자동조립을 위한 제품설계 전문가시스템

김 광 수

A Knowledge-Based Approach to Design for Assembly †

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Abstract

A study showed that the two most important obstacles to assembly automation were that product designs are generally not assembly oriented and that most components cannot be handled automatically without problems. In the view of the importance of well designed product with high assemblability, a tool must be developed to pre-evaluate a product during design phase whether it can be assembled with minimum efforts. In this research, a prototype expert system for DFA has been developed that can be used to advise the designer of difficulties that his/her design presents for automatic handling during manufacture. This rule-based system has been implemented on an IBM personal computer, using the Texas Instruments' Personal Consultant Plus.

1. Introduction

The increasing pressure of national and international competition is forcing firms to rationalize even further, especially in the field of assembly. In order to perform assembly tasks with the least possible expenditure of time, assembly facilities, space requirements and personnel, it has become necessary to include these objectives in the development stage of the product.

Design engirieers know that design governs product performance but rarely appreciate the impact it has on production. In fact, the design of a product dictates how it is made and what it will cost to produce, and can crucially affects its success in the market place. Most of the important decisions concerning product manufacture and assembly are taken during the design process. It turns out that 70 percent of a product's cost is determined during the design phase, and only 20 percent

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† This research was supported by the Ministry of Education of Korea.

during actual production[1]. It is vitally important to get it right at the design stage of the product. Ignoring the technical aspects of assembly during the design stage frequently leads to costly assembly systems being installed[2, 3].

The vast majority of assembly work is carried out manually using methods which have changed little over the past few decades. Thus, assembly costs continue to rise and are steadily becoming a larger proportion of total product cost. Automation of assembly and handling processes can contribute significantly to manufacturing effectiveness. Howerever, automatic assembly has not made the impact anticipated, even though large sums of money and much efforts has been expended upon the technology by many major organizations. Assembly research is unlikely to overcome this problem unless the area of design is included. A study of 3,500 firms in West Germany [4] showed that the two most important obstacles to assembly automation were that product designs are generally not assembly oriented and that most components cannot be handled automatically without problems.

To accomplish an adequate design for automated assembly the product designer must have a profound in-depth knowledge of asembly techniques and be familiar with current assembly technology. In view of the large range of requirements with which a designer must comply and the magnitude and diversity of the fields of knowledge required to fulfil these demands it seems impossible for designer to meet the change using conventional methods of design. This situation becomes even more critical due to constantly decreasing product life cycle. Within the tight design schedule designers can not afford to check all possible design characteristics not related to the product functionality. Thus, in practice, the designer checks a design only with respect to its functionality so that assemblability is only a minor consideration.

In the view of the importance of well-designed products with high assemblability to reduce the total product cost, a tool must be developed to pre-evaluate a product during the design phase whether it can be assembled with minimum efforts. The tool must be designed in such a way that it also helps the designer to establish appropriate design modifications if any flaws are detected. Many expert working in the field of design for assembly (DFA) have recognized the need for such a tool, and they have developed a number of different tools to help designers conceive products that are consistent with the objectives of DFA [5−9]. The main problem in using all these tools is that their application is tedious and time-consuming. In this research a knowledge-based approach to DFA is proposed.

Section 2 provides a background to design for automatic assembly. In section 3, the notion of assemblability is introduced, and some of the available DFA procedures are discussed. In section 4, a knowledge-based system for automatic assembly is explained. In section 5, the overall results of the research are presented, with the future directions of the work.

2. Design for Automatic Assembly

Optimum design or redesign of a product and its components is essential for successful, efficient, and economical automatic assembly. Considerable amounts of money are often spent to automate the assembly of existing product designs when it would be much more economical to redesign the products to facilitate automatic assembly. Design for assembly is being increasingly practiced because of the realization of potential production savings and better quality and improved reliability in the product.

2-1. Design for Simplication

The optimum product design is one that eliminates the need for assembly or reduces the number of parts to be assembled to a minimum. Use of the modern forming processes may help in minimizing or eliminating components. Such designs usually reduce total product and assembly costs. The number of parts required should generally be kept as low as possible, and their complexity should be minimized.

To determine if a part can be eliminated, the following three questions should be answered :

1) Does the part move with respect to other parts ?

