GLOBAL CAM DEVELOPMENT AND USER SUPPORT FOR MACHINING CENTER WORK

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1. Introduction

Numerical Control (NC) was invented in 1952, and has introduced dramatic evolution in metal working practices during last 50 years. Today, there is no way for manually operated equipment to compete with the Computerized Numerical Control (CNC) in terms of the quality, speed and economy of the work. Manual operated machines are mainly used today for highly demanding and special process that requires skill of experienced technicians, such as in fabrication of high quality optical lenses.

CNC machine tools offer definite advantage in continuous and repeated component production for high volume mechanical industries such as automobile. For their application to be equally effective in discrete and low-repetitive production, however, new technologies are still needed. Discrete and low-repetitive production of mechanical component is important infrastructure in terms of prototyping capability, as well as development and supply of capital goods to be used by volume manufacturers. Requirements specific to factory automation of low-repetitive component production is that correct preparations have to be available within minimum time, without repeating try and error, before a machining process becomes possible to be started.

The development of a new technology to minimize the number of processes for low repetitive machining, through-put and preparation time for operation on CNC machining center had been carried on when Dr. Anas Ma'ruf, Lecturer of Department of Industrial Engineering ITB, took study at TUT for five years since 1995. Thereafter the Institut Teknologi Bandung (ITB) of Indonesia and the Toyohashi University of Technology (TUT) of Japan had an opportunity to start a research collaboration.

During the course of the study that has been constantly supported by cooperation of industries, some outcome of the research, typically a newly developed CAM software system named the "P-CAD/CAM" has became successful in industrial application for fabrication of mechanical components by machining centers. P-CAD/CAM software has been found efficient in generating correct NC program, and preparing cutting tool to be used for works by the vertical as well as horizontal machining centers (MCs).

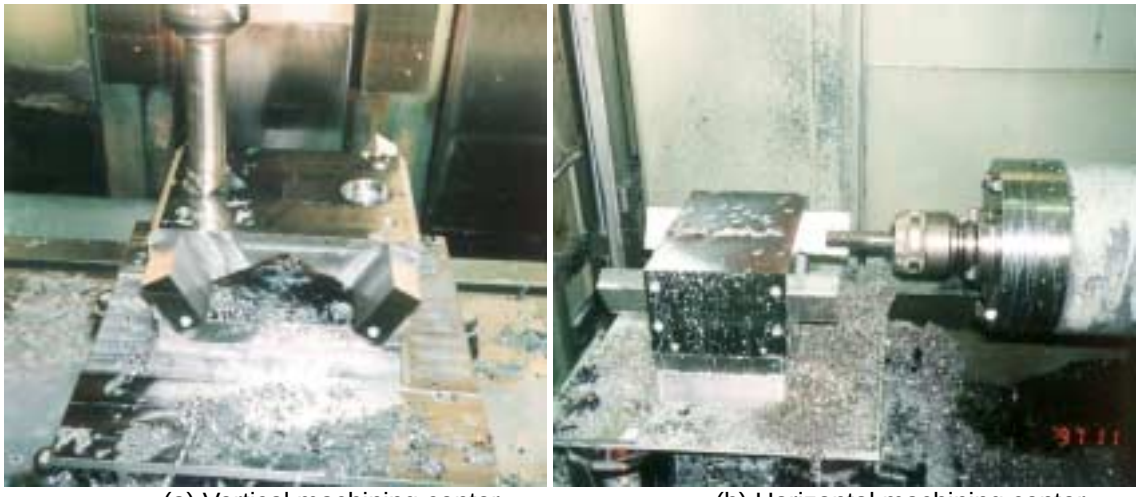
Those who collaborated in the joint study have decided to further enhance the study of CAM technology, and stride ahead for global dissemination of the P-CAD/CAM software to worldwide users who will benefit especially in their business of low-repetitive and discrete machining of prismatic components.

CAD/CAM research activity of *Laboratorium Sistem Produksi* (LSP) ITB will be situated as the central institution for research and development of the CAM technology. In parallel, a non-profitable body named "P-CAD/CAM INTERNATIONAL" (PCI) will be established for the purpose of providing technical supports to the P-CAD/CAM users worldwide through communication network, and financially supporting the CAD/CAM research activity undertaken at LSP-ITB.

