Two application programs which link design and manufacture

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INTRODUCTION

The Computer-Aided Design (CAD) Centre at Cambridge, England has pursued a policy of cooperation with various industrial organizations to specify and develop computer programs which fulfill a variety of needs. These needs are dependent on the nature of the industry involved and have resulted in diverse application programs which include: visualization packages to assist architects to "see" the building they are designing before it is built; systems to assist the design and costing of chemical plant, and programs to generate the precision artwork for printed circuit boards.

The application programs are developed by groups at the CAD Centre who have a specific responsibility for one sector of industry or one class of industrial problems. One group, the Industrial Engineering Group, is concerned with producing economically and technically sound links between the design and manufacture of components. These links are contained in two packages and the purpose of this paper is to show: the programs overall characteristics and the computer systems on which they are used; the way the packages have been developed and an outline of their facilities, and examples of the way the systems have been used.

INDUSTRIAL ENGINEERING GROUP APPLICATION PROGRAMS

The Industrial Engineering Group application packages are directed towards providing viable solutions to the problem of linking design and manufacture of a wide range of components. However, the provision of links between design and manufacture often encourage different methods of working within an organization and influence other parts of a manufacturing business such as marketing as will be seen when the application programs are discussed in greater detail below. Throughout the development of the packages, industrial participation has been an essential ingredient and it is considered that this participation has been crucial because it ensured that the resulting computer programs do provide the facilities and capabilities required by genuine industrial needs. Further assistance towards the development of viable application programs has been the adoption of at least the philosophy, if not the actual routines, of general purpose program aids, such as those associated with the production of drawings on the various graphical output devices (e.g., plotters and storage tubes) that are used. The assistance of general purpose program aids is also seen as a substantial contributory factor towards successful application programs because it reduces both the cost and time scale involved during the development time of the computer programs. The ability to move the group’s programs readily from computer to computer is a characteristic which is adhered to as much as is practicable. The portability of programs is necessary because it is intended that the programs can be supplied to those who require them and there are many different computers which have the necessary languages and operating systems. The use of Fortran IV and adoption of general purpose program aids are seen as two essential ways of assisting program portability because Fortran IV is available on most of the computers which are in all other respects suitable for such programs and as general purpose software often deals with the computer dependent problems such as are found with input and output, these difficulties only have to be overcome once.

Apart from portability, another important criterion in the specification of the Industrial Engineering Group’s application packages is that they can be easily tailored for specific problems. This is considered important because, although generalized computer solutions can be written to solve a class of problems, the resulting program is often large and difficult to use.

During the early stages of development, multi-access computers which consisted of a main or host processor and satellite computers were used to provide interactive facilities to pave the way for the more flexible forms of computer power that have come with advances in computer technology. Now, as computer hardware costs have been reduced, relatively cheap but powerful mini computers provide good interactive and economic running of these application programs while still permitting access to main frame computers when necessary. The response from the mini computer is ensured because it will be used in a dedicated manner with often only one user on the machine at any particular time. Thus, the mini computer is now being used for certain Design and Manufacturing problems in the same way that it has been used for some years to control one item or section of process plant.
Two main application packages have been developed by the group, namely:

GNC  a method of verifying the design, producing n/c tapes and checking manufactured components which are two and two and a half dimensional and
POLYSURF  a method of designing, drawing and, where appropriate, producing n/c tapes for three dimensional components particularly those which have doubly curved surfaces.

The remaining parts of this paper explain, in more detail, the characteristics of these application programs.

GNC

Development of GNC

The CAD Centre has always had the ability to produce drawings and therefore was often requested to plot the tool paths of tapes for n/c machine tools. This way of tape checking was found to be of only limited assistance because not all errors could be detected and even when errors were found there was no ready means of making the necessary corrections.

Thus, the concept of the GNC (Graphical Numerical Control) package was stimulated by the need to overcome the deficiencies of checking tool paths by plots from tapes for n/c machines. GNC was specified by active participation of three British companies (British Aircraft Corporation (BAC) of Weybridge, Plessey Co., and Midcast Numerical Controls) who not only regularly met with CAD Centre staff but provided assistance in the form of computer programs and n/c machine time. The overall specification of the system was that it should: be suitable for two and a half dimensional components (Figure 1); simplify part programming; and reduce tape preparation lead time without incurring extra costs.

