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REPRESENTATION OF FEATURES OF ELEMENTS FOR KNOWLEDGE-BASED COMPUTER-AIDED DESIGN AND EXPLOITATION

Summary. *We present a method that is suitable to represent features of machine elements for Computer-Aided Design and Exploitation. Properties of machine elements are represented using statements, that may be written as a triple <Object, Attribute, Value>. The method enables us to represent statements by means of frames used in the Expert System Shell MAS. Furthermore, a concept of application of this method to computer-aided quality assurance according to international standards ISO 9000 is presented.*

1. INTRODUCTION

In the Department of Fundamentals of Machine Design, Silesian Technical University of Gliwice, research is carried out on *Computer-Aided Design and Exploitation* of machinery. To achieve this goal, we try to apply *shell expert systems*. However, important difficulties have been identified that concern numerical representation of features (*properties* and *peculiarities*) of considered abstract objects (*system* and *design*) as well as material objects (*products*), both simple and composite (e.g. *assembly* or *sub-assembly*).

The main goal of the work presented was to investigate a possibility of numerical representation of machine elements features and relations occurring between these elements. Frames have been selected as a means suitable in representing declarative and procedural knowledge on machine elements (simple or composite) and relations between the elements. Knowledge is represented by means of *statements* written as triples (*W.Cholewa*, [1]):

`<object, attribute, value>`

Thus the method of knowledge representation makes it possible to write statements by means of frames that are applied in a shell expert system *MAS* (*W.Cholewa*, [2] [3]) developed in our Department. It is worth to stress that the method elaborated facilitates acquisition of knowledge and data on machine elements as well as verification and updating of databases and knowledge bases.

Moreover, a concept of an application of this method in computer-aided quality assurance conforming with international standards ISO 9000 has been presented (*W. Moczulski*, [7]).

2. PROBLEM DESCRIPTION

In the techno-sphere a human being has to deal with even more and more composed technical means. We should distinguish here (*J. Dietrych*, [5]) man's *operations on creations* (*abstracts* - that takes part in designing process) and *operations on products* (e.g. identified piece of a rotating compressor type *ABCD* with its stock number *1234*, operated in a plant *XYZ*). Subject of operation (of abstract or material nature) may be identified by means of *features* (*properties* and *peculiarities*). Such a behaviour is rather of *declarative character*. Features of the object described can be:

- *constructional features*, used to identify the *design of an element* - this corresponds with *abstract objects*,
- *features of the product* given (features of the given piece made in conformity with its design).

Constructional features are referred to abstract object. Features of the product are *abstract properties and peculiarities of the product*. To represent the feature given, one has to:

- identify an *object* that this feature is referred to (e.g. given element of the machine),
- define an *attribute* which is represented by a couple: the *name of the feature* and *nature of ownership* of the feature describing this object,
- give a *value* of this attribute.

Thus, to represent both the constructional features and features of the product, *statements* (subjective by default) shall be applied, that may be written down in the form of a well-known triple `<Object, Attribute, Value>` (*W. Cholewa*, [1]). Hence, *frames* are suitable as a means of representing such statements in *databases* and *knowledge bases* used in expert systems. To avoid redundancy of these bases it is possible and expedient to introduce *inheritance* of properties of the objects as well as methods how attribute values may be estimated.

2.1. Computer-Aided Design of Machine Elements

A design is the property of a *class of products*. From the operational viewpoint it is usually indispensable to perform a *record of the design*, e.g. making possible verification of the design by calculations or even simply transferring the design to the producer of a machine. Several constructional features, as: *geometric features*, *material features* and *dynamic features* (called *assembling features* as well) are subject to record. Recently it is common to aid this task by means of computers and there are well-known computer programs (e.g. *AutoCAD*®) suitable for this purpose. But besides preparing *'technical drawings'* of elements or even composite machines, other complex tasks may be aided by means of computer, as:

- creating *concepts of solutions of the technical problems* given,
- *design* - as a name of a creative process, the goal of which is to consider upon a *system of operation* and *constructional form* of the prospective product (*Ch. Tong, D. Sriram*, [9]),
- elaboration of *technological process* including *machining* and *assembly* (integrated with *manufacturing control*; *T.D. Pham*, [8], *F. Kimura et al.*, [6]),

- automatic generation of *documentation on installation, maintenance and troubleshooting*[1].