2. Machining Centers and Computer-Aided Manufacturing (CAM)

Machining centers (MC) are machine tools that cut the workpiece with a rotating cutting tool, and have the Automatic Tool Change (ATC) capability. Vertical (Spindle) machining center can cut machining features designed on the workpiece surface oriented upward as seen in Fig. l (a), while horizontal (Spindle) machining center, as seen in (b) can work on those designed on multiple surfaces using the rotational indexing of the workpiece around a vertical axis.

Another major category of machine tool is the CNC Lathe in which the cutting tool is held stationary, and cuts a rotating workpiece. Those CNC lathes with additional capability of machining by rotational cutting tools are called Turning Centers.



(a) Vertical machining center (b) Horizontal machining center

Fig. 1. Machining capability of machining centers.

Machining centers share roughly 30% in value of all machine tools supplied today, as seen in Fig.2. (a) and (b). This number includes a small percentage (about 1 %) of CNC milling machines that are not equipped with the ATC capability. CNC is characterized, both for machining centers and CNC Lathes/Turning Centers, by the motion commands for automatic operation given a list of characters, which is called the NC program.

The common language used today for the NC program was originally conceived, when the NC technology was developed in 1952/53, for humans to write. The means for creating correct (error free) NC program fast and easy have been developed. Those include early time development of the Automatic Programming System, and current developments of Computer-Aided Manufacturing (CAM) systems.

CAM, in the narrow sense, means the use of computers for automatically generate the NC program directly from the model data of the products to be made, given by the Computer-Aided Design (CAD).

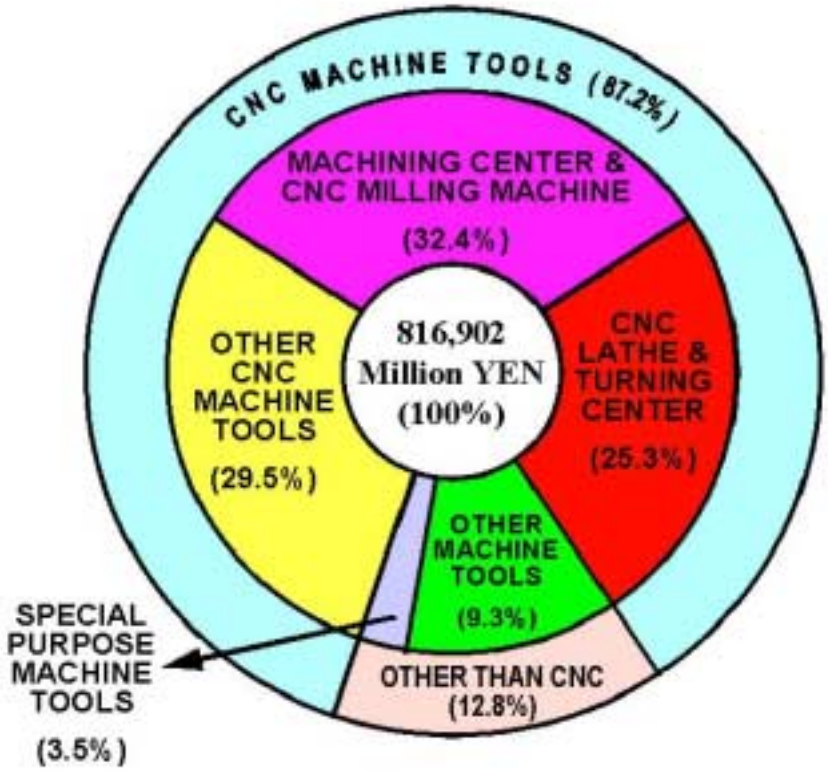


Fig. 2. Types of machine tools supplied in the year 2000 by 89 member companies of the Japanese Machine Tool Builders Association (percentage in value).

3. CAM Processing by P- -CAD/CAM Software

The characteristic of P-CAD/CAM focuses on provision of a CAM system for generating NC program for 2.5 dimensional feature machining, and hole making by vertical and horizontal MC, and does not include capability for 3D free-form surfaces.

3.1 Modeling by P-CAD

For the user to prepare geometrical model of the product component to be machined, a modeling method is provided using the parametric feature-base design method. By this method, the user selects a kind of machining feature to be designed from a list as illustrated in Fig.3. As seen in the figure, three-dimensional free-form surface is not included in the capability of P-CAD/CAM for which advanced CAM systems have been long since developed, and widely practiced mostly by manufacturers of dies and molds. The user specifies the design surface, then selects a machining feature, location, dimensions and the machining method through a dialog box as shown in Fig. 4. Results of the modeling, termed as the Product Data, are viewed as shown in an example drawing Fig.5. The Product Data are processed by the succeeding CAM stage and converted into the NC program.

