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A Representation of Assembly and Process Planning Knowledge for Feature-based Design

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The need for a product model which can support the modelling requirements of a broad range of applications leads to the application of feature-based techniques. An important requirement in feature-based design and manufacture is that a single feature representation should be capable of supporting a number of different applications. Assembly and process planning are seen as two crucial applications and a formal structure for their representation in a feature-based design system is presented. This research described addresses two basic questions relating to the lack of a unified definition for features and the problem of representing assemblies in a feature-based representation. A prototype system has been implemented using object-oriented techniques which provide a natural method of adding functionality to the geometric reasoning process of features and the complex relationships between the parts that make up the assembly. The feature-based model has been implemented using the ACIS object-oriented solid modeller kernel.

1. Introduction

The requirements for shorter product life cycles, shorter time to market and demand for high quality products makes it imperative for manufacturing industry to focus on new product development strategies in design and manufacturing processes. A critical aspect is the integration of design and manufacturing processes to provide computerised decision support tools. Product modelling refers to the activities related to representing and utilising information related to products, their design and manufacturing processes and their production management [1], and the ideal product model should automatically generate the design, functions, service life, manufacturing methods and all data needed for the processing of customer orders [2]. Various modelling approaches have been proposed [3], but as much of the information needed in the design and manufacturing process deals with the geometric shape of the product, the geometric model forms the most important component in the product model representation.

2. Feature Modelling

Manipulation of geometric models requires that part geometry be represented by high level entities that relate directly to design functionalities or manufacturing characteristics, and *features* have been proposed to serve this purpose. Instead of using a model consisting of geometric primitives the designer uses a set of features such as holes, pockets and slots which provide a natural vocabulary to capture the design intent, manage relationships and provide a basis for modelling manufacturing planning information. Features provide an alternative component representation that is suitable for a wide range of activities thus bridging the gap between design and manufacturing [5], but typical implementations are only capable of supporting a specific application domain. The ability of a feature-based representation to support more than one application is important in a Concurrent Engineering environment and to fulfil the requirement of a product model that can support the product development process. Most existing CAD/CAM systems can be classified as geometric modellers with data structures designed to manipulate individual parts whereas in most engineering design the product of interest is a composition of parts, formed into an assembly. Hence modelling and representing assemblies, generating assembly sequences and analysing assembly are all relevant issues for geometric modelling and CAD/CAM technology.

3. Assembly Modelling

Assembly modelling deals with the inter-relations among assembled parts and its understanding is a key step towards a CAD environment to support early design, to support further integration of manufacturing systems and to provide data for assembly sequencing and analysis [6]. Most of the interaction between parts occurs at mating surfaces, and the modelling representation of these mating conditions is the distinguishing characteristic of assembly modellers. An ideal system allows the link to be established between the geometric and assembly model such that designers need only to modify individual parts by using the geometric modeller and the assembly model is updated automatically [7]. Various assembly representation schemes are possible [8], but the use of features instead of piece parts as the lowest denomination facilitates assembly modelling applications by providing natural semantics for describing part interactions. A formal structure for the representation of assembly information is an essential prerequisite to the generation of systems that are capable of achieving the aims of optimising product design and manufacture and there is a need to establish feature representations that act as an integrating agent across a number of manufacturing applications. Features in this research are defined as machined volumes which are represented in a hierarchical taxonomy. A hierarchical assembly structure is also defined in which features form the basic entities and include information on mating relationships.

4. Assembly Structure and Mating Relationships

An assembly database stores the geometric models of individual parts, the spatial positions and orientations of the parts in the assembly and the assembly relationships between parts [7]. Many representation schemes have been developed, the main differences being the way in which the locations and orientations of the parts and their relationships are represented. Most use a hierarchical structure, and Wang and Ozsoy [9] are typical in using an assembly graph to hierarchically represent the assembly, its sub-assemblies and components where the mating conditions of "against", "fit" and "parallel" are stored as a set of mating links. Spatial information is typically represented either explicitly or implicitly. Explicit representation requires that all sub-assemblies and parts have to be provided with a suitable transformation matrix, whereas implicit representation allows the transformation to be determined from the geometry and mating conditions. Implicit representation has the benefit of allowing the designer to manipulate the model via the mating conditions and thus separates geometric aspects from configuration of the assembly. In this work an analysis of a number of assemblies was undertaken to determine a suitable set of mating conditions which could be used to build an implicit representation within a hierarchical structure. Example assemblies are shown in figure 1.

