A Process Planning System for Machining of Dies for Auto-Body Production - Operation Planning and NC Code Post-Processing

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ABSTRACT

This paper presents a process and operation planning system and an NC code post-processor for effective machining of press dies for production of cars. Based on the machining features, major parts of press dies are categorized into 15 groups and a standard process plan is defined for each group. The standard process plan consists of a series of processes where a process is defined as a group of operations that can be done with one setup. Details such as cutting tools, cutting conditions, and tool paths are decided at the operation planning stage. At the final stage of process and operation planning, the NC code post-processor adjusts feedrates along the tool path to reduce machining time while maintaining the quality. The adjustment rule is selected based on the machining load estimated by virtual machining.

Keywords : Press Die, IDEF model, Standard Process Plan, Operation planning, Virtual machining

1. Introduction

The external body of a car is made of about eight major panels. Usually 3 or more die sets are required to form each type of panel and die sets are different from one another. Henceforth, the manufacturing processes and their relevant data are rarely standardized. The lack of standard lowers the productivity as follows. (1) Since the process plan that specifies machining operations, machines, the sequence of operations, and the set-ups are not documented explicitly, re-working is necessary for the features overlooked or erroneous machining. (2) In operation planning, improper selection of machining methods, tool paths, and machining conditions result in inefficient machining. The lack of standards for tools and machining conditions forces CAM operator to make subjective decisions. Knowing that, machining operators do not trust the machining conditions. They override machining conditions in NC codes by their own decision. As a result, no data or knowledge is accumulated as a basis for improvement. (3) Even if we had the standard for machining condition and it were applied at the shop floor, the machining should be optimized if the feedrate were fixed over the tool paths. The machining conditions are usually selected conservatively for maximum chip load, which means machining is done slowly even for the region with light chip load. To correct these problems, all processes, operations, and their relevant data such as NC tool paths, and cutting conditions should be optimized and standardized. All manufacturing should be done by these optimal conditions and no change should be allowed at the shop floor. If an operator has better idea, he/she should first ask for a change of the standards.

Researches have been mostly focused either on automation of process planning[(1)(2)], or on optimization of tool paths[(3)(4)]. Researches on the development of systems covering process planning to NC-code generation are not common, and the researches reported usually consider dies with features of interest. Not many researches have considered all dies manufactured at the factory level to improve productivity. Furthermore, the researches for automotive industries are especially rare.

The objective of this research is to enhance the productivity in manufacturing of dies by improving data supporting the entire manufacturing procedures from *process planning to machining* as shown in Fig. 1. In this paper, the process planning system presented in authors' other paper[6] is briefly explained first, then an operation planning system and an NC code post-processor are presented.

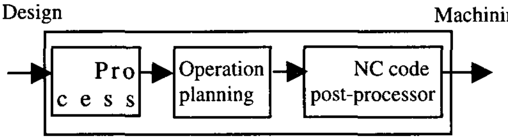


Fig. 1 Preparation of Data for Machining of Dies

2. Process Planning

2.1 Grouping the Parts of Press Dies

The body panels of automobiles are generally formed through a series of press operations such as blanking, drawing, trimming, and flanging. For each operation, a relevant die such as blanking die, draw die, trim die, or flange die is used. Depending upon the structures of press machines, drawing operations that form the shapes of panels are categorized as single action (SA) or double action (DA) drawings. In SA drawing, the punch is located at the lower die, while the punch is located at the upper die in DA drawing. The parts for S/A and D/A drawing dies are different. One die set consists of 3~4 major parts. The dies used at the same forming stage consist of the same kinds of parts. The machining area in a part is divided into the forming part that is involved in forming of a panel and the structural part that is to support and guide dies, and to control the pressure during the forming process. The forming part, which is usually a free form surface, differs depending on the shape of panels as well as on the forming stage. On the other hand, the structural part is dependent on the forming stage only. Unlike general machining features such as 'pocket', 'step', etc., the machining features and cutting tools used in machining press dies are closely related to the functional features such as 'key slot', 'U-shape slot', 'wear plate seat', etc. Therefore, we refer to the functional features in defining the machining features. Table 1 shows the categorization of machining features. Parts are divided into 15 part families depending on the similarity of structural part. In forming part families, the shapes of panels that the dies will produce are not considered. In each family, the parts have the almost same machining features. Depending on the shape of the surface of forming part, machining operation is divided further into several NC machining operations at the operation planning stage.