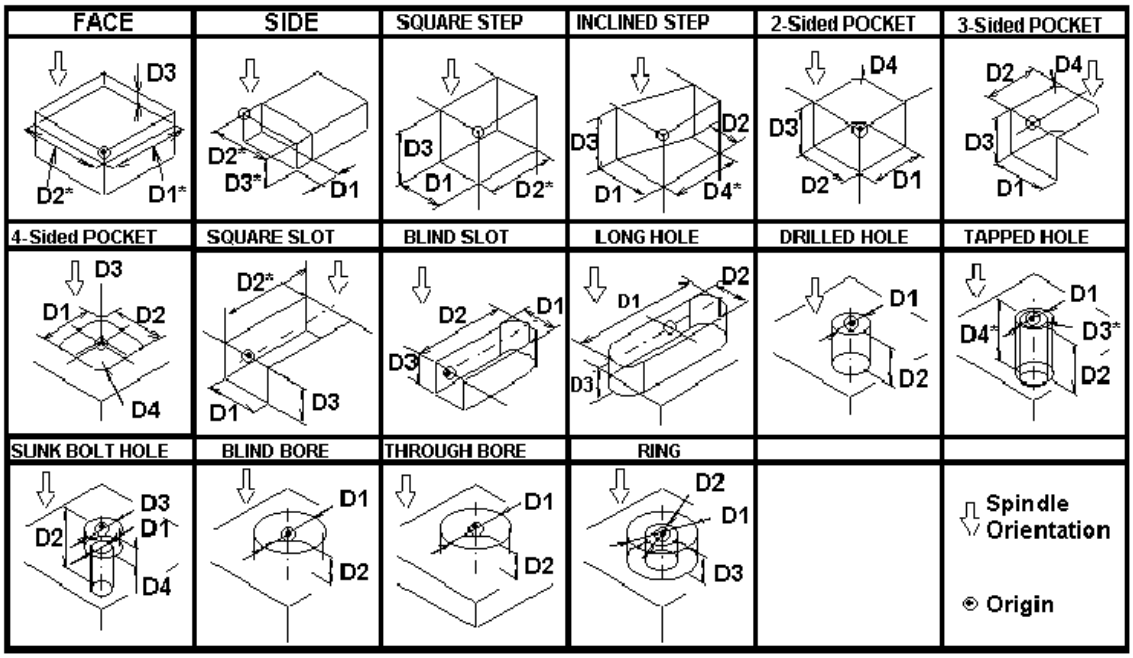


Fig. 3. List of machining features available to users of P-CAD/CAM.