2) Is the part made from a different material than the other parts ?

3) Will the part require removal for product servicing ?

An affirmative answer to any of these questions generally indicates that the part is required. Negative answers to all three questions indicate that the part may not be necessary and any function it performs may be able to trnasfered to a more essential component.

2-2. Design for Ease of Automatic Assembly

Parts to be assembled automatically should be designed for ease of handling, feeding, orienting, positioning, and joining.

(1) Feeding Considerations.

Commonly encountered feeding problems that can lead to jamming include tangling, nesting, and shingling. Tengling, caused by a protrusion on one part inserting itself into an opening in another part, makes it difficult to separate the parts for feeding and orienting. This condition can be alleviated by either eliminating protrusions and/or closing end openings.

Parts with thin flat surfaces or tapered edges have a tendency to climb onto each other and overlap, called shingling, which can cause wedging of the parts in the tracks and jamming. This condition can often be eliminated by providing thicker contact surfaces or by making the edges vertical or of a steeper angle.

Nesting of cup-shaped parts can also cause jamming. This condition can be minimized by changing the cup diameters, adding ribs, or increasing or decreasing the angle of the sidewalls.

Distortion of parts due to handling and stacking can cause serious problems. Thin metal parts, as well as soft parts and those made of plastics, are especially susceptible to these conditions. Whenver possible, the parts should be made rigid and stable, but not brittle or fragile.

Weight distribution is an important consideration in part design because gravity is used extensively in feeding systems for automatic assembly. Designers should try to avoid instability in part feeding by providing the part with a low center of gravity.

(2) Orientation Considerations

Whenever possible, components to be automatically assembled that require orienting should be provided with external surfaces, cavities, or protrusions that will facilitate orientation. Features that are often nonfunctional but that serve this purpose include holes, slots, chamfers, grooves, or pads on external surfaces. Functional features that can be used to facilitate orientation include franges and heads on cylindrical parts and threaded fasteners.

Part configurations than can be easily oriented include the following:

(i) Completely symmetrical parts such as spheres, cylinders, pins, and rods. Designign a symmetrical part will reduce the need for sensors to detect features and reduce handling. Figure 1 shows that parts could be redesigned to take advantage of the concept of symmetry.

(ii) Substantially disproportionate parts, either with respect to weight or with respect to dimensions, such as headed screws, bolts, and rivets. The center of gravity should be near one end of each part to produce a tendency to naturally feed in one specific orientation.

If a part must be asymmetrical, it should be clearly asymmetrical. If it is close enough to being symmetrical, the part generally present a large number of problems in feeding and orienting. Parts having features such as off-center holes or cavities are also difficult to orient and may require tooling outside the hopper or other storage device for orientation. Sometimes external features can be added to the parts to permit easier orienting in the hopper (see Figure 2).

(3) Insertion Considerations

Providing chamfers, raddi, tapers, or other guide surfaces on shafts and mounting holes and

