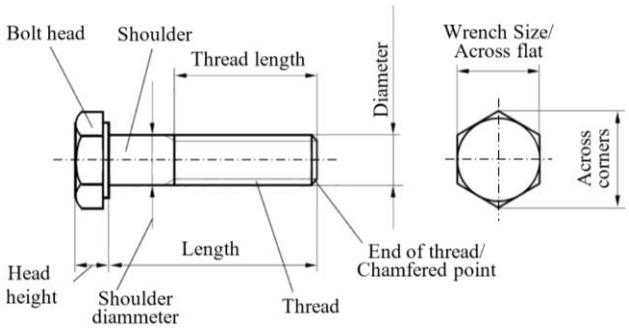

Figure 5. Parts of hex head bolt [26]

Bolted joints are used as an economical fastening method in many application areas due to their advantages such as requiring only one hole drilling or additional screwing in the parts to be connected, standardization of bolts, low-cost production thanks to mass production possibilities, and ease of assembly and disassembly. Commonly used bolt joints are loose connections made with the help of two elements, bolt and nut. They provide a highly reliable connection [27]. Bolted connections should be configured most accurately according to different criteria to be used efficiently and safely [28].

3.1. Classification And Characteristics of Bolts

There are classifications for bolts under various headings such as head shapes, body shapes and strength properties. In this study, there is a classification of bolts according to their head types. In order to determine the scope of the bolts, commonly used catalogues were taken as a basis. A common conclusion was reached among the catalogues and the most commonly used bolt types were determined. As a result, 5 bolt types as hexagon head bolt, cylinder head bolt, countersunk bolt, stud and setscrew were included in the study.

Information about bolts was compiled based on information and data obtained through scientific studies, technical documents and experience. Some bolt information contains generally accepted knowledge. The collected information was compared with the literature and its validity was checked. The information that was corrected at the end of the process was included in the current study. [23-27].

The features of these bolts, which are visualized below, are presented in order to create information and criteria for the expert system [23-27].

Hexagon Head Bolt: They are used for general-purpose applications. It is available in various sizes and dimensions. The head shape is hexagonal. It can be assembled with a wrench or socket wrench. Thanks to the hexagonal head shape, a strong tightening force can be obtained by providing high torque. These bolts are not preferred if there is any risk of leaving the bolt head out.

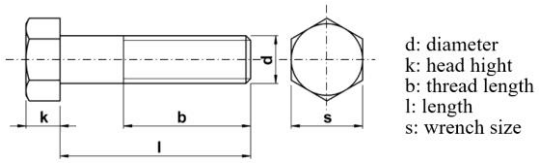

Figure 6. Hexagon head bolt

Cylinder Head Bolt: The head is cylindrical and the wrench flat is socket-shaped on the inside of the head. The geometry of these sockets can be in various shapes such as hexagonal, flat or star. These bolts can be mounted with tools such as hex wrenches, flat or Phillips screwdrivers according to these sockets. Thanks to its socket head, it provides ease of assembly in narrow spaces. These bolts are beneficial to be used in situations where lightness is aimed, since they have sockets and because the bolt head can be recessed into the connected part, some mass will be removed from the assembled part, and they can do the same job with a smaller number of bolts compared to other bolts.

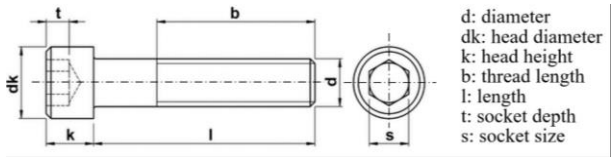

Figure 7. Cylinder head bolt

Countersunk Head Bolt: The head is the countersunk type and has a socket inside the head like cylinder head bolts. Depending on the socket type, they can be assembled with various wrenches, screwdrivers, etc. These bolts are inserted into the countersunk hole in the part to be assembled as recessed. These bolts can be preferred if the head of the bolt is not wanted to be outside and a flat surface is desired on the part. Due to these situations, it can be applied in situations where lightness is desired. It can be used for centring in the hole. The prices of these bolts are relatively lower in line with the catalogues.

