FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

COMPLETE PROGRAM SYSTEM FOR ANALYSIS AND OPTIMIZATION OF ROLLING ROTATIONAL CONNECTIONS

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ABSTRACT

During the design of rotational connections used in various applications (transport machines, cranes, technological equipment, and military machines) many problems emerge already in the phase of development and analysis of substructures, i.e. various large dimension rolling bearings, screw connections between bearing rings and supporting structures, and gear pairs. Inconsistent computer support in this phase causes much difficulty and delay in the search for the optimal solution. Therefore we decided to design a complete program system for the analysis and optimisation of the above mentioned substructures of a rotational connection, and the adaptation of their geometric relations. All the necessary data will be stored in a common database. For some typical rotational connections completely automated preparation of the technical documentation will be possible, using this database. Even in the case of non-typical designs we expect the automation of up to 75% of designer's work.

INTRODUCTION

A rotational connection can be regarded as two structures rotating relatively against one another. The rotation movement is continuous or intermittent, in one or both directions for full circle or for a limited turning angle. Such a connection carries very large loads (radial force, axial force, and turnover moment), caused by the structure weight, and the intended work. The application incorporating the rotational connection and the operating conditions can vary widely – from the usual industrial environment to the extreme climates and even environments with NBC contamination in military applications. Very high operating accuracy (quiet running, bearing play), low rotation resistance, and reliable sealing can be required, depending on the type of application. From design and technological viewpoint, it is quite difficult to satisfy all these requirements, as they are often contradicting.

The basic elements of the rotational connections are special (non-standard) rolling bearings with relatively large rolling diameters. Because the bearings are usually loaded with a combination of axial force, radial force, and turnover moment, the bearing rings are connected to the supporting structures with the pre-stressed screw connections. The bearing and the screw connections are vital to the safety of the whole structure. Failure of either of them will disable the whole structure (machine,..). Therefore in design and analysis, it is necessary to consider the latest knowledge of contact problems, structure mechanics, low cycle, time limited, and dynamic strength, and experience, as well as the standards and regulations, relevant to the customer. All these apply also to the design of the gearing – pinion gear and geared bearing ring – used to rotate the structure. In particularly demanding structures it is necessary to check the deformability of the elements and its influence on the carrying capacity and lifetime of the bearing, screw connections, and gearing.

DESIGN AND TECHNOLOGICAL PROCESS FROM INQUIRY TO MANUFACTURE AND INSTALLATION

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.

Typical development and design process consists of:

1. Inquiries and collection of offers.

   In this phase it is necessary to collect from the potential customer a large quantity of technical information necessary for correct choice of the bearing, analysis and design of details: type of object incorporating the bearing, function of the bearing, geometric limitations (min. and max. diameter, height,...), load cases, operation regimes, operating conditions, required operating accuracy and rolling resistance, required safety factors and life-time. The designers of the object incorporating the bearing usually can not reliably provide all the necessary data, and they change often their requirements. Therefore an intensive co-operation and counselling from the bearing manufacturer is necessary.

2. Choice of the bearing type and synthesis and analysis of the sub-structures of the rotational connection.

   In this phase the designer should study the acquired information and select a suitable bearing type (single- or double row, ball, cross oriented roller type, three row rolling, combined, wire cage,...). Although it is possible to use different bearings for the same problem, there is usually an optimal choice, when using the criteria of technical and economical suitability. The decision is often based on the previous experience in similar cases.

   It is always useful to check for suitable existing solution that can be used completely or in part (adaptive and variant design). Completely new designs are made only infrequently. The designer defines the geometric limits; then, with the use of iterative analyses of elements finds the optimal, geometrically correct solution of the rotational connection.

With the use of correct details, special requirements (type of screw connection, sealing, operating temperatures, climate conditions,...) must be satisfied.