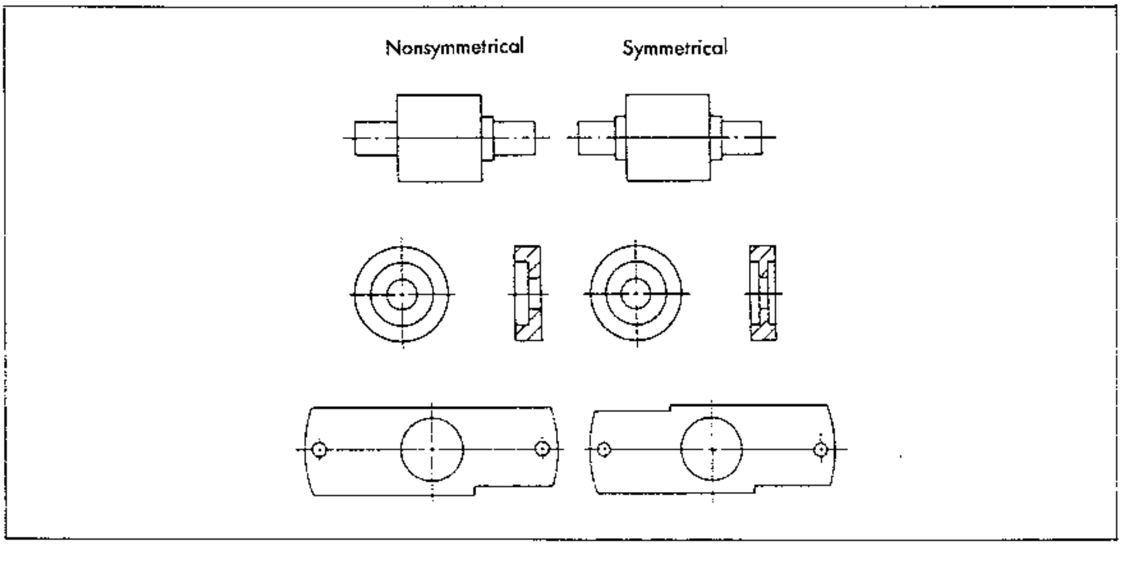

Figure 1. Symmetrical Parts for Easier Orientation[5]

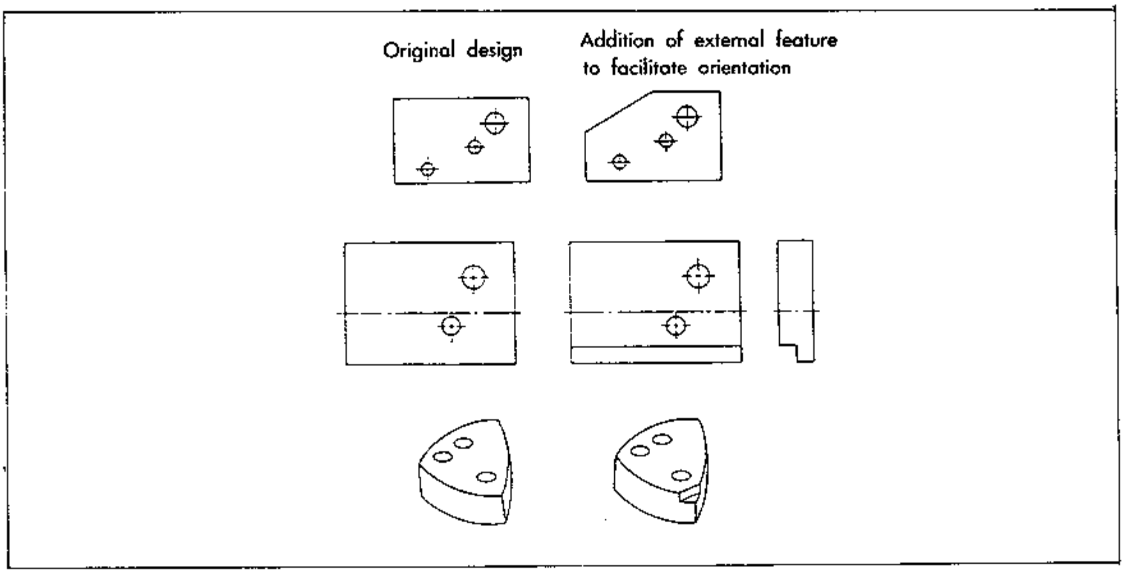

Figure 2. Addition of External Feature[5]

eliminating sharp corners whenever possible facilitates the insertion of components into assemblies. For example, cone and oval-point screws are easier to insert than rolled-thread or headed-point screws because they tend to centalize themelves in holes. Figure 3 illustrates some changes in design that facilitate insertion and mounting.