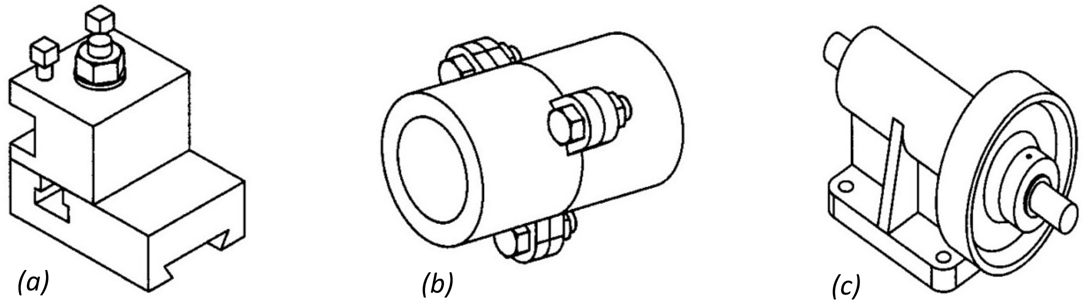
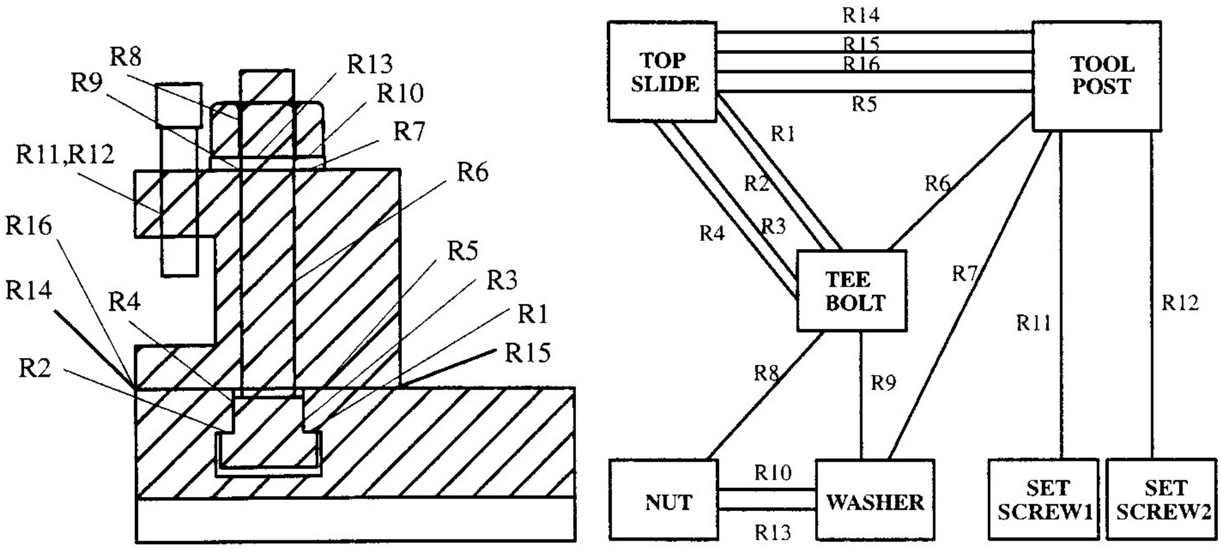


Figure 1. Examples used in Mating Conditions Analysis
(a) lather tool post, (b) valve sub-assembly, (c) bracket and pulley

