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UPGRADING A CAD SYSTEM WITH EXPERT SYSTEM

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1. Introduction

Effective 3D CAD tools are inevitable in development of complex products and represent the basic support of concurrent engineering. Almost all modern modelling packages are parametric systems based on feature history. According to VDI 2218, a feature is defined as a representation of a product form, which can be transformed into a generic form and which is functionally significant to an individual phase of the product life cycle. We distinguish between form-features and semantic features. The former being a structure-oriented group of elements (or an individual element) defining a shape and the latter connecting the form-feature to further extended data such as functional and engineering information.

In modern programme systems for 3D modelling the features are well defined in the sense of form, whilst the semantic definition is limited. Those systems have a number of insufficiencies, the main of which are: lengthy computation of geometry upon model regeneration, limited possibilities of applying dimensional and geometrical model constraints, unidirectional constraints, in some cases poorly defined modelling semantics and inadequate preservation of feature semantics [Bidarra 2000].
These problems show even more clearly in adaptive and variant design. For these two design methods intensive interventions into the model history are characteristic, which causes lengthy model regeneration. Geometrical relations between features have to be defined very exactly. The model structure frequently gets corrupted, which in turn causes inconsistent geometry.
Parallel to the feature technology, other techniques are appearing which in the first place enable automation of adaptive and variant design [Bidarra 2000]:

- *Macrotechnique* makes use of groups of characteristic parameterised elements in databases. A macro programme calls the required element from a library and updates its parameters with current data.
- *Variant programming* varies the variable dimensions of parts or groups of products and, based on these dimensions, creates new drawings, work plans or NC code.
- *Parameter- and constraint-based models* are based on a parametric database and build the model based on the data contained in such a database.
- *Semantic model* is based on declarative description of all the object properties - the geometrical parameters as well as the validity conditions in the form of constraints [Bidarra 2000]. Such a model facilitates variant and adaptive design, as well as design from scratch.

2. Problem definition

Large dimension Rolling Rotational Connections (RRC) (Figure 1) are machine assemblies, vital for operation of different kinds of cranes, construction machinery, military equipment etc. The basic parts of rotational connections are rolling bearings of special (non-standard) construction with relatively large rolling diameters. Because these bearings are usually loaded with a combination of radial force, axial force and turn-over moment, their rings have to be connected to the supporting structures with pre-stressed screw connections [Prebil 1998]. The relative rotation between the supporting and the upper structure is enabled by the gear pair - the pinion on the driving aggregate and the toothed ring integrated on either the inner or the outer bearing ring.

The bearing as well as the bolt connections are of vital significance for the function and the safety of the entire object. If they fail, the object fails. Because of this, while employing the most modern special knowledge from the fields of contact problems [Drobnic 1996], structural mechanics [Prebil 1998] [Zupan 2000], low cycle, time limited, and dynamic strength [Kunc 1998] and own experience, during design and analysis the standards and technical prescriptions [Prebil 1995], relevant for the customer, have to be considered. In especially demanding rotational connection constructions the deformability of objects and their influence on the carrying capacity and bearing lifetime of the built-in bearing, the bolt connection and the gear pair also have to be verified.

Rolling bearing with integrated screw connection and gearing is, regarding the requirements, a complicated machine element, manufactured by a specialised producer. In Europe, and even in the world, there are few large manufacturers with good experience, strong design and development department, and even an offer per catalogue. Small manufacturers, developing the bearings for low series, or even individually for new structures or overhauls, are much more frequent. The customers usually collect the offers in the phase of the general structure design, and expect very short answering time, thus the automation of design and production preparation process is necessary.