Considerably many phases of the bread-understood designing process involves the propriety of computer-aided *verification of design* by means of calculations.

.Verification of elements and/or assemblies in the designing process consists in examination whether a *given criterion is fulfilled*. Here an identification of a *network of criteria* and *methods of determining criterial values* to be used in a given stage of verification is crucial. An analysis of the collected criteria is an interesting problem (criteria may be inherited as well).

2.2. Computer-Aided Exploitation of Machinery

Numerical representation of features of machine elements for computer-aided exploitation of machinery may correspond to both the abstract objects (design of the machine given) and the products (artefacts). In the second case it is very important to give data on installation (or service) life of the described product.

We distinguish two fields of applications concerning exploitation needs, where verification of machine elements may be often necessary. There are as follows:

- *technical diagnostics* in the broad sense, including *machine monitoring*,
- development of so-called *systems of exploitation*.

We want to explain a meaning of a phrase *'verification of machine elements'* regarding exploitation of machinery. For example, this verification may include:

- identification of propagation paths of vibrations in a complex artificial system (*machine-foundation-subsoil*),
- estimation of dynamic peculiarities of the investigated system, also with application of simulation and modelling (e.g. estimation of eigenfrequencies of a shaft and critical speeds of the system *rotor-bearing supports-foundation*),
- identification of *casual-resultant relations*.

We shall take into consideration a need to represent *structure of a technical means* often constituted from many elements inter-related spatially and functionally.

2.3. Computer-Aided Quality Assurance

International standards of the well-known series *EN 29000 (ISO 9000:1987)* state that producers shall collect, analyse and update *quality records* concerning machine elements or even the complete machines (see *W. Moczulski*, [7]). In the stage of manufacturing a compliance of each piece of product with the design is examined. The design of this product is regarded here as a recipe defining constructional features of a class of machines or elements of machines. Such an examination is a task of the *Quality Control* and a *Measuring Card* is commonly used, filled-out with results of examinations of each piece of the product. *Required values* of features (e.g. dimensions or angles

[1]This concept has been presented by *W. Skarka* on the Seminar of the Department of Fundamentals of Machine Design on 15.12.1993.

with corresponding tolerances defined in the technical drawing) are compared here with *actual values* of these features measured on the examined piece. It should be stressed that the method of numerical representation of elements enables us to write down both kinds of feature values. Here the design of the given element acts as a model of all pieces of the class. Values of features of the products examined are written down as *actual values of features* into the *Measuring Card*. It is also possible to have actual values of features of the product compared with model values and tolerances determined by the designer, to decide whether the product complies with the design of this product. Such activities may be aided by means of computer programs, for example by *expert systems*. To apply the expert system it is necessary to elaborate (develop) corresponding *databases* and *knowledge bases*, that make the comparison of required values of features (together with related

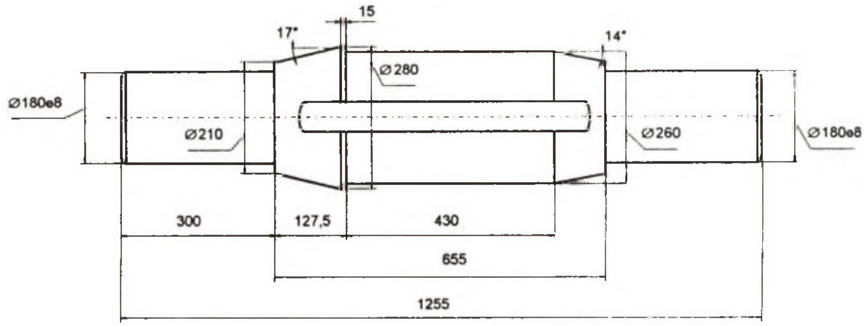

Fig. 1. Representation of the constructional form of a shaft (non-exhausting)

tolerances - defined or implied) with actual values of these features possible.