Table 1 Parts Grouped by Forming Operations

Forming Stage No.	Forming Operation	Part No.	Part Name
10	Draw (Single Action)	11	Lower BH
		12	Lower punch
		13	Upper die
20	Draw (Double Action)	21	Upper BH
		22	Lower die
		23	Upper punch
30	Trim and Pierce	31	Lower die
		32	Upper die
		33	Upper pad
40	Miscellaneous Final Operations	41	Lower die
		42	Upper die
		43	Upper pad
		44	Cam driver
		45	Cam slider
		46	Cam pad

2.2 Standard Process plans

After the parts are clustered, a standard process plan is defined for each group. First, processes are defined based on set-ups. In machining of dies, spindle axis, machining accuracy, unit operational cost of machine tools, etc. determines set-ups. Processes are then further divided into unit-operations. Same unit operation can belong to several processes. Unit operations are closely related to the functional features, e.g. key slot, U-shape slot, etc., of structural part. Whenever multi-operations, e.g. roughing and finishing, are needed to machine a functional feature, multiple unit operations are defined for the feature. Reference surface, guiding surface, and sliding surface are examples of such features.

One hundred and seventy unit operations are defined. A standard process plan consists of ordered set of processes and a list of unit operations for each process; it is not a process plan for one specific part, but a representative process plan, which includes processes that are commonly required by most of part-family members. Therefore, process planning is done by selecting 'proper' processes and operations, based on the part design, among the processes and the operations listed in the standard process plan.

2.3 Process Planning System, MP3D

A variant type process planning system, MP3D (Machining Process Planner for Press Dies), is developed based on part families. It has three major functions: process planning, management of standard processes, and management of machining time. The process planning function generates process plans and outputs operation sheets. The management of standard processes maintains standard process plans for part families, and dictionaries for processes and unit operations. Currently the operation sheet does not suggest machining conditions for the structural part of die; the machine operators select tools and machining conditions. For forming part of dies, tools and machining conditions are set when NC codes are generated.

3. Operation Planning and NC programming

3.1 Operation planning in heterogeneous CAM environment

Operation planning follows process planning. The operations and their sequence, tools, and machining conditions are determined at operation planning stage. For forming part of die, which is usually a free form surface, operation planning and generation of NC codes are done at the same time. Since each CAM system has different capability and requires different inputs and procedures, there is no standard procedure to generate NC codes. A die shop usually has various CAM systems. For instance, the die shop at company D, for which this research is done, uses CLIKS, Work NC, and Z-masters as CAM systems. Therefore, in order to use CAM systems effectively and to generate reliable NC programs consistently, we need to standardize and automate the CAM procedure. We also need a standard operation plan database that will support CAM procedure.

In this research, IDEF0 model[(6)] is used to analyze the CAM procedure. Based on the similarity of operations, the dies are clustered. For each group, a standard operation plan defining the operations, sequence, tools and attachments, and machining conditions is defined in the database. Fig. 2 shows an IDEF0 model of CAM procedure automated by AutoCAM system, which is developed in this research. Each activity in IDEF0 model is built as a module. AutoCAM reads standard database and translates CAD models into CAM models in "Database Load", and generates CL (Cutter Location) files in "Model Translation." Item, Operation, and Part in Fig. 2 represent codes for car panels, forming operations, and parts of dies respectively. The parts of dies are clustered by these codes as a group code. The lists of standard operations are retrieved by the group code. In "Holder Check", to prohibit any collision by tools, CL files are divided up to three CL files. In "NC Generation," NC files are generated with the RPM and feed-rate modified by weight factors. Weight factors are retrieved from standard operation plan database by tool diameter and length, workpiece material, and attachment type[1].