It was decided to separate the production of n/c tapes into the three distinct stages of: definition of component geometry; description of machining pattern; post processing and one stage would be checked before the next stage was started. The separation into three stages also meant that the component geometry could be specified by staff other than those usually involved with part programming. Such staff could well be part of the design team of the component who, because they designed the component, could more economically carry out the geometry definition in such a manner that it could immediately be used to describe a suitable machining pattern.

It was decided to use an existing program called KCURVES for the component geometry definition because this was immediately available and portable.

The program to describe the machining pattern was developed at the CAD Centre to be interactive, using the graphic capability of the storage tube terminal (Figure 2) to show the component and cutter path as it was generated. The output from the machining pattern program was arranged to be in a standard form so that whenever possible existing post processors could be used.

As has been shown, the original brief of GNC was to provide a more cost effective method of producing n/c tapes. Successful use of GNC by the participating and other firms has shown that this brief has been achieved. Additionally it has been found that relatively small enhancements to the machining sequence program, enable accurate drawings to be produced using a flatbed plotter which provide both: an additional way of controlling machining because the precision plots can be used for machine tools with optical followers, and a method of checking profiles because the profile of the machined component, e.g., a hob to cut gear wheels can be compared with the accurate drawing.
Facilities within GNC

The geometry definition program (KCURVES) allows components to be described as arbitrary combinations of parts of straight lines and segments of circles. The definition is carried out in the two stages of: definition of all the straight lines and circles required and description of how the parts of straight lines and circles are to be used.

Most normal engineering components can be described because at least forty different ways of describing straight lines and circles are available. An example of the way the straight lines and circles are joined together is shown in Figure 3 which also demonstrates the particularly useful feature of being able to insert fillet radii between any two adjacent parts of the complete curve without defining these radii at an earlier time. A further option is the ability to fit a smooth curve through a series of points with a number of circles; this is particularly useful when profiles, such as aerofoil and cam shapes, are defined as a table of points.

The machining pattern program is interactive and the way this characteristic is used is demonstrated more clearly in the next section which describes GNC in use. However, the main features of the program are listed below:

- automatic scaling and drawing of component curves for checking and reference
- translation, rotation, reflection and repetition of geometry
- calculation and display of offset profiles for use in cutter radius compensation
- the ability to define part programming statements to describe cutter movements and associated data
- animation of the tool movements in three orthogonal and isometric views
- editing the part program by inserting new statements and deleting those no longer needed
- reprocessing the part program to produce APT-compatible cutter location data.

Example of the use of GNC

To demonstrate how GNC can be used a sequence of figures have been prepared showing the various stages to machine part of one of the components shown in Figure 1 from a solid block of aluminium. The component geometry was prepared using the KCURVES program, a detail of one of the pockets being shown in Figure 3. The geometry definition of the component is first checked by a drawing on the screen (Figure 4). After the selected cutter size, feed rates, height at which cutter will clear the metal and depth to which cutter must penetrate the metal have been specified (indicated by the row of numbers along the top of Figure 5) the setting point for the n/c machine is given (indicated by the "**" at the bottom left hand corner of Figure 5).

To remove the bulk of the unwanted metal, the centre of the cutter is controlled by movement of a cursor on the storage tube; this is called line milling. To prevent fouling of the finished profile, the cutter centre must remain a
distance at least the radius of cutter from the final profile. To ensure this, an offset has been drawn equal to the cutter radius as shown in Figure 6.

Two successive movements, using the line milling facility of the system, were then carried out as shown in Figures 7 and 8, the cursor being used to specify the end point of each straight line movement. This way of using the cursor means that an operator can easily use his machining skills to specify the best movements to remove unwanted metal. This can be particularly valuable if special care must be taken because there are relatively fragile items in the component such as thin webs.

The finished profile is obtained by one command where the cursor is used to indicate a start and finishing point as shown in Figure 9. The other two orthogonal views can be obtained as also can an isometric view of the entire tool path and component as shown in Figure 10.