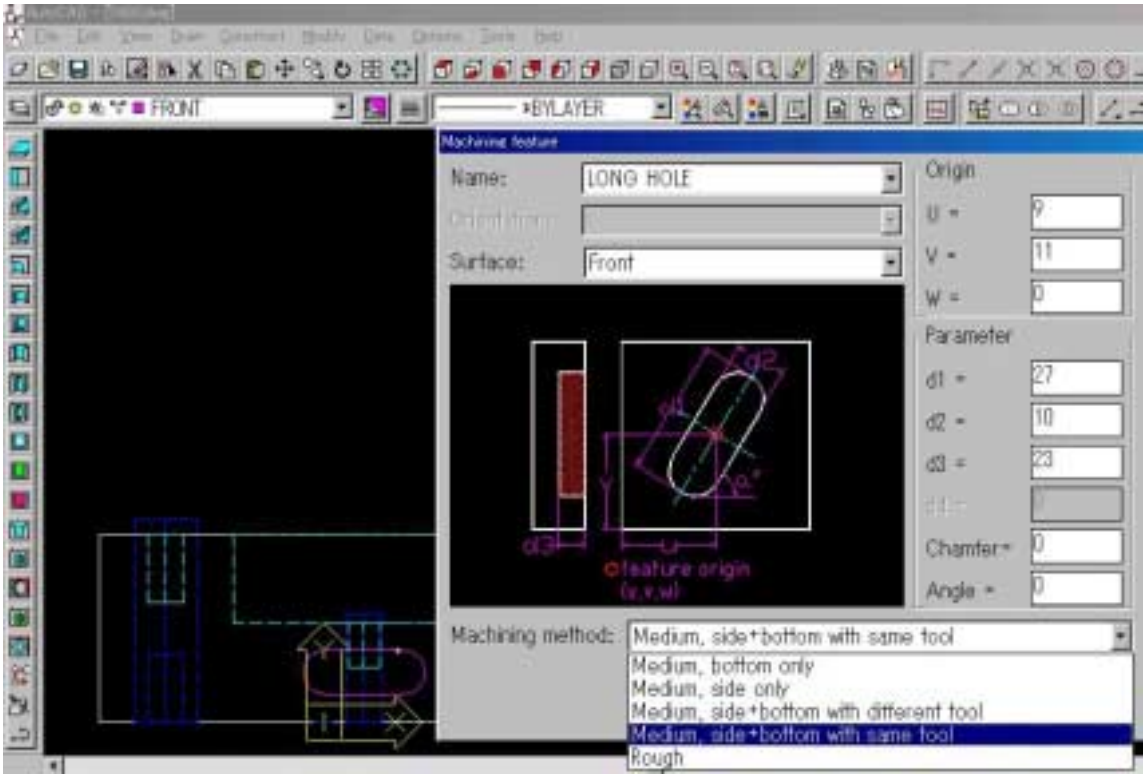


Fig. 4. Machining feature design dialog box.