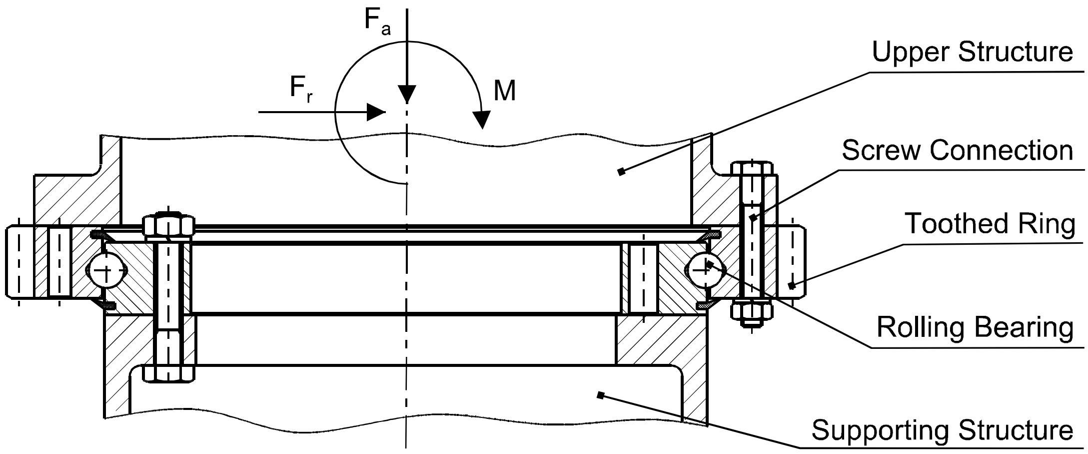

Figure 1. Rolling rotational connection composition

2.1 Previous methods of RRC design and production automation

Design of RRC involves mainly variant and adaptive design. In the design process, there is much iteration, especially in the last two phases: embodiment and detail design. In these two phases we have a set of concrete information that has to be harmonised and the workshop and the assembly drawings produced on its base. Besides that, the carrying capacity of vital elements has to be verified each time, and, regarding the particularities and changes required by the customer, carry out the optimisation of the structures and consider their deformability.

As the first step towards automation of this procedure we have developed macro programme modules in the ME-10 commercial package [Prebil 1995]. These modules automatically create 2D assembly drawing of a rolling bearing and the workshop drawings of its rings and other non-standard parts, based on the data from a geometrical database.

As a further step we have, considering the principles of variant programming, developed the Rolling Rotational Connection Design Programme Environment, which offers support to the designer throughout all the phases of the design process and takes care for the entire data structure [Prebil 1995] [Kaiba 2000]. The work is entirely automated and is done in a graphical user interface starting from the customer request input, over the design conception, carrying element dimensioning, structure optimisation, to producing 2D and 3D model and CNC control code. The developed expert system maintains for geometrical accordance of the individual elements, their dimensioning, optimisation and producing the documentation. Producing the 2D and 3D models, the documentation and the CNC control code is automated and is performed within commercial CAD and CAM packages, which are connected to the Programme Environment by means of connecting modules.

The main insufficiency of both systems lays in the fact that introducing a new type of rotational connection requires a considerable amount of work and time (even several months). Furthermore, should we wish to adapt the system to variant and adaptive design of another standardised or typified assembly (e.g. linear roller or ball bearings, linear guide-ways), we would have to re-make the entire system, which could last up to a year. Moving to another commercial CAD or CAM package would require development of a new connecting module, which is also a fairly lengthy process.

In the proceeding work, we will describe the concept of upgrading a commercial 3D modeller with an expert system, an object-oriented database and the methods as those, used in the Rolling Rotational Connection Design Programme Environment. Such a system is currently in development. Its use is mainly directed to variant and adaptive design of typified assemblies. Design from scratch will remain supported with the classic functions of the 3D modeller used.

3. 3D modellers

Modern 3D modelling packages are based on feature technology. The object in conception is divided into basic building blocks - the features, which, depending of the CAD package used can be 3D primitives (Block, Cone, Wedge,...) or sketch-based extruded profiles (Protrusion, Revolved Protrusion, Swept Protrusion,...) etc. New elements that can, besides the described ones, also be of other types like Chamfer, Cut, Hole, Thread etc., are then added to those features. All the mentioned features enable good parametric geometry definition and a clear representation of objects. Among them there are well-defined geometrical relations that determine their respective position, orientation and mutual relationships (material removal and addition, welds and edge preparation, etc).