Fig. 3 shows expanded view of "Holder Check" in Fig. 2, "Reference Model Generation" generates final shape of the part to be used in verifying tools and the holders. With standard holders retrieved, standard lengths of tools for the holders are retrieved in three groups: 'short', 'middle', and 'long' ("Tool Division"). A tool can be of different lengths depending on the length of shank held in the holder. Three to four lengths are pre-defined as standards in each group. In dividing a CL file, we use a rule of thumb, "use the shortest possible length" with a constraint that maximum 3 tools, one from each group, are used in one unit operation. While the shorter tool is preferred in reducing vibration and deflection, we do not want excessive number of divisions. From 'short' group to 'long', proper length is sought from each group until either a set of tool-lengths that can machine all surface is found or no feasible set of lengths is found ("Tool Length Check"). CL files are divided into as many tool-lengths selected. The algorithm is represented below in pseudo-C language format.

"Holder Check" Algorithm

[1] The machine tools considered in this research use various attachments for different spindle speeds and with different angle of axis.

```
0. Retrieve(tool[p,q], feature_x);
   // retrieve the tools assigned to machine feature_ x
   // where, p: tool group, q: tool number within group
   // (p=0:short, p=1:medium, p=2:long)
   // if p < p', all tools in group p' are longer than
   // any tool in p
   // if q < q', tool[p,q'] is longer than tool[p,q]
1. p = 0;      // start from short tool group.
2. T = NumberOfTools(p) – 1; q =T;
 // the longest tool from group p
3. if (collision(tool[p,q]) // interference happens
      if (q == T) // if the longest tool in p
         generate_CL(tool[p,q]); // generate a CL for
                                 // maximum possible area
         if (p == 2) // the longest tool available
            {error("there exists some area that cannot be
                   cut by standard tool set!!!"); exit;}
         else {p++; goto step 2;} //next tool group
      else // tool[p,q] collides and q≠T
           // Since tools are checked in descending order
           // of length, we know that tool[p,q+1] is
           // collision-free.
         {generate_CL(tool[p,q+1]); exit;}
   else // no collision
      if (q == 0) // the shortest tool in current group
                  // capable of machining the whole area
         {generate_CL(tool[p,q]); exit;}
      else {q--; repeate step 3;} // next shortest tool in
                                  // current group
```

3.2 DB for Operation Planning and CAM

Standards for operation planning and CAM are managed by a DBMS(Data Base Management System). Even though it is managed by DBMS on server, data are supplied to client systems in files. In our system, processing speed is not a major factor, change in data happens less than often, and Windows and Unix machines co-exist in the shop. Considering that, file system provides a cheaper and reasonable solution. Whenever standards are changed, data are automatically transferred to clients by FTP(File Transfer Protocol). IDEX1x[7] modeling is used in analyzing data. Fig. 2 shows data model with three groups of tables: tables for grouping parts of dies, tables for tools and holders, and tables for machining sequence and conditions. Since the database is for machining of free form surfaces, the shapes of panels are also considered in grouping parts. 'ITEM', 'OPERATOIN', and 'PART' tables, in which data for panels, forming operations, and types of parts are stored respectively, are used in grouping parts. Data for tools are stored in 'Tool', 'Holder', 'ATTACH', and 'Assemble' tables: the shapes of tools in 'Tool', the shapes of holders in 'HOLDER', the shapes and specifications of attachments available for machine tools in 'ATTACH', and assembly information between tool, holder, and attachment in 'Assemble'. Data about the shapes of tools, holders, and attachment are used to verify tool paths and to avoid any interference. Data regarding the sequence and conditions in machining are stored in 'Standard Operation' table. The sequence is determined based on the level of machining such as rough machining, second rough machining, finishing, and second finishing, and the types of tool paths such as pencil machining, zig-zag machining, and 3D-drive machining. 'Condition' table holds lists of machining sequence and conditions required for each part-group defined in 'IGROUP' table. Detailed information for each operation is stored in 'Standard Operation' table. Weight factors to reflect the influence of attachments, workpiece materials, and tool-length are respectively stored in 'Attach Parameter', 'Material Parameter', and 'Length Parameter.'

3.3 Operation Planning System

3.3.1 Overview

AutoCAM automates operation planning and NC-code generation for forming part of die; whatever CAM systems are used, it leads to consistent CAM procedure. From translating CAD model to generating NC codes, operation plan DB supports AutoCAM. In this research, two compatible AutoCAM systems are developed: one for CLIKS on UNIX, and another for WorkNC on Windows. AutoCAM also reduces time for CAM procedure by utilizing command scripts of CAM systems. In this paper, AutoCAM for CLIKS are presented.