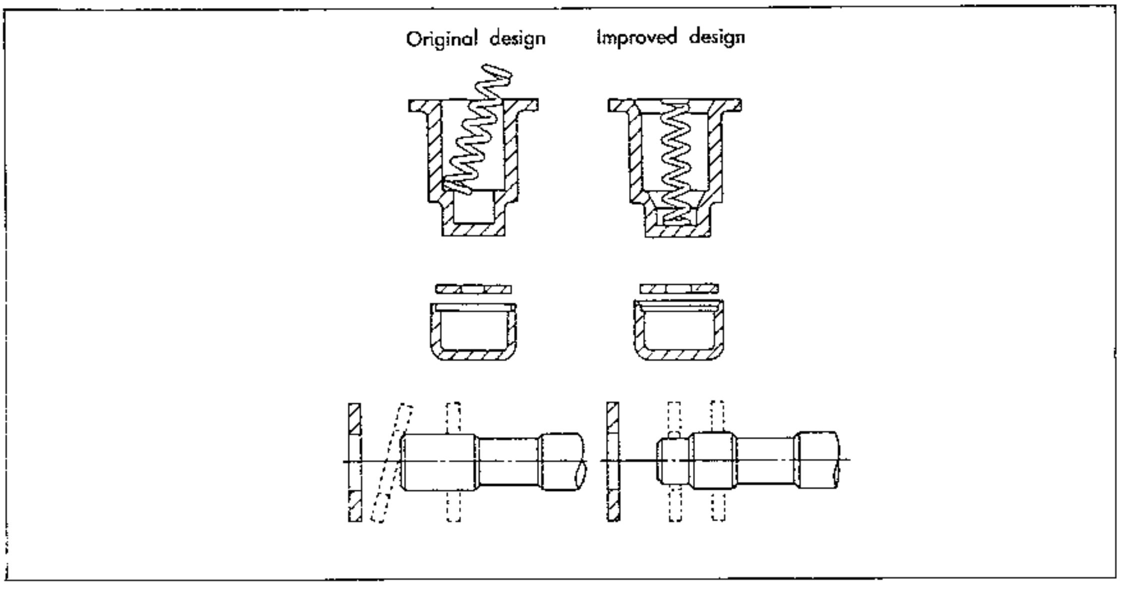

Figure 3. Design Change for Insertion and Mounting[5]

(4) Joining Considerations

It is desirable to eliminate or minimize joining and fastening operations in automatic assembly whenever possible to reduce costs and increase productivity. Use of snap or interference fits is less costly and requires less time than fasteners (see Figure 4). Staking, spinning, or welding are also often preferred to the costly feeding and driving of fasteners such as screws, bolts, and nuts.

If the use of fasteners cannot be avoided, use fasteners that can be easily fed automatically. Fasteners with flat sides and tops may be more easily picked up by using vacuum. Fasteners with a length to diameter ratio of at least 1.5 to 1 are most easily fed.

2-3. Modular and Standardized Designs

Many assemblies are too complex to permit complete automatic assembly on a single machine. In such cases, it is efficient to break down the total assembly into a series of subassemblies that are subsequently joined together. Typically, 10~12 parts are all that should be assembled on a single machine without degrading machine reliability and throughput. Subassemblies can often be standardized for a family of products, resulting in substantial savings.

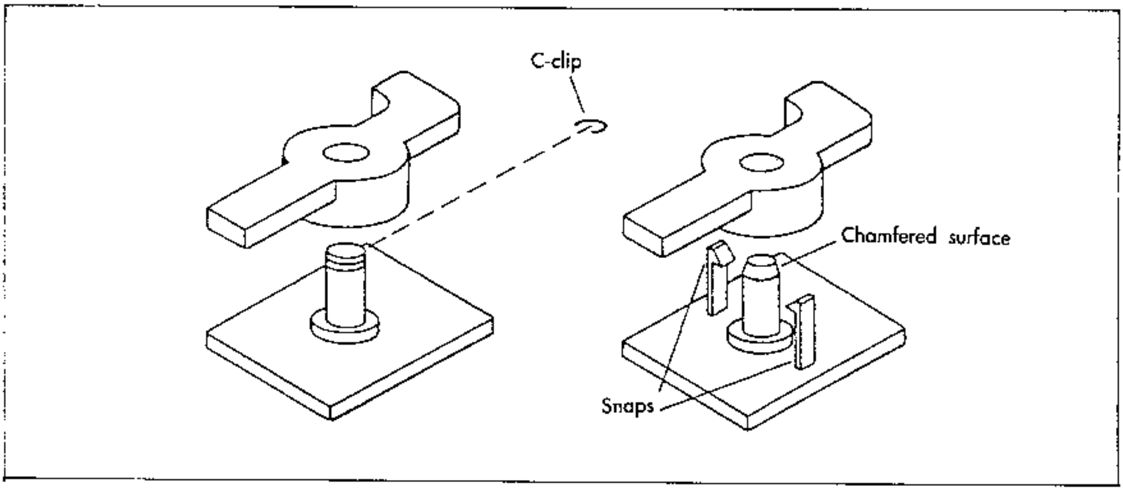

Figure 4. Joining Moving Parts without Fasteners[13]

Standardizing components in both subassemblies and assemblies with respect to design and materials can reduce tooling costs. The functions performed by several parts should be combined in a single part whenever possible, thus reducing the number of components to be assembled[10-16].