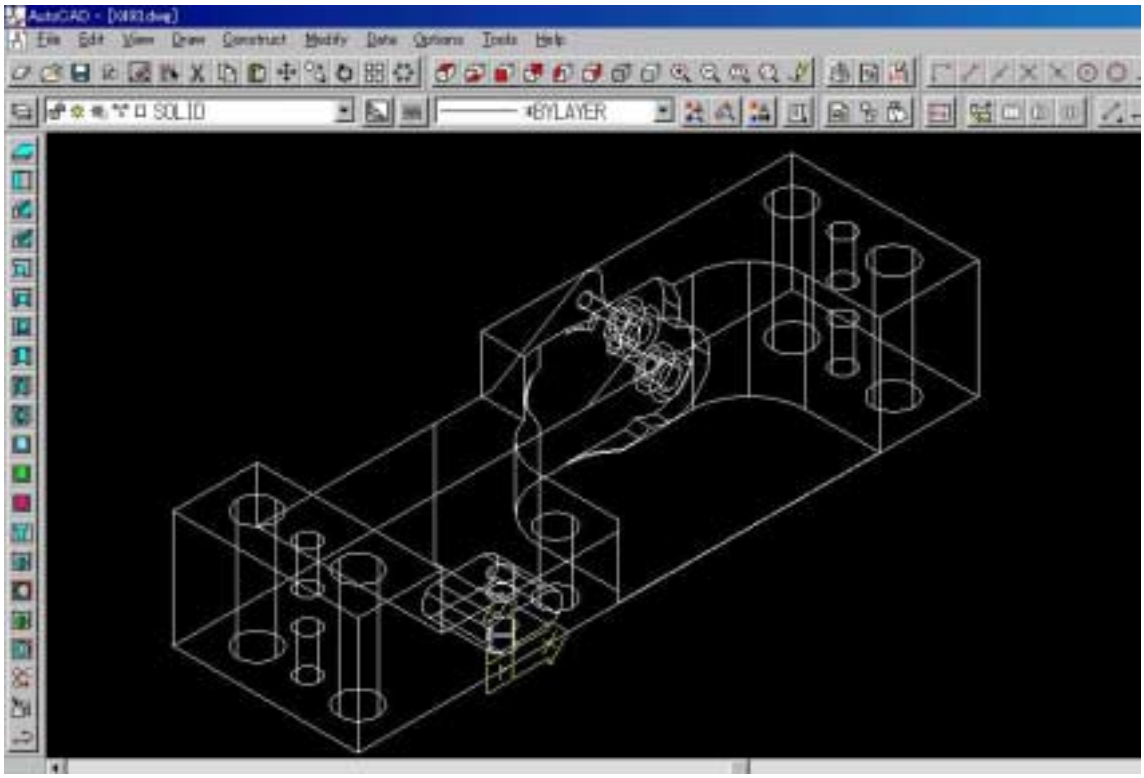
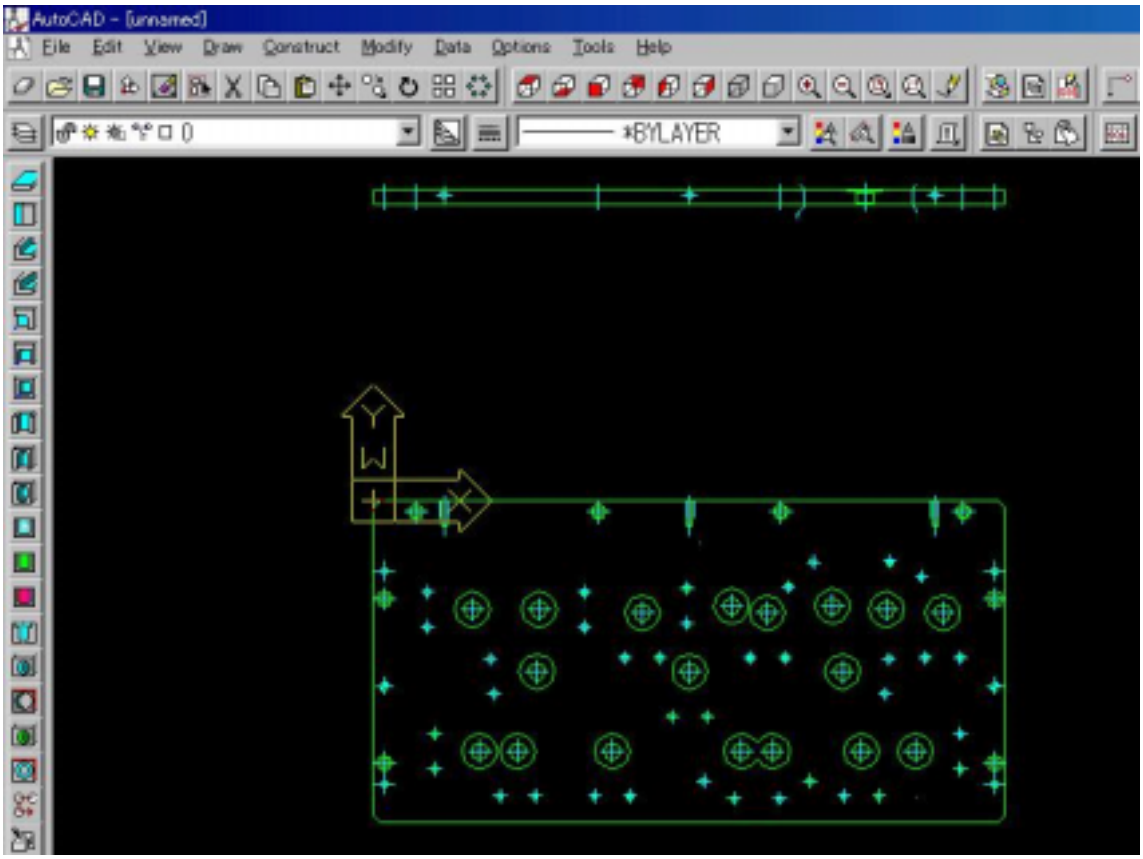


Fig. 5. Example of drawing designed by P-CAD modeling process.