3. Production of offer technical documentation.

   It consists of the assembly drawing with the basic functional, mounting dimensions and sizes, diagrams indicating carrying capacity and life-time of the rotational connection, and instructions for the correct assembly and operation. The design and development cycle should be finished with the offer.

4. Production of technical and technologic documentation.

   In this phase the workshop drawings and part lists, instructions for technology, and NC machine programs are produced. If the previous phase used extensive computer support, then this phase can be relatively short.

DEVELOPMENT OF SOFTWARE SUPPORT FOR THE DESIGN, DEVELOPMENT AND TECHNOLOGY PROCESSES

With the development of computers, the first opportunity for software support appeared to be in the design phase, i.e. the analysis of the connection elements (Figure 1.). The program part for the analysis of the rotational connection elements consists of three main modules written in C and Fortran programming languages. The basic module comprises the static and dynamic analysis, i.e. life-time computation of different rolling bearings (single row four point ball bearings, double row ball bearings, twin single row bearings, single row cross oriented roller bearings, triple row roller bearing, different types of wire cage bearings). The analysis considers the relevant international standards (ISO 76, 268), augmented with specialised knowledge for the use of non-typical materials for bearing rings and surface treatment (surface hardening – two-layered raceways). The second part contains the analysis and optimisation of the screw connection of bearing rings to the support structures. With the exception of a few details, the computation is made according to the regulations and recommendations recognised in Europe (VDI 2230). The same principle applies to the inner and/or outer gearing checks (DIN 3990). Previous research and experience have shown that insufficient stiffness of the support structures can significantly influence the carrying capacity of the raceways and screw connections. The necessary data (stiffness matrices) on required or existing stiffness of the support structures can be obtained with the use of commercial FEM (Finite Element Method) software package or with custom-made programs for the analysis of simplified models. These matrices are used in the first two modules (Figure 1.) for a more accurate determination of raceway and screw bolt loads [1].

The program part for the analysis of substructures is planned to contain three main modules written in C and FORTRAN programming languages. The base module will contain static and dynamic analysis, i.e. the computation of the life span of different rolling bearings (four point single row ball bearings, double row ball bearings, double single row ball bearings, single row cross oriented roller bearings, triple row roller bearings, and various types of wire race bearings). The analysis takes into account the relevant international standards (ISO 76, ISO 268) with the added knowledge for the use of various non-typical materials and treatments in the bearing rings (surface hardening, twin layer raceways). The second part contains the analysis and optimisation of the screw connection between the bearing rings and the support structures. This computation is made according to the in Europe established standards and recommendations (VDI 2230), and considering some special cases. The computation of the gear pair with inner or outer gearing is made in a similar way (DIN 3990).