3.3.2 AutoCAM for CLIKS

AutoCAM for CLIKS have two functions: "CLIKS Automation" for generating CL files, and "Holder Check Automation and Postprocessor" for selection of holders and generation of NC codes. The second function can be applied to CL files generated by other CAM systems.

Fig. 5 shows an example screen of AutoCAM for CLIKS. After the part family is identified by selecting ITEM, OPERATION, and PART, operation data such as operation type (OP Type), operation method (OP Way), tool type (Tool Type), type of attachment (Attach Type), Holder type (Holder Type), and FENCE file are retrieved. User selects in advance global values for raw material, panel thickness, and safety height. Material data is used as a key value in deciding weight values for

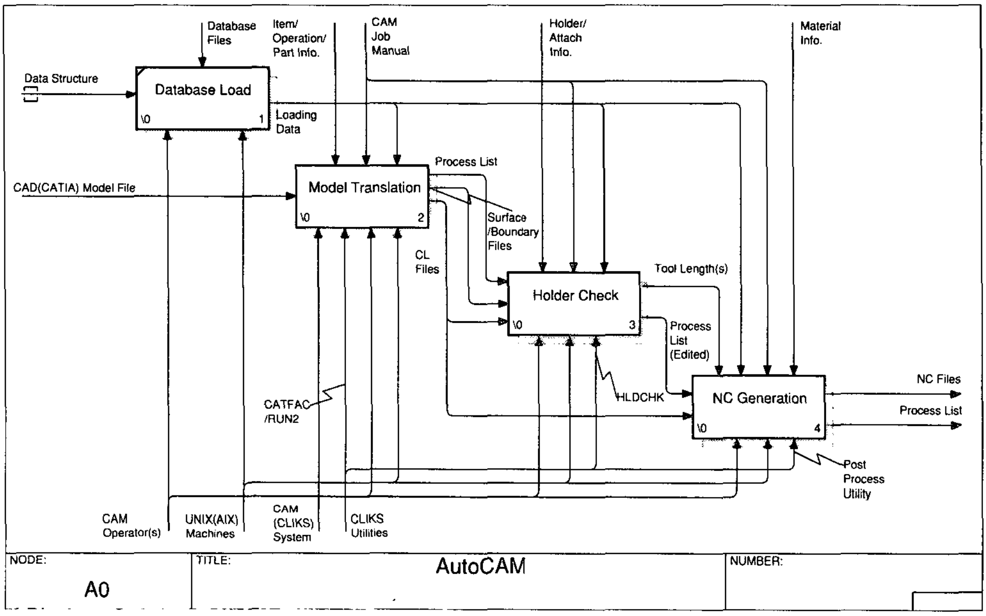


Fig. 2 IDEF0 Function Model for "CAM Procedure Using AutoCAM"