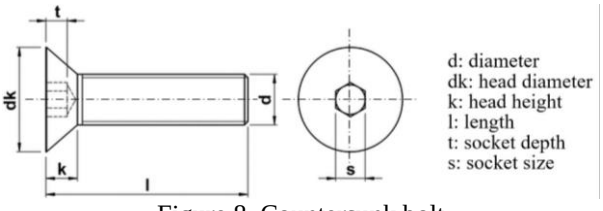

Figure 8. Countersunk bolt

Stud Bolt: These bolts have no heads and are threaded at both ends. One end is connected to the part to be screwed and a nut is attached to the other end. They can also be mounted using nuts for both ends. Stud bolts can be used in cases where other bolts are insufficient in terms of

length. It is generally produced in 1000-2000 mm lengths and can be used according to the need by cutting it to the desired lengths. These bolts are preferred in order not to damage the parts that are assembled due to frequent disassembly and assembly. It is used where high assembly precision is required. On the other hand, assembly operations are more difficult due to the absence of a bolt head or internal socket.

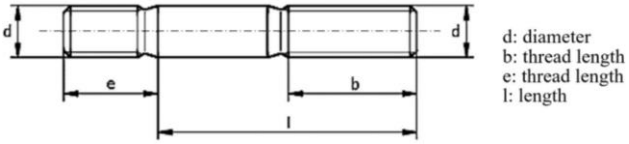

Figure 9. Stud

Setscrew: Headless bolts with screw threads on the body. For this reason, setscrews are used to fix rotating parts such as flywheels, gear wheels or pulleys on shafts and axles and to make fine tunings such as wear and gap adjustment. Another name is the adjustment bolt. It has sockets in various shapes to be mounted with allen wrench, etc. tightening tools at the end. Setscrews can be used in situations where a flat surface and lightness are required on the part since they do not have a head and have sockets at the end. They provide centring in the hole. If they are assembled, the level of disassembly is high. Their prices are higher compared to other bolts. For these reasons, it is recommended to be used only in special-purpose situations provided by this bolt.

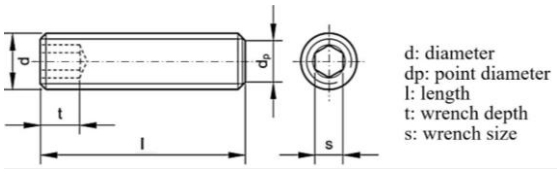

Figure 10. Setscrew

3.2. Bolt Selection Criteria

The criteria for each bolt were defined by creating a knowledge base based on numerical, technical and experience-based data, including the features mentioned in the previous title. In this way, the bolts were analysed according to their unique features and usage purposes, taking into account their possibilities, and separated according to head types.

For the developed expert system, these criteria, which will be applied during the selection of the most correct bolt according to the system, and the characteristics of each bolt, were brought together and correlated, and the answers to these were defined. The information obtained as a result of these transactions was summarized in Table 1 below. This information was used in the configuration of the expert system. Then, an example system for the use of bolt types is given in Figure 11.

Table 1. Bolt types and their relations with criteria

CRITERIA	BOLT TYPES				
	Hexagon H. B.	*Cylinder H. B*	*Countersunk H. B*	*Stud*	*Setscrew*
Abrasion, clearance etc. fine-tuning requirement	no	no	no	no	yes
Flywheel, pulley, gear etc. use in rotating parts	no	no	no	no	yes
Centring in hole	no	no	yes	no	yes
Flat surface requirement on the part	no	yes	yes	no	yes
Mounting accuracy	middle	middle	middle	high	low
Product/system weight status	high	low	low	high	low
High force-holding	yes	yes	yes	yes	no
Dusty, dirty etc. use in environments	yes	no	no	yes	no

In Figure 11 below, an example system showing the usage areas and purposes of the bolts is given. The details are explained on the basis of this figure, on the places where the bolts are connected. In this system, the hexagon head bolt was preferred because it does not require a special requirement in its location and there is no limitation in the area. The cylindrical head bolt was used because the mounting space is limited and it can be connected more easily, for example, with a allen key. The countersunk bolt was preferred in order to provide a flat surface and centering in the hole. Stud bolt was preferred because it can be found in long lengths and it is advantageous for mounting accuracy, and it was mounted in the position where it is seen in the system. Because there is a need for long bolts in order to make the connection in the region where it is located and a sensitive assembly is required. Setskur bolt was used to fix the circular part to the shaft and to secure its position.