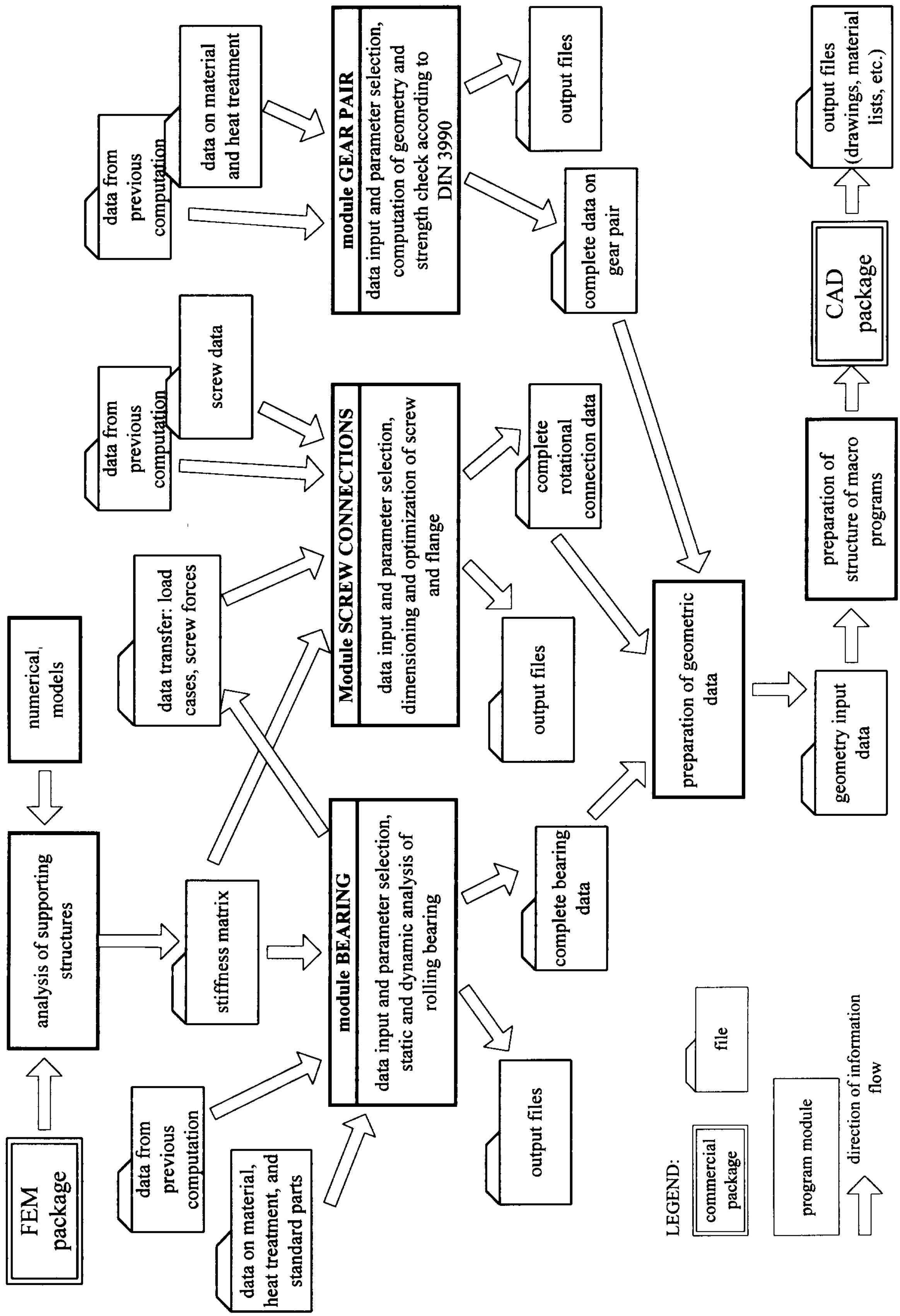

Figure 1: Initial phase of program support of the analysis of the rotational rolling connection parts

Previous research and experience have shown that the carrying capacity of the raceways and screw connections can be significantly affected by too small or uneven stiffness of the supporting structures. It is possible to determine the necessary data (stiffness matrices) with the use of the program systems for numerical analysis (FEM), and introduce them into the first two modules for a more accurate computation of raceway and screw loads.

With the advent of widely available CAD systems, the support extended to the production of the technical documentation and parts lists. Soon macro program modules have been developed for the automation of these tasks. They assemble the technical documentation automatically from the files containing geometric data. With the development of new analyses methods, new knowledge and data on relevant standards, the size and complexity of program and data structures increased quickly. This increase has caused several problems:

1. Database unified for different variants of rotational connections, and consists of several files in different formats, without a suitable data base management program.
2. Program modules for the analysis of the elements of the rotational connection are separated, because each solves a separate technical problem considering the relevant standards, and including optimisation. Incompatibilities appear when optimising the rotational connection as a whole, where all the elements are geometrically interrelated.
3. It is difficult for the practical designer to manage the increasing number of program modules for the analysis of the elements, and the attached increased number of data files. The same difficulty appears with specialised design and technological knowledge.
4. The number of the necessary macro program modules for the automatic generation of the technical documentation increased very quickly, with the increased number of bearing types and detail variants. These modules should be interconnected, and integrated with the geometry database, but further development of this system became un-transparent and virtually unusable for the practical designer.