3. Design for Assembly Procedures

How should design for assembly be carried out in practice? The problem is that the designer knows about design, selecting the working principle and structuring the product to satisfy the functional requirements, while the production engineer knows about the rules and problems of design for assembly, but seldom knows enough about the engineering requirements and functional specification. Therefore, the base solution to the design for assembly problem is cooperation in the early stages of design.

If designs are to be produced that are amenable to assembly and automation, the designer needs a mechanism for analyzing a design and comparing alternative solutions. There are two types of means: guidelines/calculations made by hand, and guidelines/calculations applied by computer in conventional code or as expert systems.

Design for assembly has traditionally relied on the use of general guidelines and examples to aid the designer. More recently, works on design for assembly have concentrated on the evaluation of assemblability in order to facilitate design improvements. Systems have been developed that enable designers and production engineers to measure the ease or difficulty with which components can be handled and assembled. These systems tend to operate by guiding the engineer through an analysis procedure in which the problems associated with components and processes may be quantified, based on some points system, and information can thus be fed back to the system user.

Assemblability evaluation is generally carried out on completed product designs, existing products or prototypes, but some degree of assemblability analysis may also be possible at the conceptual drawing stage, and this is preferred, rather than forcing the designer to reject and redesign. A number of such systems are being exploited in industry, and here we will discuss two of them: 1) the widely known design for assembly method being exploited by Boothroyd and Dewhurst [9, 17], and 2) the Hitachi Assemblability Evaluation Method [18, 19].

3-1. The DFA Procedure Used by Boothroyd and Dewhurst

The DFA procedure is mainly aimed at mechanical assemblies. There are separate analysis systems for manual assembly and automatic assembly. The particular analysis system is identified from a procedure for the selection of the appropriate assembly method. The assembly method likely to be most economic for the product under consideration is founded by considering factors such as annual production volume, number of parts to be assembled, number of product styles, and payback period required.

The next step is to apply the appropriate analysis system, i.e., manual or automatic assembly. In these procedures, classification systems, developed specifically for each of these technologies, are used to arrive at the data that is used to assess the components in a design for ease of handling and insertion.

In the analysis for automatic assembly, the clasification systems for handling and insertion processes provide cost indices for component design classes. These give an indication of the relative cost of the equipment required to automate the process, compared with the cost of equipment needed to process the most simple or ideal design.

An analysis is carried out using a DFA form or worksheet. Each of the two procedures has its own special form. A row of the form is completed for each component in some order of assembly. The complete worksheet provides a quantative way of measuring the performance of a design in terms of its assemblability, and can be used as basis for comparing alternative designs.

3-2. The Hitachi Assemblability Evaluation Method(AEM)

The Hitachi method makes use of assemblability and assembly cost ratio indices to identify the weak points of a design. From drawings or samples, the analyst completes an AEM form by entering the part names and numbers in the same order as an appropriate structure of assembly work. The assembly processes involved in product construction are analyzed, using close to 20 AEM symbols.

The next step is the calculation of the evaluation indices. Scores are calculated for each part, and the product assemblability evaluation score is then determined. The evaluation score may also be correlated to an assembly cost ratio. This step is followed by the so-called judgement stage, where the evaluation indices are compared with target values. Finally comes design improvement, if necessary.

The AEM does not distinguish between manual, robotic and automatic assembly. Two reasons for this are given : the strong correlation between the degree of assembly difficulty involved in manual, robot and dedicated assembly, and the difficulty involved in predicting the product mode at the design stage. Production of the same design could well be moved from manual to some form of automated assembly.