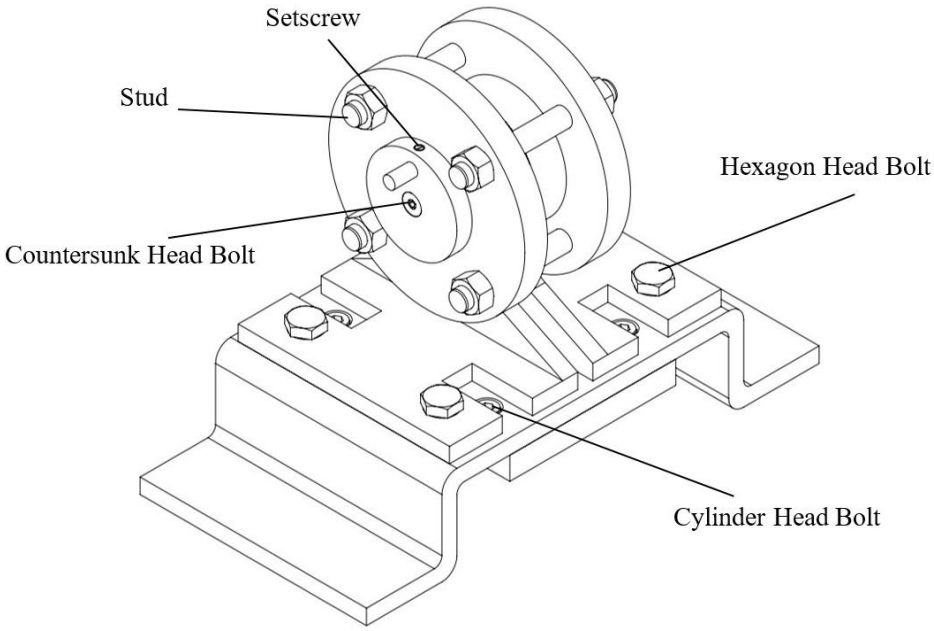

Figure 11. An example system for the use of bolt types

3.3. Design Rules and Criteria

The intended use of bolt head types is from general to more specific. As one enters from general use to more specific use, the availability of bolts according to head type decreases and their costs increase. According to the head types, the use of bolts from general to more specific can be listed as hexagon head bolt, cylinder head bolt, countersunk bolt, stud and setscrew. This situation was determined through data obtained from catalogues widely used in the market.

User responses to bolt selection may require bolts with more specific uses. In this case, the selection process tends towards these bolts. If user responses do not require special use bolts, the trend in the selection process is towards the more general use bolt head type.

With this expert system, questions are asked to the user about situations such as usage purposes, usage areas and working conditions. Questions are asked to the user from more specific to more general situations. The responses received are controlled by criteria related to these situations. Matching bolt head types are determined as a result of the control. If only one bolt head type is specified, it is reflected to the user as the most correct choice. If more than one bolt head type is specified, the general and special usage situation is taken into consideration and the more general use bolt head type is recommended to the user. The flow of design rules with Figure 12 is given below with the general programming structure.

Bolt types according to head shapes:

· Hexagon Head Bolt (HHB)
· Cylinder Head Bolt (CyHB)
· Countersink Head Bolt (CHB)
· Stud (STD)
· Setscrew (SSW)

User questions and possible answers:

[1] Abrasion, clearance etc. fine-tuning requirement: (y) yes, (n) no
[2] Flywheel, pulley, gear etc. use in rotating parts: (y) yes, (n) no
[3] Centring in hole: (y) yes, (n) no
[4] Flat surface requirement on the part: (y) yes, (n) no
[5] High mounting accuracy requirement: (y) yes, (e) either
[6] Intended system weight status: (l) light, (h) heavy, (e) either
[7] High force-holding: (y) yes, (n) no
[8] Dusty, dirty etc. use in environments: (y) yes, (n) no