The first stage of the analysis is to establish relationships between the components that go to make up the assembly. Figure 2 shows the Component Relation Graph for the lathe tool post. Physical interactions between the components are identified and labelled (figure 2(a)) and from this information a graph of the relationships can be formed (figure 2(b)). At this time only the *existence* of a relationship has been established and the *type* of such relationships remains to be determined. Component Relation Graphs are useful in assembly planning as they capture information that is useful in determining the creation of sub-assemblies. For example it is clear from figure 2(b) that the set screws could be assembled to the tool post to form a sub-assembly. Similarly, components that might be considered as candidates for being the base part to which other components might be assembled could be identified as those having the most relationships (the top slide in this case). Particular rules for assembly are not however based on these kinds of considerations alone. In particular it is also necessary to have knowledge of the type of relationship and the geometric conditions.



Component Relationships *(b) Relationship Graph*

Figure 2. Component Relation Graph for the lathe tool post assembly

In this work three basic mating relationships were determined from the analysis of example assemblies. Against is a relationship between faces which ensures that the normal vectors to the faces are in *opposing* directions. This is most commonly found where both faces are planar (e.g. between the bottom of the tool post and the top of the top slide), but other face types (e.g. cylindrical) are within the representation scheme. Fits is a mating relationship where two features are required to fit together with clearance or interference (e.g. the tee-bolt into the tool post hole). A *fits* relationship typically generates a co-linearity condition on the centre-lines of the two features and can be subclassified according to the method or difficulty of assembly (i.e. *tight fit, screw fit, clearance fit*). The *Align* relationship exists for example where centre-lines of two holes must coincide (e.g. bolt holes on the two halves of the valve sub-assembly in figure 1(a)) or where two planar faces must lie on the same surface (e.g. the faces of the top slide boss and the boss of the tool post). The significance of these mating relationships is not only in being descriptive of the assembly process, but also in forming an essential part of the geometric reasoning required to maintain an implicit representation of the spatial relationships between components.

5. Feature-based Assembly Modelling

The discussion of mating relationships in the previous section clearly demonstrates that the Component Relation Graph (and its manifestation in a data structure) is inadequate to completely represent the situation. It is *features* of components that are important to assembly, and not just components themselves. Hence there is a need for the further level of detail provided by the *Feature Relation Graph* (figure 3). In this graph each component is represented by a set of features and the mating relationships are now shown as existing between features. A *Feature Relation Table* (not shown) consists of a matrix of possible feature relationships from which it can be determined (for example) that relationship R5 in figure 3 must be either *Align* or *Against*. The addition of geometric conditions determines that it is actually *Aligns*.

For some conditions the feature-feature relationship might be capable of fully specifying the configuration of components in the assembly, but frequently the more detailed information provided by the *Face Mating Graph* (figure 4) is required. Faces can be considered as sub-features which play an important role in representing assembly information. Equally importantly, faces are crucial to the manufacturing of the components as the end result of machining and as the carriers of process planning information such as dimensions and tolerances. Features and faces together form the important common ground between the assembly planning and process planning activities and hence the objective of a single representation for multiple applications can be achieved. The *Face Mating Graph* contains all the topological information relating components, features and faces and can be simply extended to include any level of sub-assemblies. It has also been extended to the *Component Connectivity Graph* which contains additional process planning relationships from our earlier process planning work (tool access directions, set-up directions, dimensions and tolerances) represented at the face-to-face level [10].

6. Implementation

The assembly representations described above have been implemented using the ACIS solid modelling kernel using a C++ object-oriented approach. The details of the implementation are beyond the scope of this paper, but classes have been created for assemblies, features, feature types, profiles, feature relationships, etc together with appropriate methods for their creation, manipulation and use within the ACIS environment.