Within a modern 3D modeller, the technical system being developed is divided into basic building blocks - the features that represent only the bare passive knowledge, required for the graphical representation. The parametric nature of the feature geometry, and thus the parametric nature of the models, enables variations in design. However, a model (or an assembly) defined this way is dependant on the history of the building blocks it consists of. Upon any change in the sequential order of the building blocks, it often happens that the object can no longer be updated. The relations between the principal building blocks must then be reviewed and properly corrected. Such a procedure is a time consuming one, especially if the designer has to perform modifications to the technical system after a longer time period. Furthermore, the relations can only contain quantitative values and formulae that determine mutual dependencies among building blocks [Bidarra 2000].

In some modellers the designer can also attach semantical descriptions (such as material, tolerances and surface quality) to individual entities. Regardless of this, the semantical description is still insufficient as it is based on the feature composing history and insufficiently considers the operating conditions and numerous technological parameters [Bidarra 2000]. Procedures of dimensioning and optimising the vital carrying elements cannot be automated. Thus, we cannot describe the numerous data and constraints, which have to be considered during design as for the construction to be properly devised and in conformity to various criteria of the *Design For - DFx* principle [Hubka 2000]. Numerous requirements and sight points have to be considered:

- <u>*manufacturing technology*</u>: bending length limits, physical boundaries of machining capabilities,
- <u>*input material*</u>: sheet metal dimensions, lengths and other dimensions of purchased profiles, class gauges of standardised elements, available washers,

- *required carrying capacity and life span*: dimensioning and optimising of elements and designs (VDI 2230, DIN 3990, ...),
- *maintenance*: the available tools and maintenance equipment, spare and replacement parts, consumer materials,
- recycling, ergonomy, price, etc.

4. Upgrading the 3D modeller

The expert system of the Programme Environment [Kaiba 2000] was adapted and upgraded so that it is able to read in a 3D model, made with a commercial 3D CAD package (Unigraphics or SolidEdge). Doing this, the expert system recognises the objects that represent the basic features the model is composed of, and copies them into its own data structure. Geometrical relations within the features are not recognised, so they cannot be considered and changed with the expert system. The data that is recognised and considered by the expert system are:

- type of feature, its identification number and its position within the structure of the model or the assembly,
- geometrical data about the dimensions of the feature (the parameter ID and its value),
- global co-ordinates for positioning within the assembly or within the element,
- relations and parameters for positioning within the assembly or within the model and
- the data needed for textual and symbolic representation and identification.

During recognising the 3D model, we can determine the part type (*common object, gear pair element, bolt connection element, rolling bearing element*) for each assembly object. For each individual data (from each part and its building features) we can add its textual description and determine its type. We distinguish between three data types:

- *Type 0*; a data that represents a customer request or constraint that must not be changed. Should the designer want to change such a data, the expert system issues a warning. In case changes in other data lead to changes in any *type 0* data, the expert system first tries to find another design variation, and only upon failing to do so it terminates its job and issues a warning about the conflict.
- *Type 1*; represents a data, a change of which requires the expert system to consider the prescribed numerical methods and re-dimension the element. Numerical methods are programmes written and compiled in arbitrary programme language (Fortran, BASIC, C etc.), while the expert system only contains a rule about the record format and a calling procedure (command line) that it uses to launch the calculation.
- *Type 2*; represents a data that doesn't have influence on the carrying capacity of the element or has only informative meaning and can be optionally changed in any case.