PROGRAM ENVIRONMENT FOR THE DESIGN OF ROTATIONAL CONNECTIONS

To solve the problems mentioned above, we designed the program system shown on Figure 2. It is connecting the structure analysis modules with the commercially available FEM and CAD packages, serves as a user interface, manages the database and expert system, and offers extensive help. The program modules for the structure analysis are still written in the C and Fortran programming languages, the basic shell (Figure 2) however is written in C++. Here we used the object oriented programming paradigm (OOP), for the data base management an object oriented data management system was used. We made these selections, because it was our intention to build a user interface for Windows 95/Windows NT (Figure 3), thus providing better control over data and course of dimensioning. This is important especially for the users, that do not know all the theoretical details and procedures for the dimensioning of rotational rolling connections, and the interrelations of the elements. The transition to GUI brings a better help system, set-up of multi-level help, considering the knowledge level of the user. It is also possible to teach the designers with limited experience. GUI is a great advantage in detailing of the rotational connection design, when the designer is defining the less important elements (chamfering, contact surfaces, bolts,...) (Figure 3). The interactive editing of dimensions gives a better overview of the design. In the future an added expert system will warn the user of inconsistencies in the dimensions of elements, important dimensions that must be exact (coming from the modules for the analysis, or are vital for the

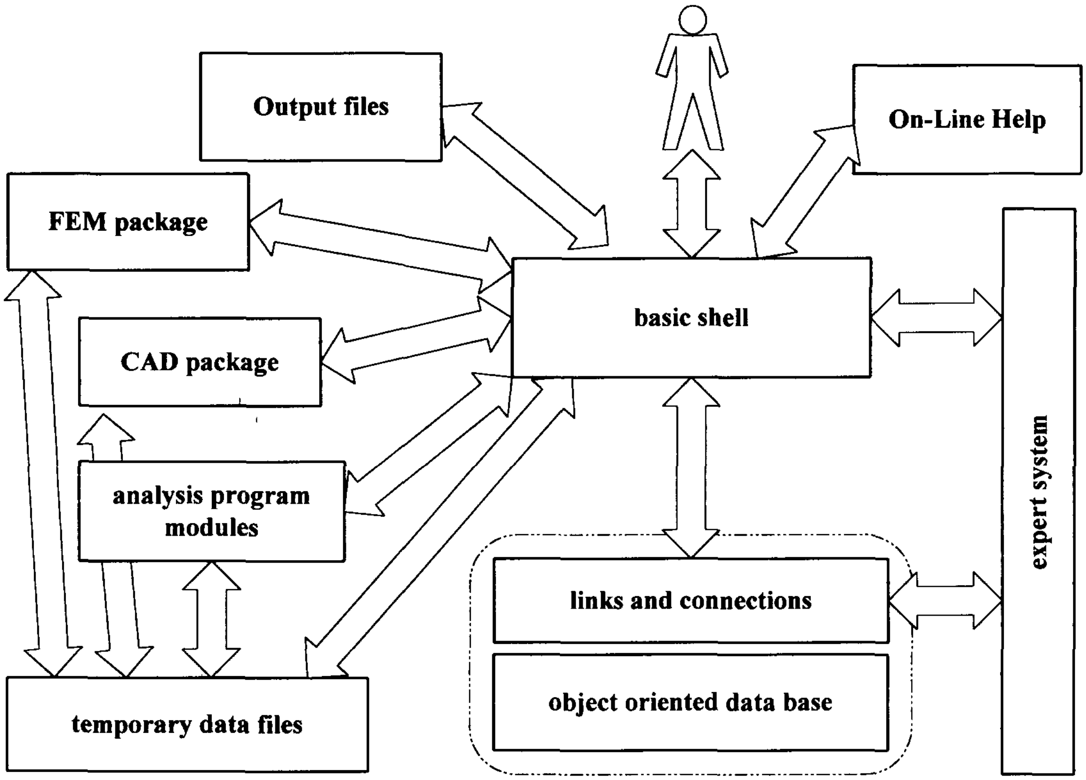

Figure 2: Model of the program system

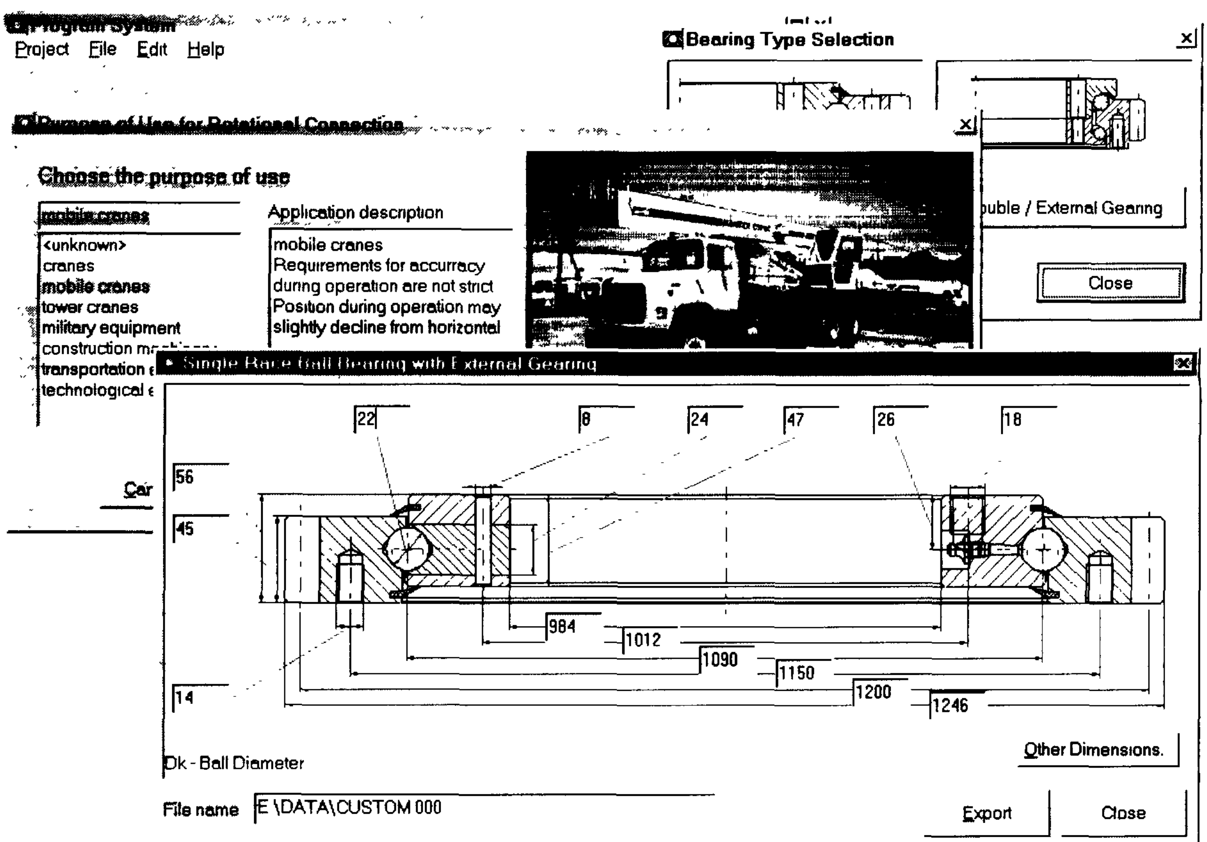

Figure 3: Checking and editing of dimensions with the use of the graphic user interface

functionality of the element), and dimensions that can be changed within certain limits. Careful planning is needed for the set-up of the graphical interface. The correct course of the design process (according to VDI 2222) must be considered, and the possible incorrectness in every step must be prevented. In every step of the design process it is necessary to evaluate the solution and make a decision, based on estimation criteria, whether to proceed to the next step, repeat the current step, or return to one of previous steps [2]. The use of multi-level dialog boxes gives a much better overview of the progress in the design process (Figure 3).

