MDM-I: A COMPUTER AIDED MOLD DESIGN AND MANUFACTURING SYSTEM

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ABSTRACT

This paper describes a CAD/CAM system used in the design and manufacture of injection molds for plastic parts of electrical consumer appliances, such as vacuum-cleaner bodies or TV-set cabinets. The paper discusses a number of techniques for representing curved shapes, describing surface shapes, and cutting a set of three dimensional sculptured surfaces using a three axis numerically controlled (NC) milling machines.
Features of this system are as follows:

a) Surface representation technique which is suitable for such complicated three dimensional objects as vacuum-cleaner bodies, TV-set cabinets, etc.
b) Data input based on design drawings, not on clay models or prototypes, that is, surfaces are interpolated using information of their boundary curves on the line drawings.
c) Structured programming capabilities of the shape description language to describe objects.
d) NC-tape generation features with cutter interference check capabilities which are applicable to not only flat surfaces but also extremely curved surfaces.
e) Ease-of-use and faster turnaround by sharing functions between a large scale computer and a distributed graphics system.

The system has been implemented on a HITAC M-200H large scale computer and a HITAC G-730 distributed graphics system, and it has been successfully applicable to practical products.

KEYWORDS: CADCAM, Mold design, Surface Representation, NC machine, Graphics Language

1. Introduction

The need existed in the field of the design and manufacturing for electrical consumer appliances to make their injection molds in less time at lower cost with higher quality. Such plastic products as vacuum-cleaner bodies or TV-set cabinets consist of some complex shapes like sculptured surfaces. It is difficult to visualize these shapes or difficult to produce them, because they are made up of complicated geometry. Usually details of these shapes are expressed on the line drawings with some literal explanations, or their clay or wooden models are made by skilled hands in order to clarify the three dimensional shapes.

However, these methods require much man power, time and cost. And, moreover, since two dimensional drawings have some difficulties to express three dimensional objects completely, the information on geometric data on the drawings may be understood inaccurately, especially in case of curved surfaces. As for clay models, hand-made shapes

contain incorrectness of position to be digitized which brings about undurations on the product surfaces. In order to solve these problems, over last several years we have been developing a computer aided mold design and manufacturing system: MDM-I. The techniques developed here include

a) surface representation technique for sculptured surfaces,
b) data input method based on line drawings,
c) shape description language with structured programming capability,
d) NC cutter interference check capability,
and
e) interactive operation on a computer graphics system.

These techniques allow the surface designer to construct geometric models in computers. He can use them in the design and manufacture, because the geometric models are established as data structure. This system has reduced time and cost, and increased accuracy of the

injection molds.

2. System Configuration

MDM-I has been implemented on a HITAC M-200H large scale computer and on a HITAC G-730 distributed graphics system. The host computer constructs a surface-oriented data structure based on an enhanced surface interpolation technique. The geometric calculations to display object shapes and to create NC cutter paths are accomplished through the programs on the host computer. The designer can manipulate the surface shapes interactively to verify and modify the results from the host computer on the graphics system. The graphics system, which consists of 16 bit computer with storage tube display and data tablet, gives the disigner the capability