A *common object* is not supported with numerical procedures for dimensioning and optimising and can only contain *type 0* or *type 2* data. Within the expert system each entity can have its global and semantical data besides its read-in geometrical data, its added commentaries and its appointed data type:

- technological data about material, surface state and machining methods,
- constraints regarding input semi-works and raw pieces,
- physical boundaries and ergonomically constraints,
- economic and organisational data (manufacturing and retail price, control protocol, element affiliation etc.)
- the container of relations that define the geometrical data modification rules and the rules for modifying the relations and parameters of the connections to the neighbouring entities within the model or within the assembly.

This data is used in determining the relations between the data, read-in from the 3D model an in determining the constraints that the expert system has to consider when performing changes. The structure of the read-in model and all its data can be reviewed in a specially designed dialogue window (Figure 3). The user interface also enables searching for any particular data by its description or its name. The expert system enables work with several design variations, so that the designer that develops the design variations can review and verify various modifications.

The designer that makes the design conception starts by working on the design in a commercial 3D modeller. Afterwards he transfers the data into the expert system, defines the data descriptions and data types and makes the knowledge base. In this database the conception designer describes how the data about the structure and its entities is interconnected. The knowledge base is presented as a graph, where the connections between the data represent the relations between the data (Figure 2). Within the connections (relations), the rules and the constraints are determined that the expert system has to follow in varying and adapting the design. The work is performed the same way as in the Rolling Rotational Connection Design Programme Environment [Kaiba 2000] (Figure 2) and will thus not be further described. The inference engine, the rule and decision following and the database, where the knowledge base and the design versions are stored, are the same as in the described Programme Environment [Kaiba 2000].

The designer that performs variants and adaptations of the design begins the work in the expert system. They can review and alter the design and design variation data by using the user interface, either as table or as a tree structure (Figure 3). Upon each data change, the expert system is automatically activated to verify consistency of the required change. Regarding the rules in the knowledge base, the expert system accordingly changes the data that is connected to the data being changed, performs dimensioning of the carrying elements, or prevents the change if it conflicts with a *type 0* data. After the variation or adaptation of the design is finished, the designer opens the prototype model, outlined by the conception designer, in the 3D modeller, and the expert system updates it with the altered data and triggers regeneration process.