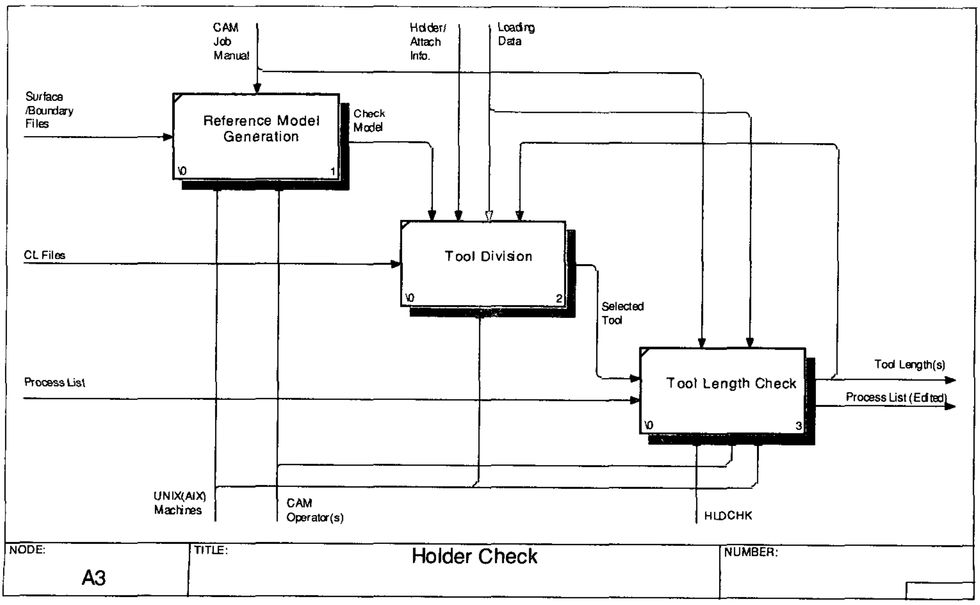


Fig. 3 IDEF0 Function Model for " Holder-Check Using AutoCAM"