[1] **if** (fine-tuning requirement = yes) **then =>** SSW **else if** (fine-tuning requirement = no) **then =>** HHB or CyHB or CHB or STD or SSW

[2] **if** (use in rotating parts = yes) **then =>** SSW **else if** (use in rotating parts = no) **then =>** HHB or CyHB or CHB or STD

[3] **if** (centring in the hole = yes) **then =>** CHB **else if** (centring in the hole = no) **then =>** HHB or CyHB or STD

[4] **if** (flat surface requirement = yes) **then =>** CyHB **else if** (flat surface requirement = no) **then =>** HHB or CyHB or STD

=>

[5] **if** (high mounting accuracy = yes) **then =>** STD **else if** (high mounting accuracy = either) **then =>** HHB or CyHB

[6] **if** (system weight level = light) **then =>** CyHB **else if** (system weight level = heavy) **then =>** HHB **else if** (system weight level = either) **then =>** HHB or CyHB

[7] **if** (high force-holding = yes) **then =>** HHB **else if** (high force-holding = no) **then =>** HHB or CyHB

[8] **if** (use in dirty environments = yes) **then =>** HHB **else if** (use in dirty environments = no) **then =>** CyHB

Figure 12. Design rules

4. CLIPS EXPERT SYSTEM PROGRAMMING LANGUAGE AND TOOL

In this study, CLIPS expert system programming language and tool was used.

CLIPS (C Language Integrated Production System): CLIPS is an expert system programming language and expert system creation tool. Developed at NASA's Johnson Space Center from 1985 to 1996, CLIPS is a rule-based programming language useful for building expert systems and other programmes where a heuristic solution is easier to implement and maintain than an algorithmic solution. Written in C for portability, CLIPS can be installed and used on a wide variety of platforms. Since 1996 CLIPS has been available as public domain software [29].

The CLIPS program is widely used due to its features such as being rule-based, using the forward chaining method, being open-source software, being easily available, being able to run on many systems, interacting with other programs, ease of use, and having comprehensive user guides. Because of these features, the use of CLIPS was preferred.

4.1. CLIPS Structure and Images

Some rule structures of the CLIPS programming language and then the interface and usage of the CLIPS 6.4 expert system tool are presented.

4.1.1. CLIPS Rule Structure

The “defrule” structure, which is one of the CLIPS structures, is used for rule definition. The part before the ”=>” statement is an “if” statement. The part after “=>” indicates a “then” structure. However, conditions can be created for desired situations with the expressions "or" and "and". It is sufficient to meet one of the conditions for the expression "or". For the "and" statement, all the conditions specified must be met.

```
(defrule rule1 ""
(or (criteria1 answer 1)
(and (criteria1 2 answer2) (criteria1 3 answer 3)))
=> (assert (conclusion inference)))
```

Figure 13. CLIPS rule structure

4.1.2. CLIPS Expert System Tool

The operating system in which the CLIPS programme is installed has two launcher applications, CLIPSDOS, which uses the DOS environment, and CLIPSIDE, which uses its editor. This study was carried out on CLIPSIDE.

The environment tab is actively used on the CLIPSIDE window. The developed expert system is loaded into the programme with the "Load Construction" option under this tab. When the programme is wanted to be run, the "Run" option is clicked to run the expert system. If the system is wanted to be restarted after the expert system is started and terminated, the “Reset” option is selected to delete the remaining data from the system that was previously operated and the system is reset. If desired, all texts on the editor can be cleared with the "Clear Scrollback" option. After these steps, the expert system can be “Run” again (Figure 14).