Through the OOP concept, i.e. the use of principles of data hiding and inclusion, data access over public user functions and inheritance we get better control over the data [3]. The possibility of rule and limitation inclusion in functions used for access of modules to the data is of vital importance. The OOP concept means at the same time the concept of the object oriented database, therefore we used the data structure of the program system also for the data base structure. The data dealing with the design of the rotational connection are separated from the data used for GUI. With the use of the object oriented database we can easily save also the complicated data structures, and data structures, where it is difficult to predict their size in advance [4] (stiffness matrix, drawings of individual parts, accompanying documents). At the same time the danger of data loss is minimal, and data redundancy is decreased with the good program layout according to the OOP rules. With the database it is possible to save and manage the development versions of the design, in the final phase of the design the rejected basic and supplementing functions can be deleted. Figure 4 shows a rough concept of the database for a rotational connection, using the extended notation according to Chen [4,5]. The wide "ISA" arrows show the directions of inheritance between classes that represent the types of the structure elements. Inheritance is required to set up the hierarchy of elements of the rotational connection, represented by objects derived form their respective classes. In this way the sequence of creation and editing of data is defined. When an object changes, the rules in the methods for the access to these data trigger the requests to change the linked objects, where the data do not correspond to the changed state of the first object, and the set limitations. The thin lines and arrows designate the cardinality of relations (Figure 4) required for the control and saving of the structure and development versions of the rotational connection design. The objects shown in Figure 4 contain data fields representing object properties and methods. These properties and methods are used to access the properties, present and analyse (when the analysis is not included in a separate program module for the structure analysis) the objects in CAD packages.

After the phase of basic design has been finished, the shapes and dimensions of all the elements of the rotational connection are defined in the detailing phase. The program system searches the design structure stored in the database, and, according to the rules, links the macro programs for the production of assembly and non-standard element drawings. In the case of typical rotational connections, the technical and workshop documentation, including the parts lists, assembling and maintenance documentation, is finished. In the case of non-typical rotational connections the changes in shape and dimensions are input partly with the use of graphic interfaces, as shown on Figure 3, the rest is usually made interactively, directly on the drawings in the commercial CAD package. If the basic design of the rotational connection being adapted is supported in a parametric CAD module, then the changes are reflected also in the object database. In this case the changes in vital parts of the design can, due to the rules incorporated in the methods for data access, return the procedure to the phase of basic design, or structure analysis, or, when the designer rejects the new iteration, return to the previous state.