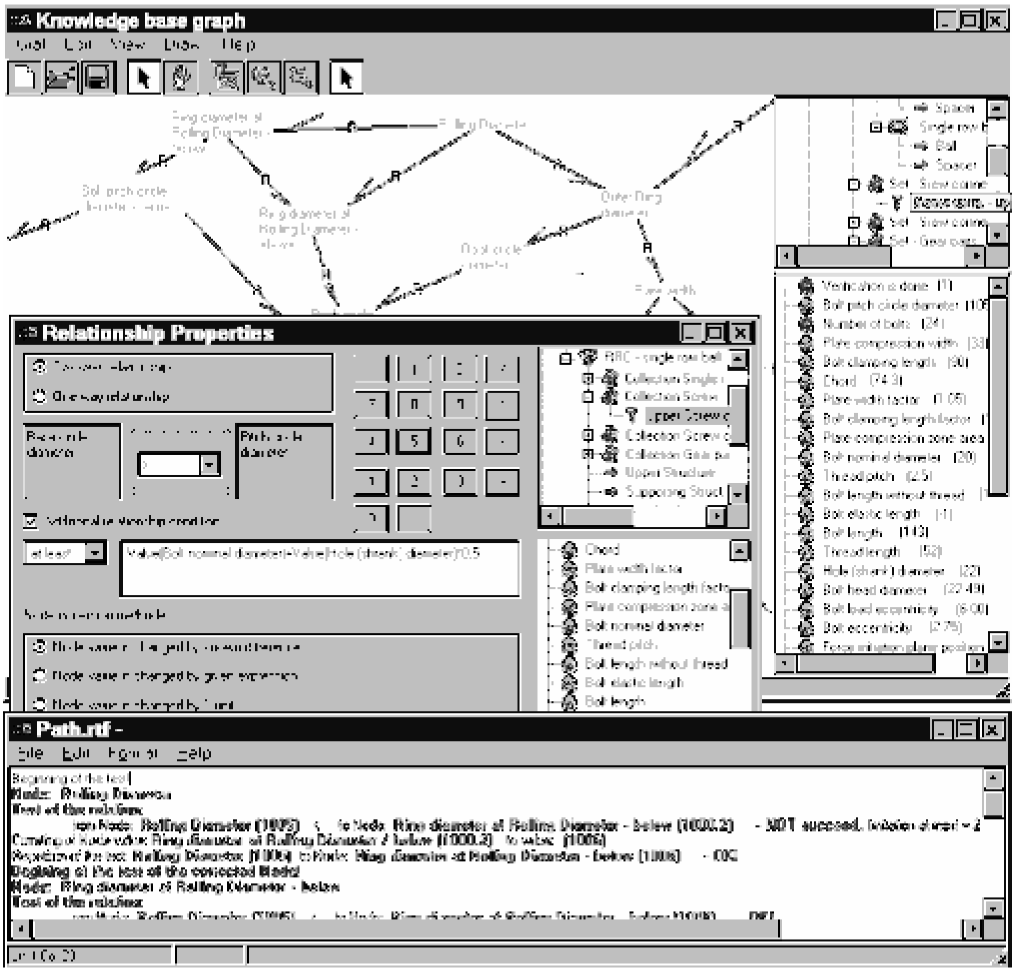

Figure 2. Overview of a part of the knowledge base, rule determination and change following based on the rule execution

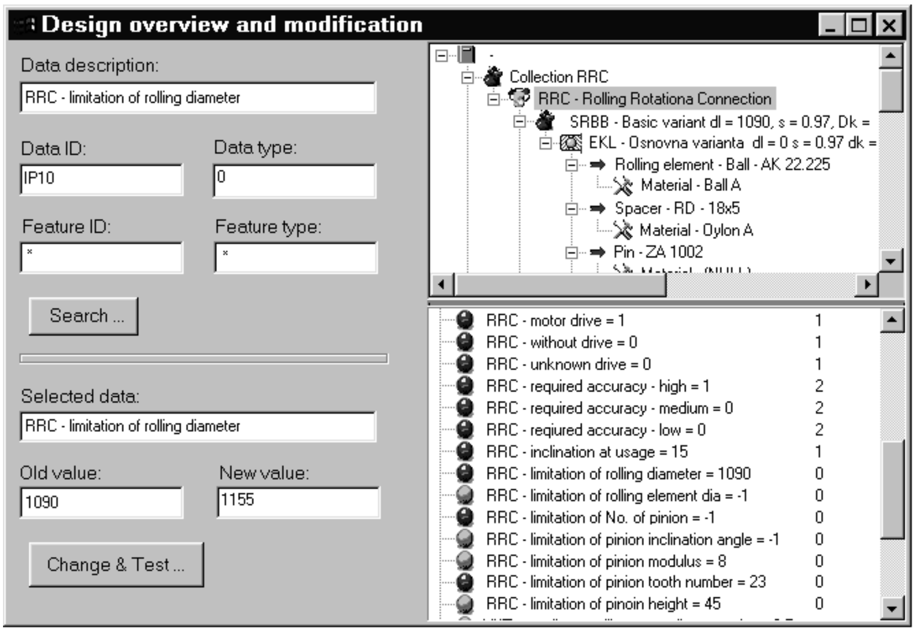

Figure 3. Overview, search for and changing of the model and its data

5. Conclusion

The designer, who develops new designs for typified or catalogue retail, starts his work using commercial CAD package. He prepares and optimises the design using the standard functions of such CAD system. After that the described upgrade of commercial 3D modellers enables him to quickly prepare the expert system for producing variations or adaptations of new typified designs. In relation to previous macro programmes or the variant programming approach a 70 % time saving can be noticed, while the production of variations and adaptations of rotational connections itself is performed with approximately the same speed and effectiveness as with the Rolling Rotational Connection Design Programme Environment.

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