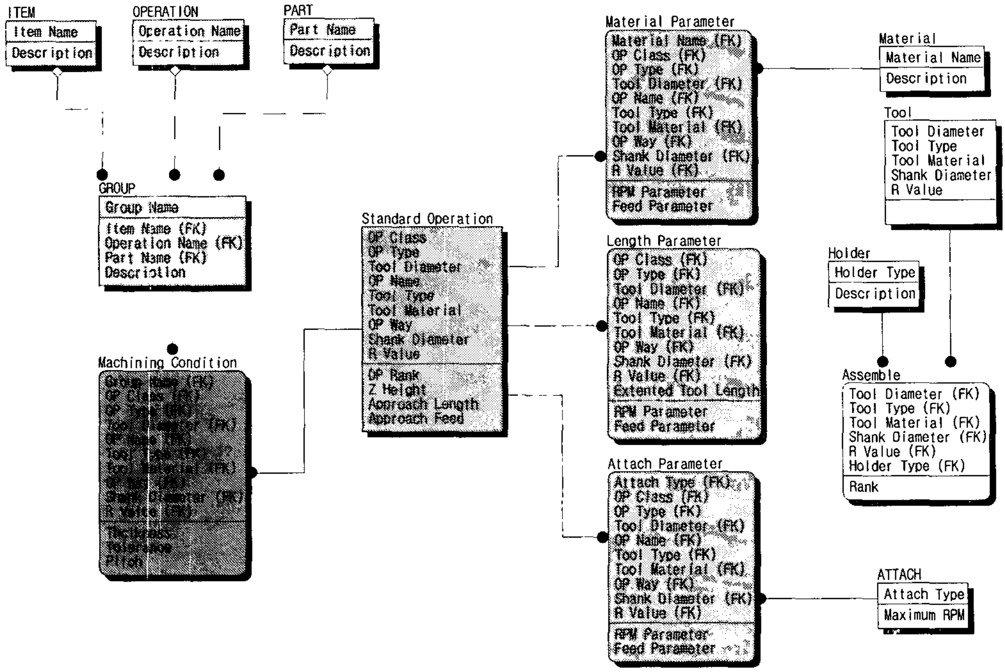


Fig. 4 Entities of Standard Operation Plan Database

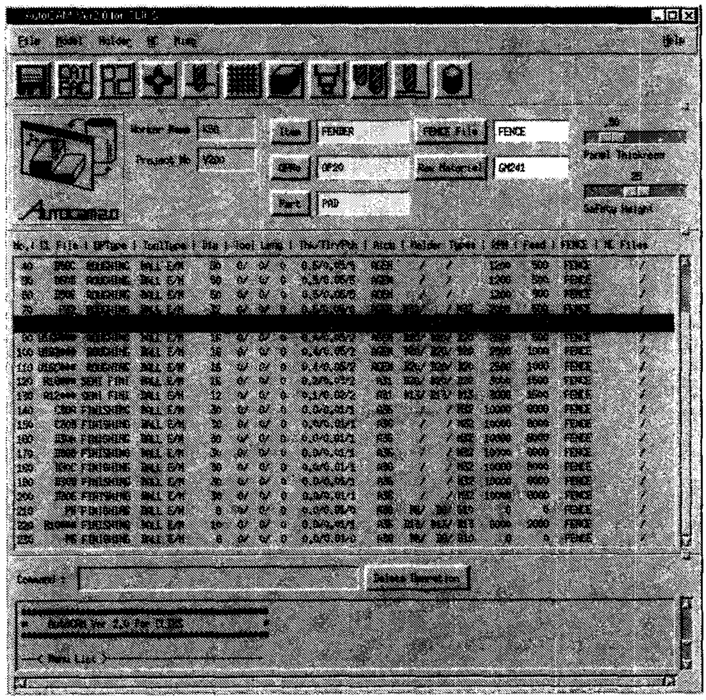


Fig. 5 Retrieval of standard operation plan

machining parameters. Panel thickness is used when CL files are created, and safety height is used as input in generating NC files.

4. NC-code Optimization by virtual machining

4.1 Needs for NC code post-processor

In fear of defecs by overcut, or tool failure, or poor surface finish by overload, etc., CAM operators tend to conservatively set machining conditions and parameters. In practice, time and cost are significantly wasted in fixing defects. In order to enhance the productivity in manufacturing of dies and in preparing NC codes, we need a system to inspect and optimize NC codes. For that purpose, we need virtual machining technology(8)(9) as well as standards for machining operations, tools, types of tool paths, and machining conditions. Virtual machining enables us to predict the result of machining and to manage data related in an integrated manner.

4.2 NC-code post-processor

In this research, CAMplus/AFC the NC-code post-processor is developed. It performs virtual machining to predict the machined surface and machining load by analyzing NC codes, verifies the machining process and the results, and adjusts feedrates based on the machining load estimated. After having been applied at the shop, CAMplus/AFC was proven to enhance the productivity while keeping the quality of the machined surface.

4.2.1 Virtual Machining

CAMplus/AFC uses Z-map[(10)(11)(12)(13)] in calculating the surfaces created in virtually machining with virtual tools by NC-codes. In calculating the machined surface, Some commercial CAM systems have functions to check collisions and to optimize feed-rate. However, the functions are far from being complete. Even if they were useful, a significant investment would be required to purchase new CAM systems. Therefore, NC code post-processors which adjusts feedrates independently of CAM systems gain popularity, but they consider only the amount of directional changes in tool paths.

we use existing method as in Choi's paper[(10)]. Fig. 6 depicts this method. First, from the top view, the grids swept by the cross-section of tool while the tool moves along the NC tool paths are identified. Among the grids identified, the grids whose heights before machining are higher than the corresponding point of tool tip, represent area where metal is removed.

Fig. 7 shows an example surface modeled by Z-map. As in Fig. 7 (b), surface roughness can be 'seen' and the quality of the machined surface can be predicted.

4.2.2 Prediction of Machining load

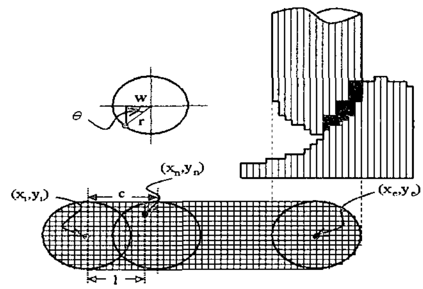
The adjusting rules for feedrate are applied according to the machining-load (ML) estimate. In this research, we define the machining load for a tool in cutting a segment of tool path as 'the ratio of material volume removed over maximum volume that can be removed.' Unlike traditional concept of chip load where modeling at tooth level is required, overall geometry of tool is considered in ML.

- Z-directional machining

$$\mathrm{ML} = \frac{\text{material removed}}{\pi \times (\text{tool dia.})^2 \times \text{tool path length}} \times 100$$

- Other directions

$$\mathrm{ML} = \frac{\text{material removed}}{\text{tool length} \times \text{tool dia.} \times \text{tool path length}} \times 100$$



$$\Delta x = x_e - x_i,\ \Delta y = y_e - y_i,\ \Delta z = z_e - z_i$$

$$d_p = (\Delta x^2 + \Delta y^2)^{\frac{1}{2}},\ l = \frac{\{\Delta x \times (x_n - x_i) + \Delta y \times (y_n - y_i)\}}{d_p}$$