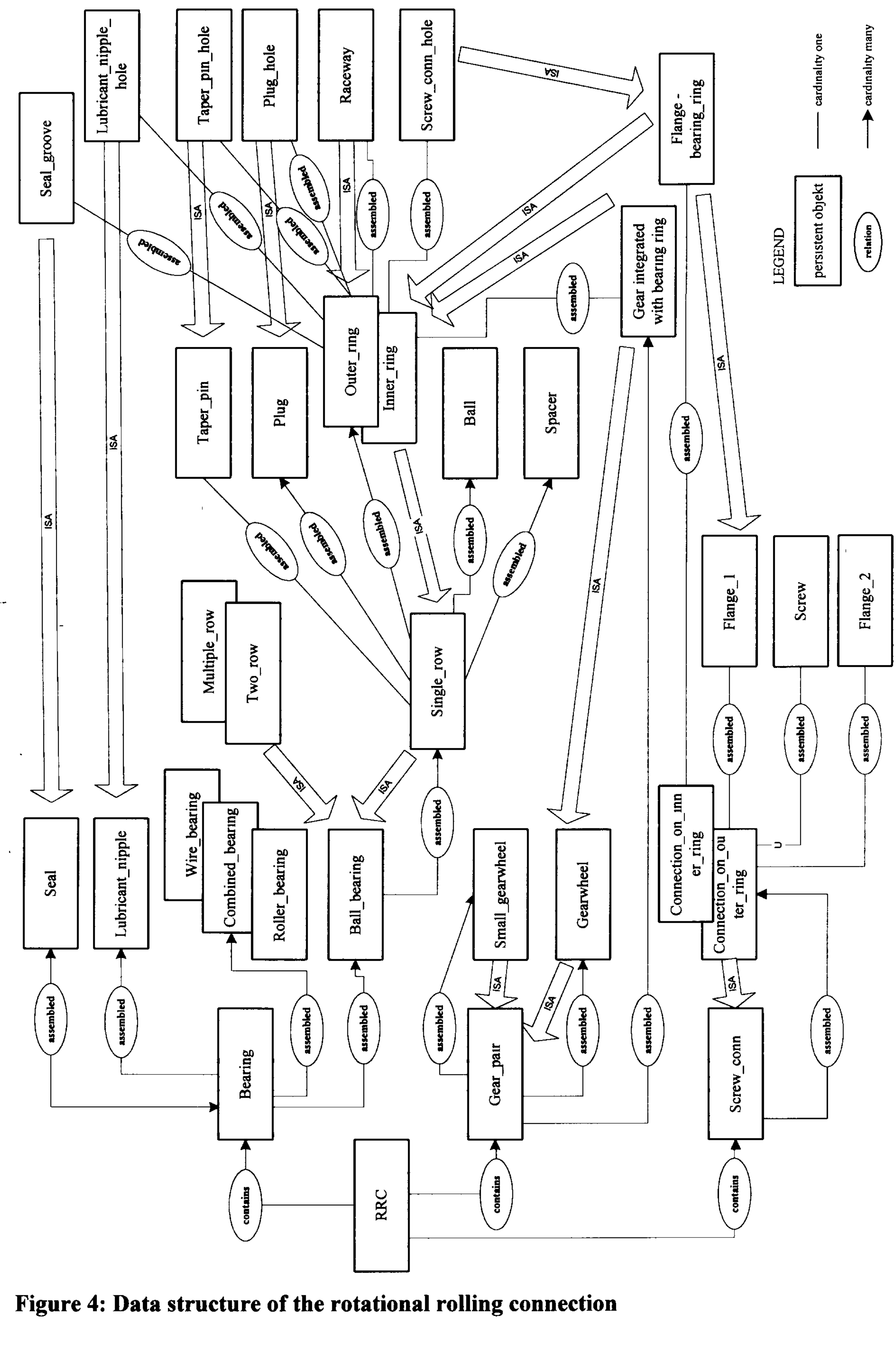

Figure 4: Data structure of the rotational rolling connection

CONCLUSION

Such a program system can be essential for small companies, that, due to the financial limitations, can not afford a large technical staff, and the time to offer must be kept short. The knowledge incorporated in the program system is a welcome help to the designer, who should have a relatively broad spectrum of design knowledge, technologic procedures, and particularities linked to the design and production of rotational rolling connections.

In the future we are planning the automation of NC program assembly for the manufacture of non-standard elements of rotational connections. The preparation of data for the programming tools for NC machines will be simplified, due to the object-oriented concept. We would also like to extend the specialised expert system with the methods of the general expert systems. In this way the re-coding of the whole system will not be necessary, when new knowledge in dynamic analyses, and operating mechanism of the rotational connections is to be incorporated. In this case only the already set rules will be checked and, when needed changed, with the use of a user interface.

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