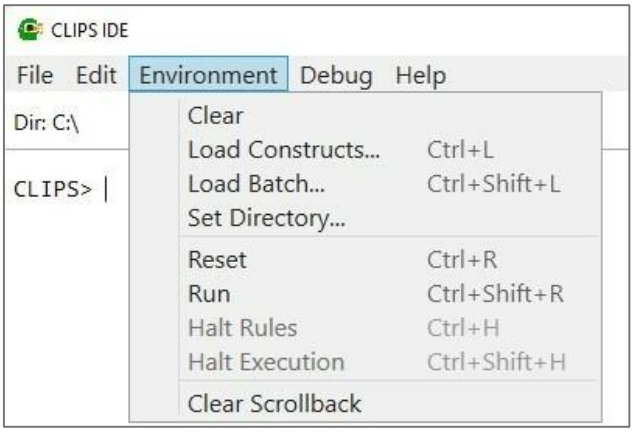

Figure 14. CLIPSIDE editor and Environment tab

5. DEVELOPED EXPERT SYSTEM

An expert system was developed to select the bolt type and to make this selection most correctly. CLIPS 6.4 expert system tool and programming language were used in the development of this system called *Exbolt System*.

Exbolt System: It is an expert system developed with the CLIPS programming language in order to select the most correct bolt type to be applied to a system. In this expert system, a total of 8 criteria was determined for 5 bolt types. At least 40 rules were developed for the criteria. Relevant rules were defined by using information and data obtained through scientific studies, technical documents and experience. In the query rules, questions were written in order to determine the selection criteria by taking answers from the user. The number of questions may vary depending on the answers given by the user. A series of scope narrowing processes are carried out according to the answers given to the questions. Thus, a selection process was structured to reach the most accurate bolt type. The selected bolt is printed on the program screen and recommended to the user.

After the program is run, it returns results once. If the result is to be obtained again, the system must be reset. Thus, it can be restarted and the result can be obtained. Since the selection process is based on clear cause-effect relationships, it can produce the most accurate results every time. In this way, results can be achieved in a logical way.

Exbolt System rules was created with codes written with criteria that can provide bolt selection.

Figure 15 and example result rules of the *Exbolt System* are given below. In the "if" structure of the "hhbconc" rule, which expresses the Hexagonal Head Bolt type, the "weight", "forceholding" and "dirtyenvironment" criteria are checked in the "or" bracket. When the user answers the questions "heavy", "yes" and "yes" to the criteria of "weight", "holding strength" or "dirtyenvironment", respectively, if any of these conditions are met, the "if" part of the rule is passed to the "then" part. With the "assert" statement in this section, "Hexagon Head Bolt" information is assigned to the result variable and the most accurate bolt-type result is reached. Other rules are checked similarly according to the answers given by the user to the questions. Thanks to this system, the relations of the answers with the criteria are checked, the conclusion rule that meets the conditions is run and the result is reached.

```
(defrule hhbconc ""
(or (weight heavy) (forceholding evet) (dirtyenvironment yes))
=> (assert (conclusion "Hexagon Head Bolt")))

(defrule chbconc ""
(or (flatsurface yes) (weight light) (dirtyenvironment no))
=> (assert (conclusion " Cylinder Head Bolt")))

(defrule chcconc ""
(centring yes)
=> (assert (conclusion "Countersunk Head Bolt")))

(defrule studconc ""
(mountingaccuracy yes)
=> (assert (conclusion "Stud")))

(defrule setscrewconc ""
(or (finetuning yes) (rotating yes))
=> (assert (conclusion "Setscrew")))
```

Figure 15. A sample rules part of the expert system

5.1. Application Example

The images of the process of operating the expert system called *Exbolt System* through the CLIPSIDE programme are given below with their explanations. These explanations will be based on an example flanged pipeline system with bolted joints.

This flanged system is widely used and this system mostly uses the hexagon head bolt type. Because of these situations, it was seen as a reliable sample and was preferred.

The developed expert system and established rules were tested on the already existing bolted flange connection. In order for the expert system to produce accurate results, the working environment and conditions of the bolted flanged connection were analysed in detail. In this direction, the expert system test process was carried out. The results show that the rules work correctly in the selection of the bolt head type and thus give a logical output. In this section, a detailed explanation of the case study is given.