3. OUTLINE OF THE CONCEPT

The object is described by means of its features. It is recommended to represent features of abstract objects (representation of design of the object). The design of the object is represented by features common to the class of the products, which conform with the design. Furthermore, it is necessary to represent features of artefacts (products), identified within the following stages of its 'life' during:

- *manufacturing process*,
- *final inspection and testing, in-house or in customer's shop* (when the machine is installed),
- during *exploitation of the given piece of the product* (representation and recording of *states of exploitation of the product*).

3.1. Representation of Elements

A method of representation chosen should take into account different aspects that are used by participants of designing process when they determine constructional features of an element already designed (*Ch. Tong*, [9]). The designer exactly determines these constructional features, taking into consideration specific peculiarities of the designed element regarding its operation and co-operation with other elements constituting an assembly. A production engineer will determine constructional features of the same element, considering respective manufacturing operations.

The above mentioned aspects may influence way of identifying objects, attributes and values of these attributes, represented by means of statements. In the case of an element it is often necessary to distinguish *parts of this element*[2]. Representation of constructional features numerically does not mean that this element has been *decomposed into several parts*; on the contrary, we consider features of the element using system approach. Thus the system of dimensions of the element is very important because it enables us to express different methods of dimensioning *from constructional bases, machining datum surfaces, measuring bases* or common *reference lines* (see Fig. 1). Instead of operating seemingly separated parts between others, we distinguish *views*[3], *sections* and *details*, just like in the *working drawing* or *assembly drawing* of the element.

It is possible to find out some similarities between the method presented in the paper and the so-called *verbal representation of design of an element* (see *J. Dietrych*, [4]) that may be regarded as a set of statements concerning constructional features of this element.

Numerical representation of constructional features of the elements by means of statements may be insufficient if we concern advanced needs. For example, if one wants to verify reliability of the element exposed to varying loads it is necessary to represent *procedural knowledge* covering methods that determine *measures of influences of different notches* that affect surface of the element.

3.2. Representation of Assemblies of Elements

An assembly is a complex of elements joined through different relations, distinguished with respect to several operations, which in particularity:

- have to be executed by the elements constituting this assembly (operation of the assembly),
- may be performed on these elements, for example within assembling,

[2]Notable achievements in this field (eg. concerning hudraulic servomechanisms) has the group of *R. Knosala* from Silesian Technical University of Gliwice

[3]Suggestion of *W. Cholewa* given on the Seminar of the Department of Fundamentals of Machine Design.

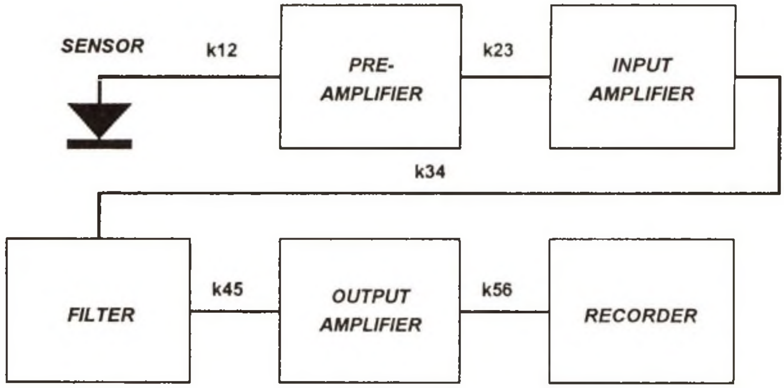

Fig. 2. Relations between elements of the measuring channel of a diagnostic signal

- shall be carried out in the stage of exploitation of the machine (maintenance, repairs, etc.).