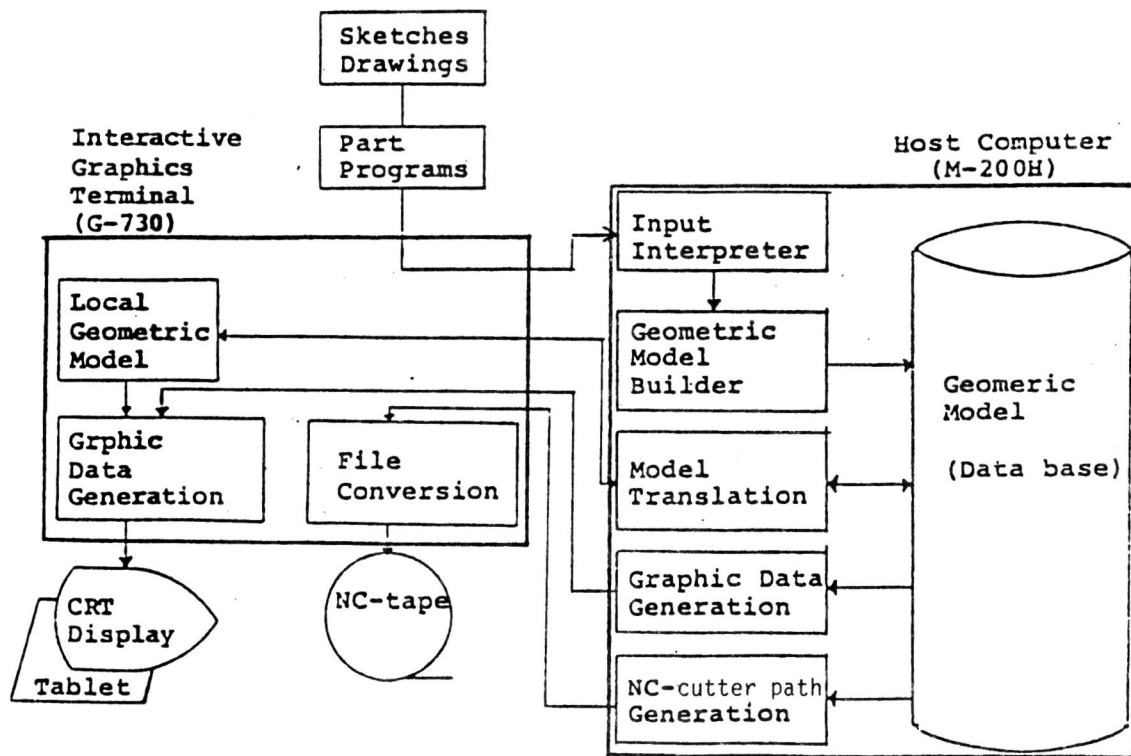a) to input and transfer part programs to the host computer or to take out the results from it as a remote job

Figure 1: System Configuration

entry station,
b) to display perspective views or cross sectional views locally,
c) to check NC tape paths visually on the display,
and
d) to convert NC tape format as a post processor.

The system configuration and software subsystems are shown in Fig.1. As illustrated in Fig.1, the designer describes the object shapes by using a specific programming language or interactive commands through data tablet and graphics display. The input shapes at the terminal are wire-frame models, and the models, then, are interpolated into three dimensional data on the host computer. Since this three dimensional data are kept in a graphics database, necessary geometric calculations are carried out by using this database. The system provides several kinds of graphical verification techniques for information stored in the database, and therefore the designer can verify the shapes on the graphics system. Geometric properties like surface area, volume for required plastics, etc are also calculated from this database.

3. Surface Representation

The surface representation technique is one of the important ideas which change the input method of surface shapes from digitizing many points to describing boundary curve shapes.
The surface shapes described by a shape description language are generated by an algorithm which is a generalization of the Coons algorithm. The algorithm has rotating and scaling factors Ri (3 by 3 matrices) for the boundary curves of the surface in order to obtain the shapes which consist of curved surfaces like spheres, cones, cylinders as well as sculptured surfaces. The interpolation algorithm is based on information on position vectors and tangent vectors of the four known boundary curves of a surface. The Coons algorithm is expressed as follows in the matrix form [1].
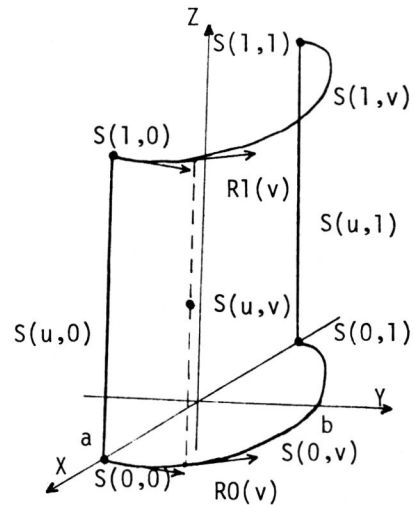

Figure 2: Surface Representation

$$S(u,v) = [b0(u) \quad b1(u)] \begin{bmatrix} S(0,v) \\ S(1,v) \end{bmatrix}$$

$$+ [S(u,0) \quad S(u,1)] \begin{bmatrix} b0(v) \\ b1(v) \end{bmatrix}$$

$$- [b0(u) \quad b1(u)] \begin{bmatrix} S(0,0) & S(0,1) \\ S(1,0) & S(1,1) \end{bmatrix} \begin{bmatrix} b0(v) \\ b1(v) \end{bmatrix}$$

where $b0(u)$, $b1(u)$, $b0(v)$ and $b1(v)$ are the blending functions which are continuous and monotone, and