The purpose of use, places of use and working conditions of the flanged pipeline system and bolts, which are considered as an example for the control of selection criteria, are examined. Accordingly, fine-tuning conditions such as wear and clearance are not required. It is also not used for fixing rotating parts such as flywheel, pulley and gear wheel. High centring is not intended in the holes where the bolt connection will be made. It is not a problem to have the bolt head and the nut on the surface of the part, so there is no requirement for a flat surface. Connections do not require high assembly precision. It is not a question of aiming to make the system light or heavy. Additionally, this system does not require high-force holding. However, the system is used in an environment with dust, dirt, etc. (Figure 16).

Figure 16. Bolt-on flanged pipeline system

Considering these working conditions, the process of running the expert system called the *Exbolt System* was carried out. Accordingly, the CLIPS programme was opened via the IDE, and the user is greeted by an editor that included the programme's version number and date information. The expert system file with the name and extension ExboltSystem.clp, which was developed with the CLIPS programming language, was loaded into the CLIPSIDE environment by specifying the location with the "Load Construction" option under the "Environment" tab (Figure 17).

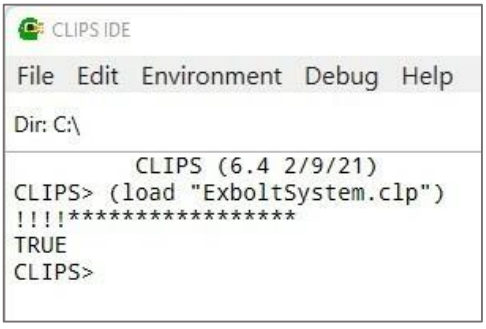

Figure 17. Installing the expert system called Exbolt System

Following the installation process, the "Run" statement was selected on the Environment tab on the CLIPS window, and the expert system was run. Then the first question was directed to the user by CLIPS (Figure 18).

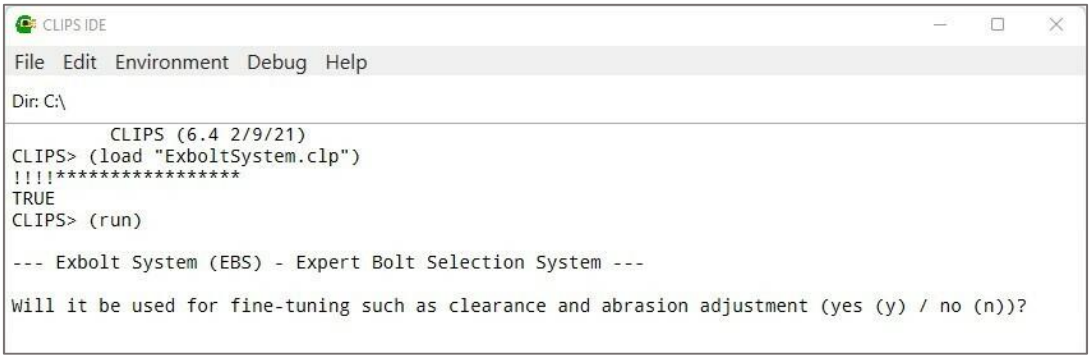

Figure 18. Running the programme

With the expert system called *Exbolt System*, every necessary question asked to the user during the bolt selection process was answered by the user and the expert system rules in the background were run. According to the criteria determined together with the answers received, a conclusion was reached by using the expert system inference engine and the most accurate bolt selection was made. Then, the extracted result was printed on the screen and conveyed to the user.

The answers to the questions posed by the programme are determined according to the system in Figure 15 and the specified working conditions and entered into the programme. Possible answers are “yes (y), no (n), light (l), heavy (h) and either (e)”. For example, if the answer "yes (y)" is considered, both "yes" and the initial letter "y" can be entered into the programme.

In the beginning, there are 5 bolt types in the scope of the expert system as hexagon head bolt, cylinder head bolt, countersunk bolt, stud and setscrew. Accordingly, the user was first asked about the usage status for fine-tuning. With the no (n) response, there was no narrowing in the scope of the bolt type, and accordingly, the system decided on the next question and directed it to the user. The no (n) answer was given to the question of use in rotating parts, hexagon head, cylinder head, countersunk head and stud bolts remained within the scope. Then, similarly, other questions were directed to the user and their answers were received. According to all these answers, only Hexagonal Head Bolt was the type of bolt that matched the criteria previously stated in the expert system. As a result, the message “Bolt selection is complete” was given to the screen by the expert system. The selected bolt type "Hexagon Head Bolt" was conveyed to the user and the suggestion process was completed (Figure 19).