4. A Knowledge-Based Approach to DFA

Conventional programs, where the assembly knowledge is "hard-wired" into the problem-solving method, do not fully satisfy the requirements of a consultation system for designers. The weak point of these programs are :

1) programs can become difficult to modify even if for their implemntor. 2) no real possibility of updating by persons unfamiliar with the software, 3) because the programs are difficult to read it is hard for other persons to pick up and extend the work, 4) no natural way of expressing knowledge about the problem, and 5) no mechanism is available for discussing their knowledge with the user. This led to the investigation of knowledge-based expert systems[20-22].

4-1. Knowledge-Based Systems

An expert system is a knowledge-intensive computer program that emulates the performance of a human expert in a specific domain. Like the human expert, it asks relevant questions and can explain its reasoning. In general, it can be said that knowledge-based systems are well suited to problems solving where : 1) the problem requires the use of heuristics, 2) the problem requires expert knowledge and judgement, 3) the expertise is based on experiences over a long period of problem solving, 4) conventional programming is not applicable due to intractable problem, 5) there is a significant demand for the solution, and 6) the benefits of the system are accountable. It should be noted that the above conditions are present to a large extent in the area of design for assembly [21].

A key feature of an expert system is that the knowledge base is independent of the inference engine that accesses it to solve problems. Since the knowledge base is separated from the algorithmic programs of the inference engine, should new information become available or knowledge stored become obsolete, it is relatively easy to make necessary changes. All that you have to do is add new rules, remove old rules, or correct existing rules.

4-2. An Expert System for DFA

A prototype expert system for DFA has been developed that can be used to advise the designer of difficulties that his design presents for automatic handling during manufacture, and to suggest remedies. The system has been implemented on an

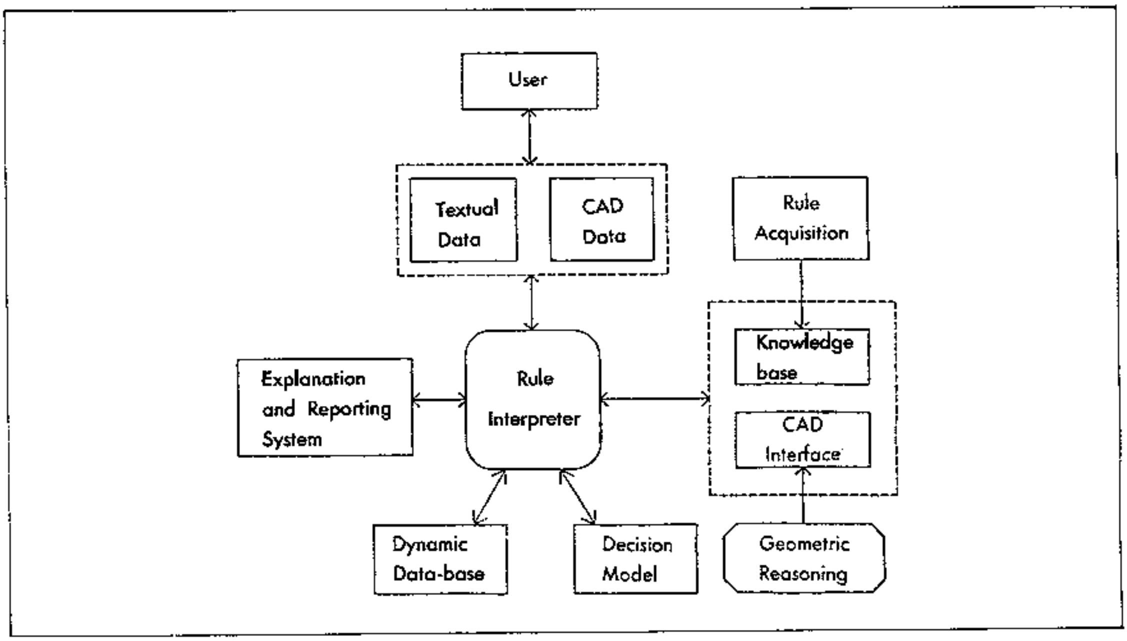

Figure 5. Overview of the Expert System

IBM personal computer, using the Texas Instruments' Persoanl Consultant Plus expert system development shell. The main elements of the expert system are : knowledge base, rule interpreter, data base, explanation subsystem, and user interface (see Figure 5). The system is used in a converstional mode with the user supplying all the data on request.