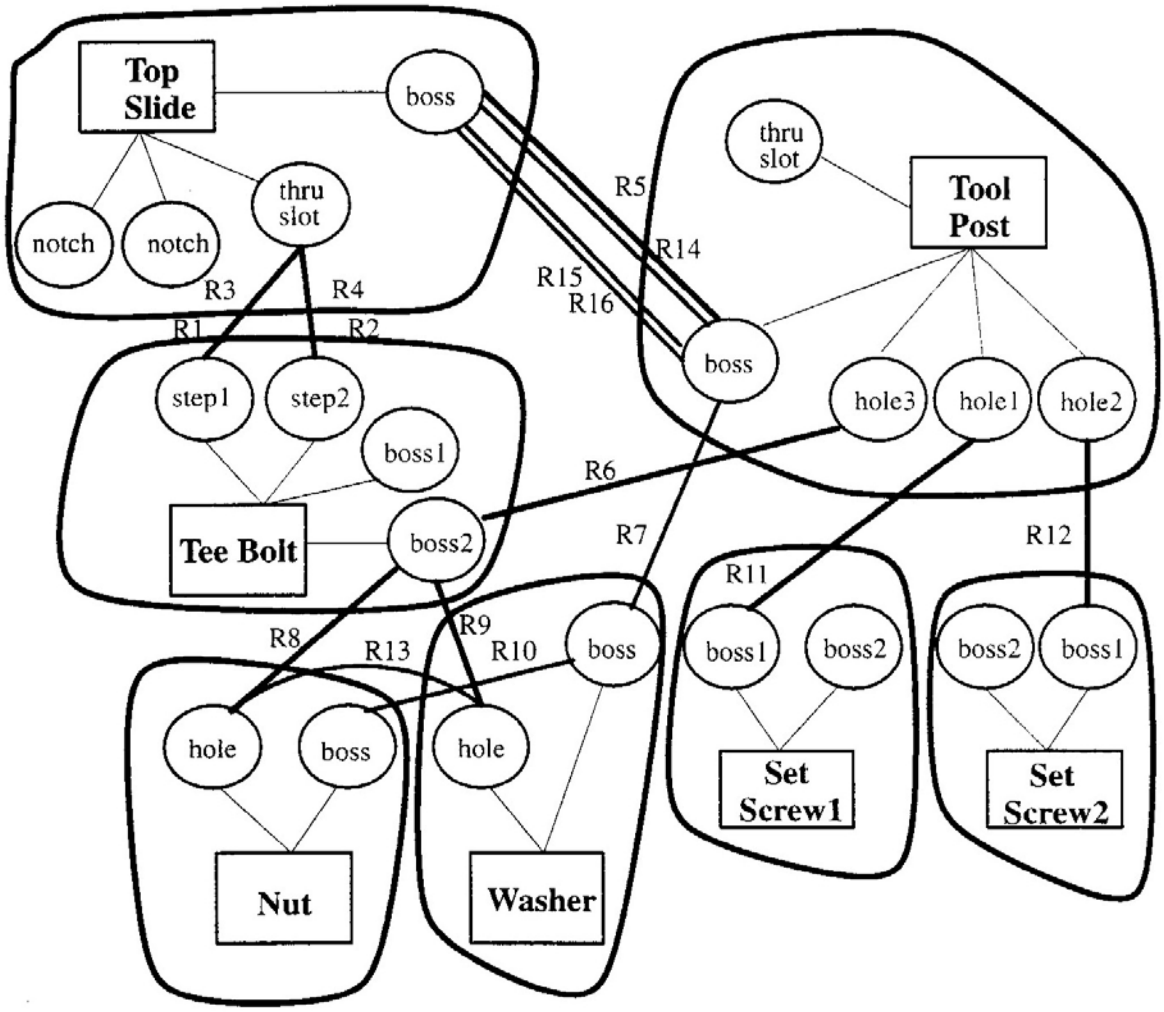


Figure 3. Feature Relation Graph for lathe tool post assembly

7. Conclusions

The research presented here reinforces the idea that features can be used in multiple applications. Features which have previously been used for process planning have been used in an enhanced form to represent assemblies. The use of features for assembly modelling provides a natural representation, since in assembly operations it is the feature that dictates the way in which parts are assembled. The approach adopted provides a design tool to create mechanical assemblies in terms of features and in a form which is applicable for subsequent manufacturing planning activities. The feature representation methodology implemented is suitable for the concurrent representation of knowledge on process planning and assembly modelling. Clearly, this does not conclusively establish that *all* aspects of design and manufacturing can be encapsulated in a single representation, but it goes some way to confirm the feasibility of the idea.