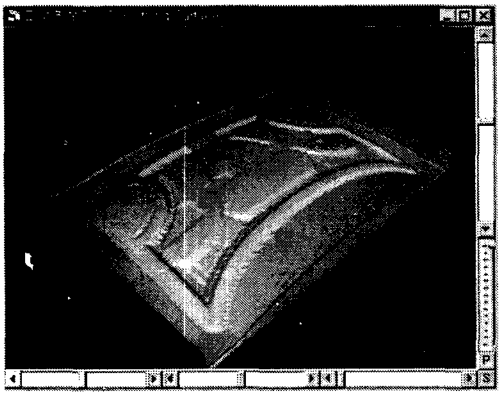
$$w = \frac{|\Delta x \times y_n - \Delta y \times x_n + x_i \times y_e - x_e \times y_i|}{d_n}$$

$$\phi = \tan^{-1}\left(\frac{\Delta z}{d_n}\right),\ \theta = \cos^{-1}\left(\frac{w}{r}\right),\ t = r \times \sin\theta$$

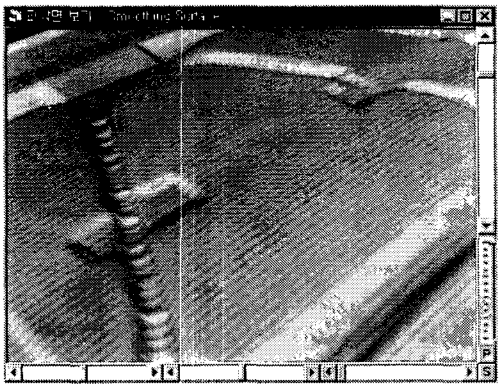
$$h = t \times \sin\phi,\ c = l - h,\ z_n = z_i + c \times \tan\phi - t \times \cos\phi$$

Fig. 6 Z-map model of machining process

Compared with the rules using the outputs of sensors such as tool dynamometers or spindle current sensors, it is easier for operators to understand the rules and to incorporate knowledge since the adjustment rules are based on ML. It is also easier to apply rules using ML than other complicated methods based on chip load, since the operation types or the shape of tools do not affect ML equations.



(a) Virtually machined surface



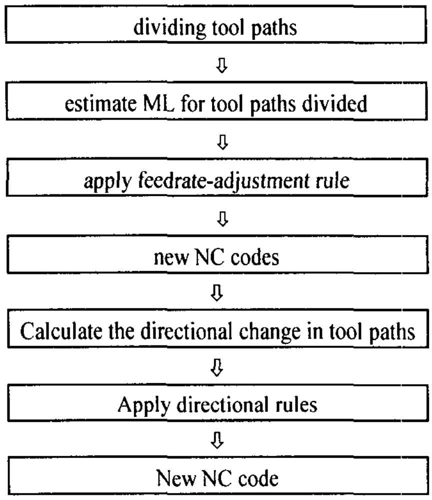
(b) Virtually machined surface (magnified)

Fig. 7 Machined surface represented by Z-map

4.2.3 Adjustment of federates

In order to find an optimal feedrate, we need to consider ML as well as the cutting direction. Some commercial systems adjust feedrates where the cutting directions abruptly change or in z-directional machining. Due to the dynamics of the machine tools, overcut or undercut are expected in these region. On the other hand, in order to adjust feedrates based on ML, we need surface models before and after machining, tool path, and tool geometry. Few commercial systems have these capabilities but they are at primitive level.

In this research, we use virtual machining technology to predict ML and to adjust feedrate. Knowledge for adjustment rules are collected from operator's know-how, theory, and experiments. CAMplus/AFC, the post-processor developed in this research selects reference feedrate, and adjusts it by multiplying weight factors. MLs are divided into 20 regions, on which weights are assigned. The type of part, operation, and tool diameter are keys of adjustment rule base. Fig. 8 shows the procedure for adjusting feedrates and an example screen