The knowledge contained in the system has been compiled from two main sources. The first source of expertise comes from a DFA expert. The second source of expertise is the DFA handbooks. A major difficulty in setting up an expert program is to capture and examine the various knowledge elements used in the solution of the problem, suitably to express this knowledge in rules. The rules of the knowledge base are mainly interpreted using backward chaining. The knowledge base is made up of separate modules for feeding, orientation and presentation of components.

The feeding module is to decide whether a given component can be fed automatically at all. Rules has been captured to allow feeding problems to be defined. If a problem is identified then, depending upon its severity, design advice would be issued. Although some rules are certainties, a number of rules captured are non-conclusive and only suggestive of a result. An example feeding rule is shown below.

IF : CYLINDRICAL AND L-D-RATIO>4.5
THEN : FEED-PROBLEM CF 85 AND
PRINT "Parts cannot be fed. Reduce the L-D ratio."

The rule is given in ARL (Abbreviated Rule Language). The rule represents a situation where there is a possibility that a problem may result, and suggest a design remedy which, if implemented, could eliminate the feeding problem. Further feeding rules deal with other handling problem characteristics including tangling, flexibility, size, quality, etc.

The orientation module is to determine if the component has some property which will allow it to be uniformly oriented to a specific attitude. The orientation rules are used in the situation where orientation is considered to be feasible. In the case of orientation being impractical for the component, then design advice is issued. An example orientation rule is shown below.

IF : CYLINDRICAL AND L-D-RATIO<1.5
THEN : ORIENT-PROBLEM CF 75 AND PRINT
"Parts will require manual handling. Increase the L-D ratio."

The presentation module is to determine a method of presenting components to the orientation zone, and a method for transferring oriented components to the assembly zone. The presentation rules infer a tooling element or process. An example presentation rule is shown below.

IF : PART-THICKNESS>1 AND MAX/MIN-DIMENSION<10
THEN : PRESENT-METHOD CF 85 AND
PRINT "Presentation method : wiper blade."

An explanation subsytem has been provided. With the explanation subsystem, users can ask "Why ?" or "How ?" and the system can give an answer. For example, if the system asks for additional input data, the user might wish to ask why. Usually, the system would respond by saying it needs the information to evaluate a particular rule and it may show which rule it is attempting to satisfy. Asking how usually causes the system to show the full sequence of rules it examined in order to reach its conclusion. By seeing the logical reasoning process, users can better accept the outcome.

The explanation subsystem is also an excellent feature for instructional purposes. Through solving a number of problems and at the same time asking for an explanation on each, users may begin to understand the reasoning process. With enough practice, users might become experts in their own right.

5. Conclusion

Close cooperation is required between design and manufacturing engineers in evaluating a product design for improved assembly. The inherent capabilities and limitations of assembly operations should be considered during the early design or redesign stages. At the earliest possible design stages, it is also best to assess the parts for the ease with which they can be supplied and oriented. If components and products are to be designed so that they are suitable for automation, then designer must be provided with adequate information on the consequences of his design decisions, as they are made.

Computer-aided design for assembly can be pursued by the development of conventional programs, where the assembly knowledge is hard-wired into the problem-solving method. Such systems do not fully satisfy the requirements of a consultation system for engineering designers. This leads to consider knowledge-based expert systems.

Expert systems are better suited to design for automatic assembly than conventional hard-wired programs. The separation of the rule interpreter from the expert knowledge and the devision of this knowledge into separate rules, gives the knowledge-based approach a number of advantages. The knowledge contained in these system can be accessed and modified far more conveniently.

An expert system has been developed with the aim of aiding the application of design for assembly, offering assistnce with design analysis and providing suggestions for design improvement. The rule-based expert system has been implemented on an IBM personal computer, using the Texas Instruments' Personal Consultant Plus expert system development shell.

Further developments that should be investigated are the extention of the current work 1) to link knowledge-based system to engineering drawings produced at a CAD workstation, where a substantial proportion of the data may be obtained directly, and 2) to add more rules to improve the performance of the current knowledge-based system.

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