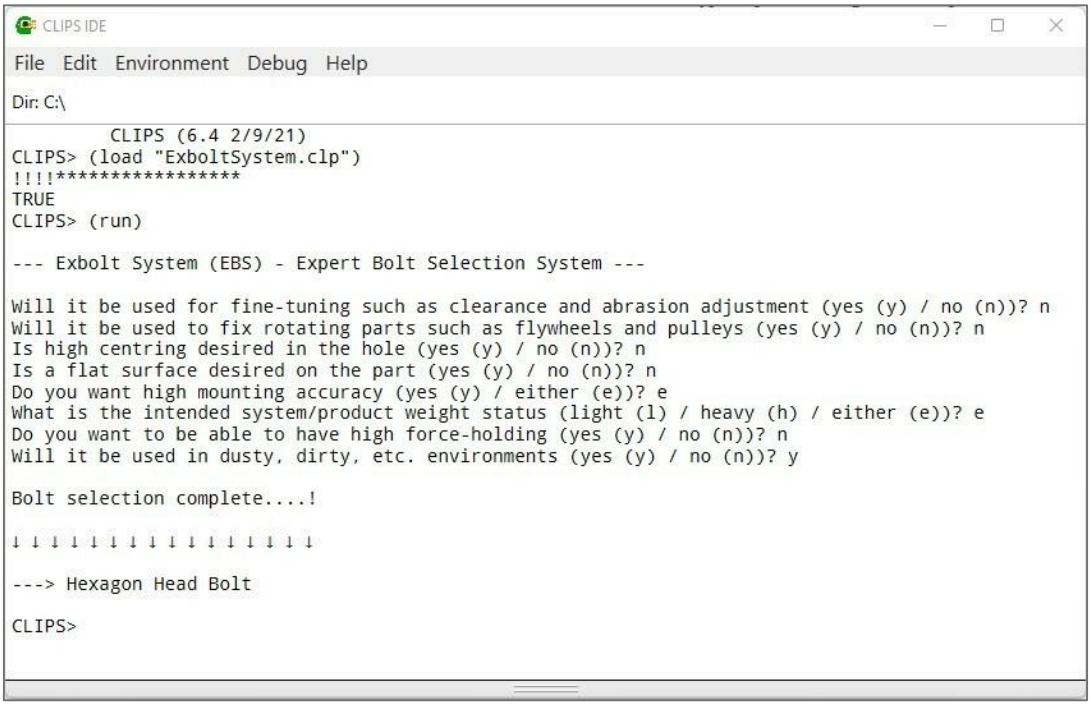

Figure 19. Asking the required questions by the programme, getting the answers and choosing the bolts

With the result that emerged after this process, it was observed that the bolt type used in the existing system, which was taken as an example, and the bolt type recommended by the expert system matched. Based on this, it has been understood that the expert system called

Exbolt System has reached the right result in the selection of bolt type that requires expertise.

6. DICCISSION

Artificial intelligence is a technology used to enable a computer system to mimic real human thought and behaviour. By using artificial intelligence, machine learning, data mining, neural networks and other technologies, it enables systems to learn, understand and be understood and continuously improved.

Artificial intelligence can be applied in various fields. For example, it can be used in speech recognition, image recognition, language processing and automatic machine learning. Artificial intelligence is also used in various industries such as machinery, robotics, automatic control, finance and e-commerce.

Artificial intelligence has developed rapidly in recent years and is finding more applications thanks to technologies such as larger datasets, more powerful processors and more complex algorithms. In the coming years, artificial intelligence will improve people's lives and will be used more and more in various sectors.