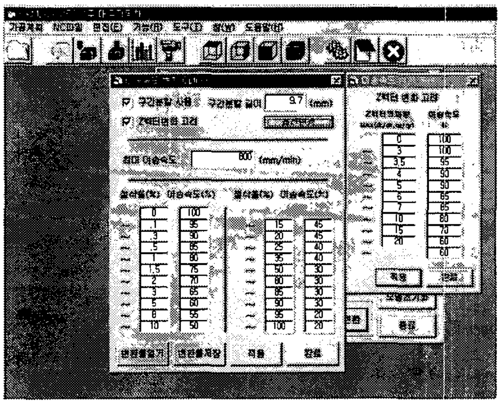


Fig. 8 A process for adjusting feed rate and the screen for setting the adjustment rules

5. Manufacturing of dies by standard procedure

Fig. 9 shows the redesigned manufacturing procedure of dies. Dies are designed first, and MP3D generates process plan while CAM procedure is done with surface models for forming part of dies. AutoCAM generates NC codes and the NC codes are optimized by CAMplus /AFC. Finally operation sheet as in Fig. 10 with drafts of dies, and NC-code list are sent to the shop floor. On the draft, machining areas are differentiated by colors; each process has different color. After finishing each unit operation, the operator marks it on the operation sheet. It makes it easier to manage the progress in machining of die, which usually takes days to weeks. It also helps to communicate between operators from contiguous shifts.

Fig. 9 Manufacturing of dies by the standard procedure

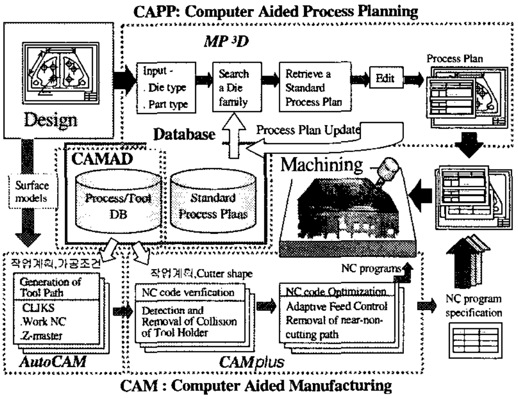


Fig. 9 Manufacturing of dies by the standard procedure

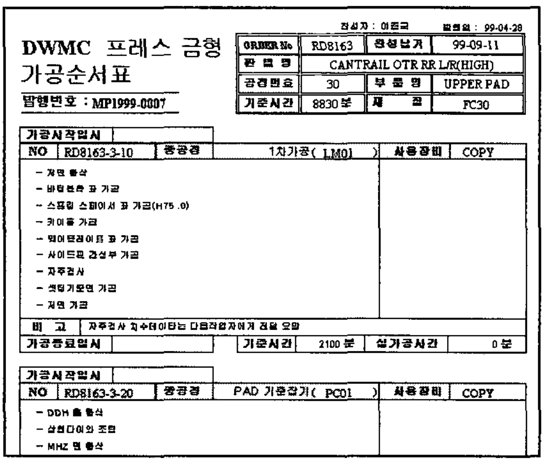


Fig. 10 Part of operation Sheet

MP3D increased productivity by 54%. Time in understanding drafts, in making decisions as required in selection of processes was reduced. The time for reworking the part for areas mistakenly cut, or overlooked was also reduced. AutoCAM attributes to 30% increase of productivity in preparation of data. In order to verify the effect of CAMplus/AFC, we selected 2 dies with almost same machining features: one to be manufactured by post-processed NC codes and the other in traditional way. For this purpose, dies for left and right fenders were machined. It showed that machining time was reduced by 15~30%. Should the effect of standardization be included, actual effect on productivity would be higher.

6. Conclusions

In this research, the manufacturing procedure of dies from design to machining was analyzed. The result was implemented as a system: DBs for standard process plans and operation plans, a process planning system to determine operations and their sequence, an operation planning system to generate NC codes for forming part of die, and an NC-code post-processor to improve NC codes by modifying tool paths and adjusting feedrates.

After applying our system at the die shop, time for preparing data for process planning and operation planning and machining time were reduced. Reduction of defective parts and improvement of quality are also expected. In the long run, it can be said that a foundation for knowledge based engineering is laid. A process planning system that can recognize 3-dimensional-solid features of dies will be developed in the future. Considering that some features of dies are manufactured by third party, dynamic process planning considering availability of resources distributed over die shops will be another research issue.

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