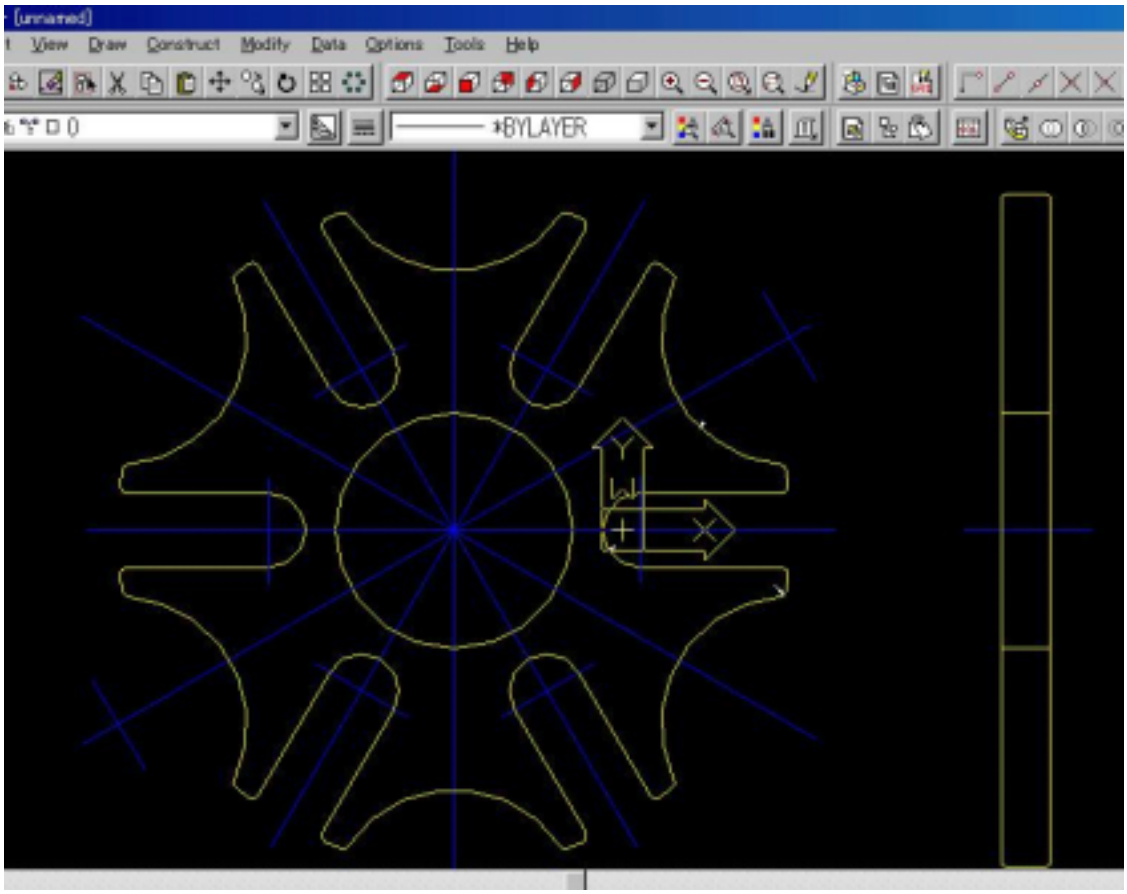
3.2 Modeling by Feature Recognition (FR)

The user has another option of using the feature model directly transferred from external design source, such as the design department of the company or the customer, based on 2-dimensional (2D) mechanical drawing which is imported through the DXF file format. In this case, a specially developed Feature Recognition (FR) software is activated for semi-automatic modeling of the features to be machined. The FR capability has been developed by Dr. Mohsen Shakeri who took study at TUT for 5 years since 1995 [1,2]. Dr. Mohsen is continuing research at Mazandaran University in his home country Iran, and taking care of the FR technology.

As an example, drawings as illustrated in Fig. 6 (a) and (b) are imported through the DXF file format, and opened for automatic analysis by the FR capability into the Product Data.



(a) Drawing with many hole-making features.



(b) Drawing with 2D contour feature.

Fig. 6. Example drawings imported for Feature Recognition (FR) processing.

The Product Data as automatically analyzed by FR are viewed in a dialog box as shown in Fig. 7, for the confirmation or modification by the user.