$$b0(0) = 1, \qquad b0(1) = 0$$
$$b1(0) = 0, \qquad b1(1) = 1$$

$$b0(u)+b1(u)=1, \quad b0(v)+b1(v)=1.$$

The parameters u and v vary from 0 to 1 along the relevant boundaries. $S(u,v)$, $0<u,v<1$, represents the interior of the surface patch. $S(u,0)$, $S(1,v)$, $S(u,1)$, and $S(0,v)$ represent the four known boundary curves.
One of the surface representation algorithms of this system is expressed as

$$S(u,v) = [b0(u) \quad b1(u)] \begin{bmatrix} S(0,v) \\ S(1,v) \end{bmatrix}$$

$$+ [R0(v) \cdot S(u,0) \quad R1(v) \cdot S(u,1)] \begin{bmatrix} b0(v) \\ b1(v) \end{bmatrix}$$

$$- [b0(u) \quad b1(u)] \begin{bmatrix} S(0,0) & S(0,1) \\ S(1,0) & S(1,1) \end{bmatrix} \begin{bmatrix} b0(v) \\ b1(v) \end{bmatrix}$$

where R0 and R1 as illustrated in Fig.2 are the operators (3 by 3 matrices) with scaling and rorating factors.

Ri(v) (i=0,1) is determined by a rotation matrix between two tangent vectors at S(i,0) (or S(i,1)) and S(i,v). For example, as is shown Fig.2, suppose that S(0,v) and S(1,v) are elliptic arcs on the planes which are parallel to XY-plane. Ri(v) can be obtained as

$$Ri(v) = \begin{bmatrix} pCos\pi v & -qSin\pi v & 0 \\ qSin\pi v & pCos\pi v & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where

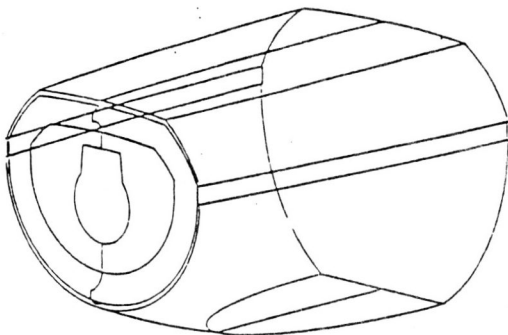$$S(i,v) = \begin{bmatrix} aCos\pi v \\ bSin\pi v \\ c \end{bmatrix}$$
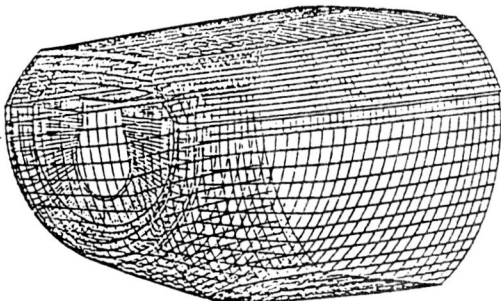

Figure 3: Boundary Curves

Figure 4: Generated Surfaces

and

$$p = b/\sqrt{a^2 + (b^2 - a^2)Cos^2\pi v},$$
$$q = a/\sqrt{a^2 + (b^2 - a^2)Cos^2\pi v}.$$

Even if S(i,v) has a complex shape as a general function, Ri(v) can be calculated similarly if the first derivative of S(i,v) exists.

Fig.3 shows a perspective view of the boundary curves of an electrical appliances. The shapes of the boundary curves obtained from the design drawings. The boundary curves in Fig.3 are used for interpolation to generate the surfaces as shown in Fig.4.

4. Shape Description Language

A specific language is provided for an effective description of the surface shapes, while a command language is used for interactive input. In this system, the boundary curves of the surfaces are expressed as aggregations of line segments, polygonal lines, circular arcs, elliptical arcs, cubic splines, and intersectional curves between two cylinders. The surfaces are described by the shape of the four boundary curves and specifications on their interior shapes. The language compiler Extran [2] allows the designer to construct objects (shapes) by structured programming techniques, that is, global descriptions can be defined first, and precise descriptions, then, follow them.
A sample description is expressed as

```
DE(shape_example
      start
          upper_surface
          side_surface1
          side_surface2
          lower_surface
   )
ME(start
          xlength=100
          xwidth=50
          xr1=10
          .....
   )
ME(upper_surface
          curve_def_1(100)
          surf1=surface/(c1,c2,c3,c4),
               (mode,3,type,4)
          surf2= .....
   )
```

```
ME(curve_def_1(xarg)
        point_def_1
        planexy(xarg)
        c1=arc/p1,p2,xr1,ss,ccw
        planeyz(x_value(p1))
        c2=seg/p2,p3
        planexy(0)
        xw=sqrt(150**2-xarg**2)
        c3=arc_arc/p3,p4,100,ss,
        ,p3a,p4a,xw,ss,ccw,'xyyz'
            . . . . .
    )
ME(point_def_1
            . . . . .
    ).
```

DE and ME stand for "definition expression" and "macro expression" respectively.