In the machinery sector, it is used for selection, diagnosis, maintenance and even more different purposes. When the studies carried out for the purpose of selection of artificial intelligence are examined, it was seen that there are studies on the selection of machinery and machine elements. One of these machine elements is bolts. Studies was carried out on the selection of bolts under various classifications. In the present study, it was aimed to choose the most correct bolt type according to the head types. For this purpose, an expert system was developed. The results of this developed system were checked over an existing system. Program outputs and obtained results were compared with previous studies and their aims, differences and superiority over each other were evaluated.

The *Exbolt System* test process was carried out taking into account the place of use and operating conditions of the already existing flanged connection, which is considered as an example. The bolt type obtained at the end of the test process was compared with the bolt type used on the flanged connection and it was seen that a correct selection process was carried out (Figure 20).

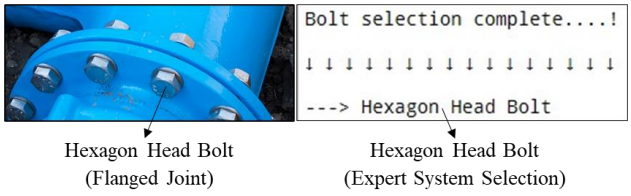

Figure 20. Comparison of existing flanged joint and developed expert system

In the closest study to this study in the literature, an expert system was developed for the selection of machine screws for the design of industrial products. This system was created using the PC-PLUS expert system tool [5].

The current study, which is compared with this study in the literature, considers bolts and bolt head types instead of screws. Different head shapes were used in the studies. Therefore, the scope of bolt head types in this study was formed in a different way. In the selection of bolt type, more places of use, purposes and working conditions were taken into account. Thanks to these features, the *Exbolt System* has become a more targeted study.

The work in the literature includes rules on assembly techniques and material properties. In addition, fixing strength, corrosion resistance, magnetic properties, electrical conductivity, thermal conductivity, thermal expansion, safety, cost and appearance factors were also taken into account to improve the quality of the selection. The *Exbolt System*, on the other hand, is based on the selection of bolt head types. For this, the place and purpose of use, working conditions, including criteria such as the need for fine-tuning, use in rotating parts, centring in the hole, flat surface requirement, mounting accuracy, system weight status, high force-holding and use in dirty environments are taken into account.

7. CONCLUSIONS

The selection of bolts, which are used for various purposes in almost every field from past to present, is complex, thought-provoking and therefore a time-consuming process. To improve this situation and to select the truest bolt, an expert system called *Exbolt System* was developed with the CLIPS expert system programming language. For this developed bolt selection system, a total of 8 bolt selection criteria was determined, including concepts such as working conditions and mounting situations, and the number of which may vary according to the answers given by the user. Catalogues that are widely used in the sector were examined and a common conclusion was reached and the most commonly used bolt types were determined. As a result, 5 bolt types were reached and an expert system was designed accordingly. The programme and the questions directed to the user was structured in a clear, clear and understandable way. Time is saved by asking only the necessary questions depending on the answers. The developed expert system evaluates the answers to the questions according to the determined criteria and suggests the user by reflecting the truest bolt for the relevant situation on the programme screen. With the expert system called *Exbolt System*, which has an effective structure, the most accurate result was achieved in a simpler and shorter time without the need for an expert in the bolt selection process, which requires expertise, is complex and takes time. In this way, a more effective and efficient selection process was passed.

With the expert system developed within the scope of this study, the head type selection of the bolts was handled in a different dimension compared to the literature and various criteria such as the purpose of use of the bolts, the places of use and working conditions were taken into consideration. This study is based solely on the head type selection of the bolts. In this direction, subjects such as bolt threads and profiles, material information are not included in the scope of the study. By using this expert system at the beginning of the design process, the user can prevent unforeseen limitations and errors that may be created by future usage conditions before they occur. In this way, labour and time savings can be achieved by minimizing design repetitions and tests.

Based on this study, the scope of bolts can be expanded by including other bolt types in future studies, and a more detailed selection process can be carried out by increasing the number of criteria. The material properties of bolted connection systems can be included in the study. A more extended expert system can be written by conducting various analyses such as static and dynamic within the programme. By developing a user interface and providing expert system integration, an interactive visual expert system that can provide visual content and technical information to the user can be developed.

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