If we consider an assembly, we find out that it is possible to identify manifold relations between elements composing the assembly. Criteria of separation of assemblies of elements depend on given stage of design process (eg. these applied in the stage of design differ from those used when a technology of assembling is elaborated). Thus *simple* and *composite/compound elements* should be distinguished regarding the criteria of separation or identification of elements discussed previously.

Numerical representation of structure of a complex technical means is very important. The structure may be introductory described by determination of relative position of an element given respective to other element, ways of co-operating of elements (eg. *meshing*), mounting elements on shafts, etc. *Kinematic and dynamic structure* of a given assembly (due to principles of *mechanical theory of machines*) may describe essence of relations between elements constituting the assembly.

Because the representation of elements for the needs of technical diagnostics and monitoring is necessary as well, we should give our attention to a peculiar case of *measuring chains* used to observe diagnostic signals as carriers of information on technical state of the investigated machine. In this case, relations between elements of such an assembly become simplified (notation k_{ij} in Fig.2): since usually relative placement of the elements is unimportant, whereas connections between elements of the measuring chain are realised by means of cables with defined peculiarities (capacity, wave resistance, etc.).

3.3. Descriptions of Elements and Parts of Elements

The method of numerical representation of machine elements should make it possible to represent *procedural knowledge* that determines how *descriptions of machine elements may be generated*. Representation of elements for the needs of design requires creation of *lists of elements* and *bill of materials*. Corresponding routines should create names of standardised elements regarding to techniques described in the respective standards.

```
class <class name> :: <list of _superclasses>
{
    //   private and public "fields"/components
    //   (eg.: serial No, type)

    //   private and public functions/methods (verification of
    //   objects, estimation of features of these objects,
    //   creation of descriptions of these objects)
}
```

Fig.3 The way of representing a class of elements

When we intend to apply the knowledge on elements in a diagnostic expert system, descriptions of elements created by respective routines may be used to *formulate conclusions in diagnostic reasoning* or to *generate explanations as answers to questions of the user of this expert system*.

4. IMPLEMENTATION OF THE METHOD

To represent data and knowledge on constructional features and exploitation states of classes of elements as well as individual pieces belonging to these classes, statements may be applied or other more flexible means of representation as *frames* and *decision tables*. Such a representation is possible in a *FDL (Frame Definition Language)* in an environment of a shell expert system *MAS* (*Maintenance Aid Shell*). The system *MAS* is an application package operating on IBM PC AT with a microprocessor 80386-SX or higher, under the operating system *MS-DOS* and *MS Windows 3.1*. The system *MAS* has been developed in the Department of Fundamentals of Machine Design, Silesian Technical University of Gliwice (see *W. Cholewa* [2] [3]).

Representation of elements for Computer-Aided Design and Exploitation is also possible by means of *Object-Oriented Languages*, e.g. *C++* (See Fig.3).

Moreover, individual statements may also be written down as separate records in a relative database (see *W. Cholewa*, [2]).

Numerical representation of machine elements by means of such techniques as frames and classes may be suitable to reduce redundancy of databases and knowledge bases. To achieve this, suitable structure of a set of frames and/or classes is necessary. For the needs of Computer-Aided Design and Exploitation it is expedient to apply *multiple inheritance* yielding *network-like structure of classes*.

5. RECAPITULATION

The research described has confirmed the possibility of numerical representation of features of machine elements and relations between simple elements (within the assembly the element belongs to) and representation of assemblies of composite elements. Representation of properties and peculiarities by means of frames and decision tables facilitates acquisition of data and knowledge as well as verification and updating of databases and knowledge bases. The *Frame Definition Language FDL* used in the Shell Expert System *MAS* may be applied for representation of features of machine elements. It is possible to represent constructional features (of the design - abstract) and features of peculiar elements. In the next stage of research we are going to define a hierarchical set of classes of machine elements and their assemblies and subsequently define class functions intended for verification of simple and complex elements and creation of descriptions of these elements.

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