The functions of the language are listed as follows.

a) curve definition
b) surface definition specified by the boundary curves
c) placements of surfaces
d) auxiliary point and line definition
e) coordinate-system definition
f) macro definition
g) arithmetic expression
h) input/output.

5. Graphics Output

Various design assist functions (subsystems) are also provided, which help the designer examine and check the shapes. Displaying parallel and perspective views, hidden line eliminated views, and cross-sectional views of surface shapes and cutter paths are performed for the above purposes using the local data structure on the distributed graphics system. Since the local data structure for two dimensional data is also preserved in the terminal, interactive editing and drafting of figures generated by the host system are available on the graphics system.

Stratified cross-sectional views of an object are shown in Fig.5. The algorithm to get intersection curves between surfaces is applied to the calculation of cross-sectional views, where one of the surfaces is a plane.
A surface of revolution which is obtained using the rotating factor in the interpolation expression is
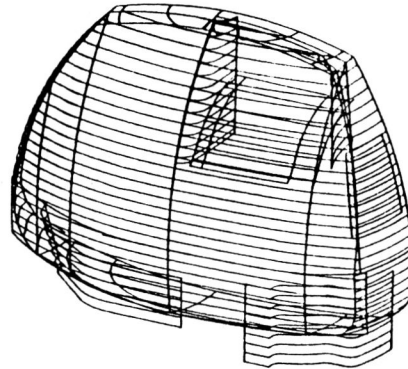
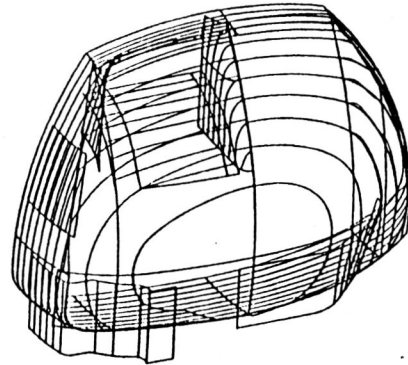displayed with hidden-line elimination as shown in Fig.6.
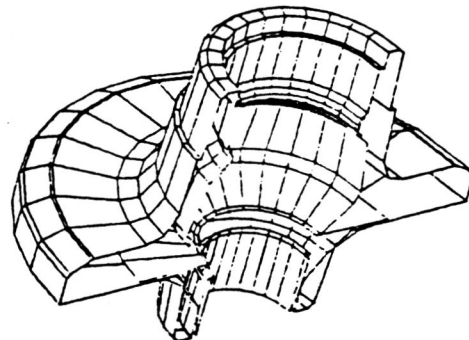
Figure 5: Cross-sectional Views

Figure 6: Hidden-line Eliminated View

6. NC cutter path calculation

After verified the geometry of parts using the graphics system, the same geometry is used as input to the NC cutter path calculation. A surface is represented as a set of small patches, so that the user can deal with the surface by its name and the system can use the parametric expression of the patches. The NC cutter paths are created by specifying cutting information such as cutter shapes, cutter radiuses, cutter speed, feeds and tolerances, part surfaces, check surfaces, cutting directions, thickness of plastics, shrinking factors for electric discharge machining, etc.

When a ball-ended cutter is used for machining, the tool center moves on another parallel surface, offset from the original by an amount equal to the deference between the cutter radius R and the plastic thickness. The cutter interference checks have capability of calculation for up to 16 check surfaces at the same time in order to cut a large curved part surface surrounded by many other surfaces. The check surfaces can be connected with one another by logical operations "and", "or" and "not" as shown Fig.7. These logical operations are calculated by adding information on cutting-region vectors to every knot of the intersection curve between the part surface and the check surface. These operations are indispensable to this system, because it is necessary to regard a surface as both a part surface and a check surface in case of cutting all object shapes, and because the same surface geometry is used for cutting both the outside and the reverse side to make the mold cavities and cores.