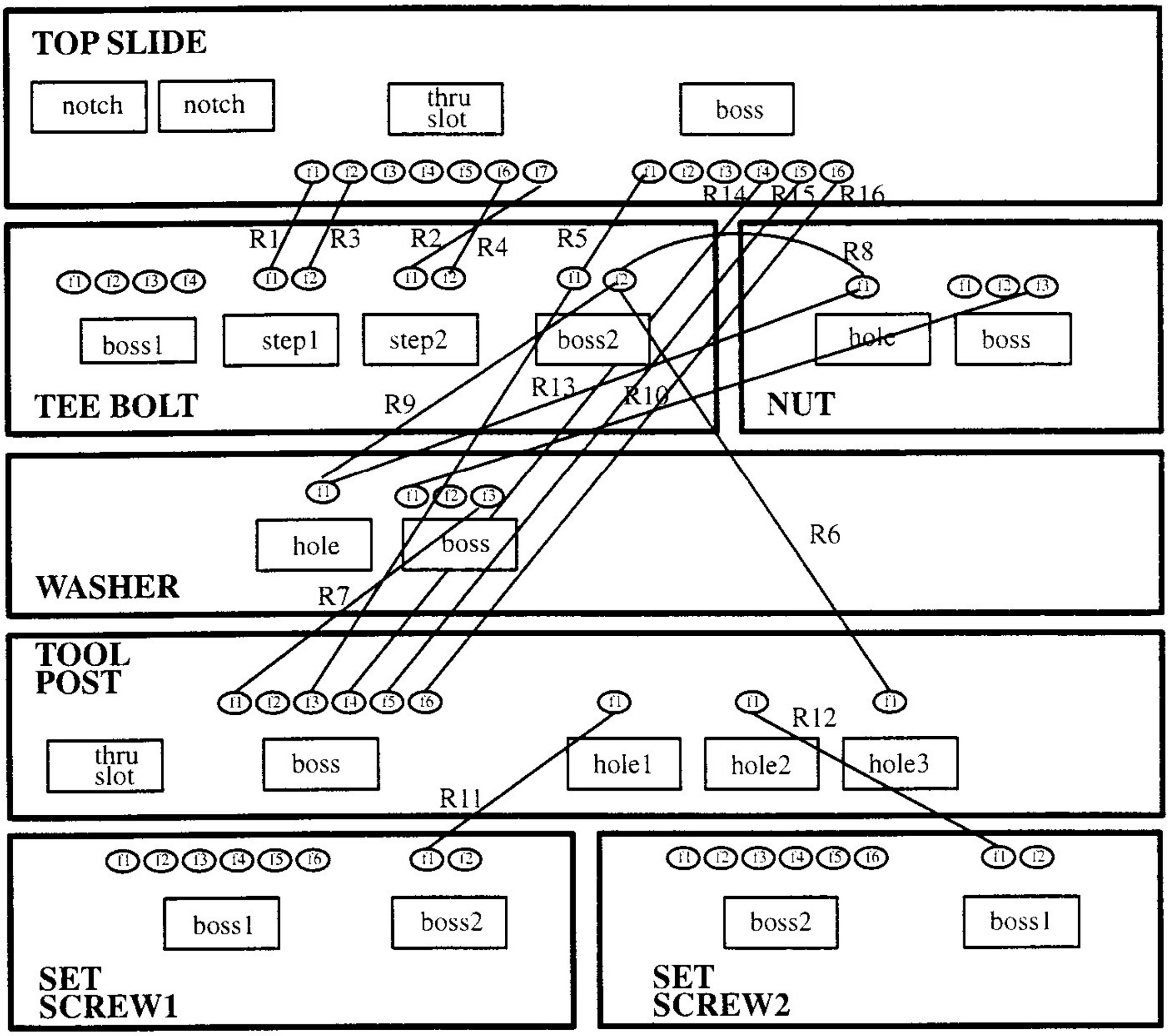


Figure 4. Face Mating Graph for lathe tool post assembly

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