**POLYSURF**

**Development of POLYSURF**

Many components and objects found in various industries ranging from shipbuilding to bottle making are difficult to design because their shape is sculptured i.e., it has a free form which cannot easily be defined. Traditional methods of designing such objects are usually imprecise and may be restricted to the definition of a series of sections through the object as shown in Figure 11. When a component is manufactured from such a limited definition, the final detailed shape would be left until manufactured. Thus, if the component were to be moulded, the final shape would be determined by the pattern maker who possibly would make no reference to the designer but would rely on some “accepted code of practice” within that particular industry.

The fundamentals of computer techniques to overcome the difficulties of imprecise definition were developed as early as 1966. Work at several places within the United Kingdom has been carried out since that time. Of these, the CAD Centre was able to draw directly on the research and development experiences of Cambridge University and BAC, Weybridge to specify the POLYSURF* system which (although still under development) can be used for the design and manufacture of a wide range of sculptured components. This research and development work showed that the inexact and incomplete definitions of components implied by traditional methods which simply define the geometry as a series of section lines, could be overcome by using mathematical equations to define the components’ shapes. This solution had to be computer based because any practical mathematical definition needed a computer to carry out the necessary numerous calculations.

To develop a satisfactory system, and to be satisfactory it was essential that designers and production personnel from industry could readily use the system, two main
types of problems had to be overcome, namely: the solution of the necessary mathematics of handling the equations used, and finding the means of using the mathematical solutions.

Both types of problem are important because poor means of using the mathematics would obscure the powerful tools that were provided and inadequate mathematical techniques would result in clumsy means of achieving satisfactory results.

During the time POLYSURF was being developed, various industrial organizations actively participated by working with Centre staff on specific design and manufacturing examples. The industries were widely based so that the list of components which were used as test pieces include:

- a shoe last
- ship hulls
- bottle moulds
- chair shells
- cab for high speed train
- turbine blades
- car dash panel
- jug mould
- sailplane fuselage.

In this way, pressure from demanding clients ensured that the POLYSURF system contained the necessary facilities which could be readily used. One consequence of using a computing means of defining components is that with the use of other computer methods which can generate half tone pictures of components (Figure 12), realistic pictures of the finished article can be obtained even before it is manufactured. This can be of great value during the initial marketing of the product as well as helping with the aesthetic appraisal of the design.

**Facilities within POLYSURF**

The POLYSURF system consists of three main modules which deal with the design of the component; drawing of the component, and production of tapes to control n/c machine tools.

This modular structure enables different sections of the program to be run independently so that the system runs...
with the minimum of overheads and can be used in a variety of specialized circumstances. The design module enables the component to be defined by the equations which not only apply to free form or sculptured surfaces but also to the more usual geometric forms such as planes, cylinders, cones and spheres. To assist the design, points can also be used as a means of checking whether or not the surface of the object passes through or near certain control positions. Geometric descriptions from the design stage can be stored for further manipulation by the design module to carry out any necessary refinements; the drawing module; the n/c tape preparation module; and other programs which are needed for specialist tasks like analysis or production of pictures by other computer programs.

The drawing module enables line drawings to be produced on a number of different graphic displays with the following options:

- parts of, as well as, complete components to be shown
- different scales or orientations to be chosen
- different arrangements of views and perspective drawings to be selected
- outline drawings to be produced
- principal features to be included and sectional drawings to be obtained in any chosen plane.

The n/c tape preparation module produces data suitable for standard post processors. Any area of the designed component can be cut by specifying the enclosing boundary as any combination of surfaces, planes, cones, cylinders and spheres. Additional options include differing cutting patterns and tool forms. The user must also specify the tolerance to which the surface must be cut.
Examples of the use of POLYSURF

An n/c machine tool supplier needed to demonstrate to a potential customer that the particular n/c machine was able to cut blades for compressors and turbines. The customer had already designed the blade and coordinate data was available at a number of points on both sides of the blade. Figure 13 shows the distribution of the points for one side of the blade. The POLYSURF system was used to fit a series of mathematical equations so that one equation applied to the area between each set of four points and there was continuity of position slope and curvature across the boundaries between adjacent areas. The resulting boundary lines between the areas can be seen in Figure 14 and sections at various depths are shown in Figure 15. The n/c tape preparation module was then used to prepare tapes to cut the blade surface between the leading and trailing edges which were defined in the original data; the cone which defined the root of the blade, and the cone which defined the top of the blade.

The blade surface was then machined giving the form shown in Figure 16 which also shows a finished blade.

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REFERENCES