In order to calculate intersection curves between surfaces which consist of many patches, stepwise interference checks are performed by successive application of spherical, box-like, parallelpiped [3] and polyhedral bounds on the patches to the calculations, so that those patches whose bounds are not intersected by other patches may be rejected without further calculations.

check surface

part surface S0
intersection
curve between S0&S3

S1 and S2 or S3

cutting-region vector
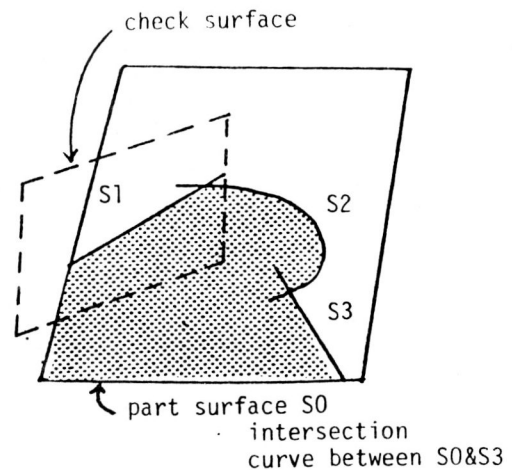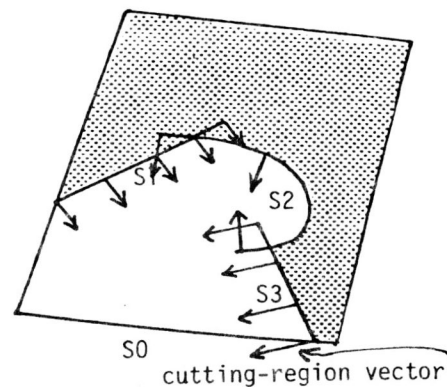
notS1 or notS2 and notS3

Figure 7: Logical Operation
for Check Surfaces

If the bounds are intersected by another surface, the two surfaces are divided into 2 by 2 small surfaces, and the division procedures are repeated until getting the sufficient initial values for the Newton-Raphson method.

Fig.8 shows a perspective view of NC cutter paths of a vacuum-cleaner bodies. Fig.9 shows a back cover of a TV-set cabinet. The user can verify the NC cutter location using these views.
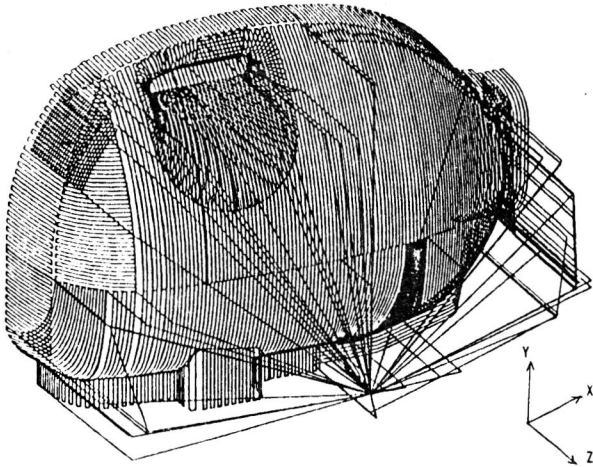

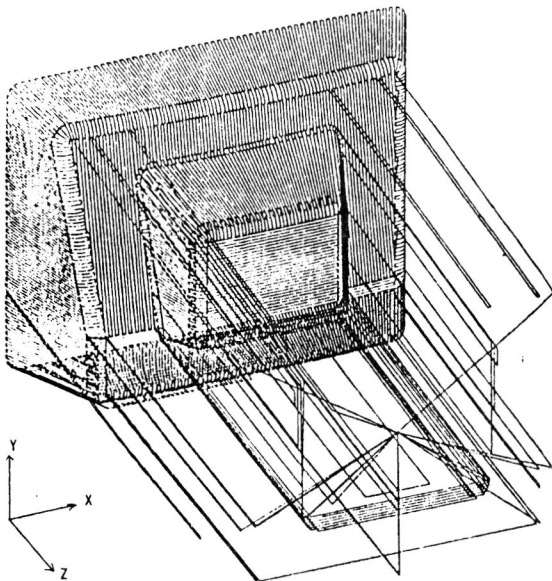Figure 8: NC Cutter Paths
(vacuum-cleaner body)

Figure 9: NC Cutter Paths
(TV-set cabinet)

7. Conclusion

The CAD/CAM system MDM-I, which is mainly applicable to injection molds of plastic parts of electrical consumer appliances, has been developed for several years and has been implemented on a HITAC M-200H large scale computer and a HITAC G-730 distributed graphics system.

The major significance of this system is that the user can obtain the NC tapes for the product shapes which consist of complex curved surfaces, without making detail models for digitizing the many internal points on the surfaces.

The next step is to move toward a solid modeling system based on the representation techniques for these surfaces and regions.

8. Acknowledgements

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9. References

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