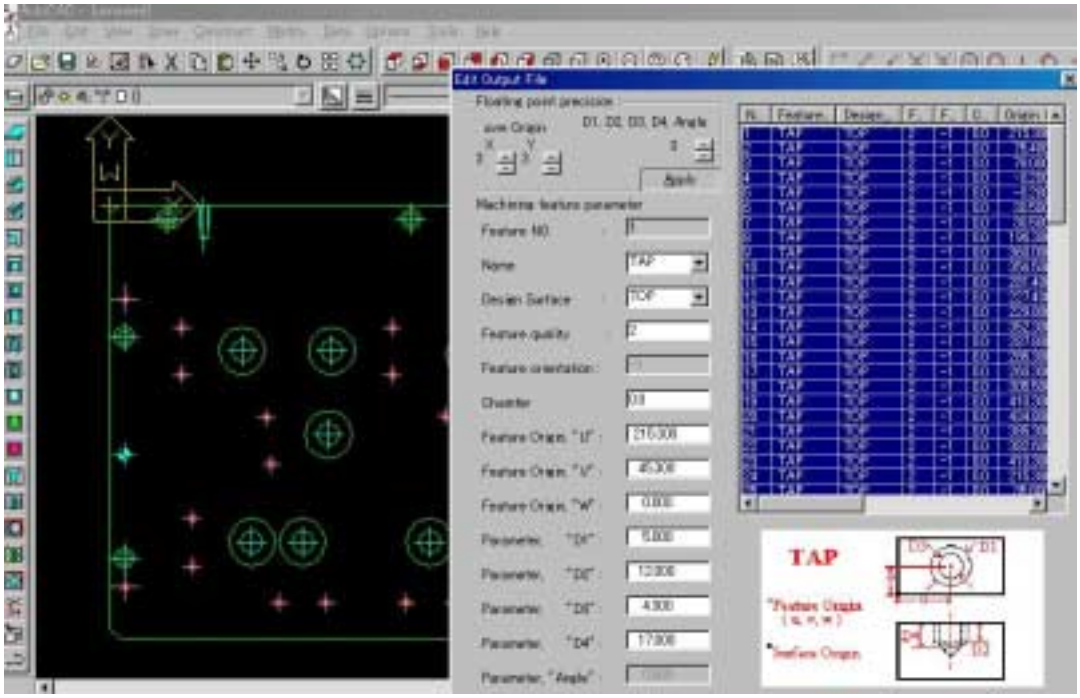


Fig. 7. Example Product Data automatically analyzed by the FR capability and presented for confirmation or modification by the user.

3.3. CAM Processing

CAM capability of P-CAD/CAM software automatically analyzes the Products Data, decides operation details referring to the CAM database, and presents the results for the user confirmation or modification as shown in Fig. 8.

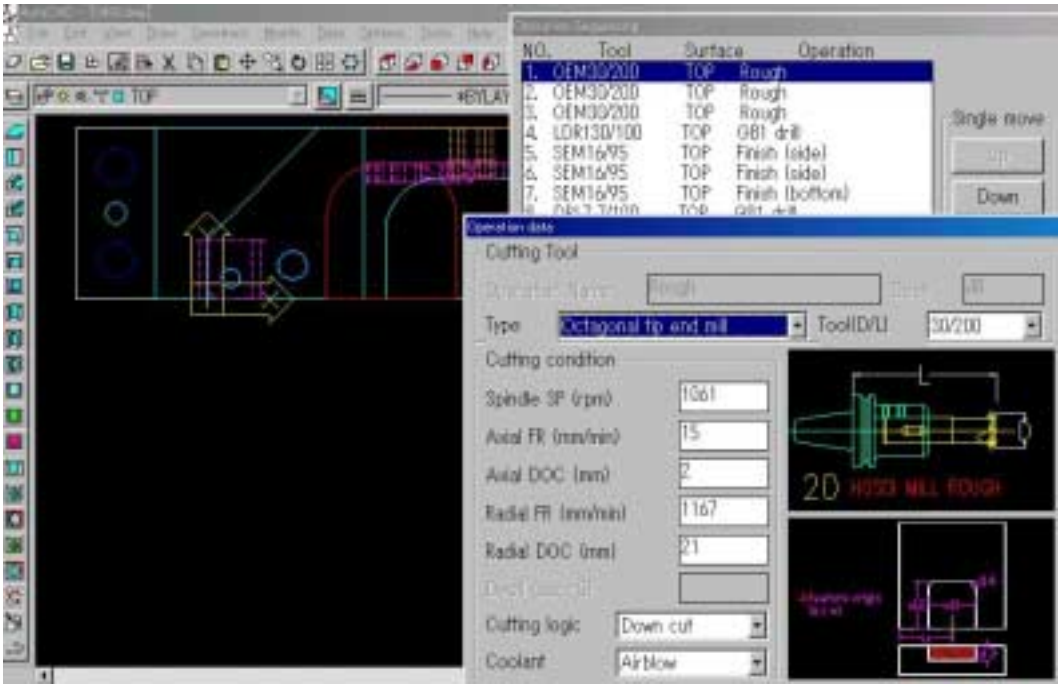


Fig. 8. Example operation details presented by the CAM software for confirmation and/or modification by the user.

Users spend most of time in confirming whether the presented tools or cutting conditions are right and available for the needed machining situation, or whether it needs some override by the human judgement. Other decision-makings are conducted automatically by the CAM system, and finally, the NC program is generated automatically as shown by an example Fig. 9 ready for uploading to the specific MC assigned for the job.

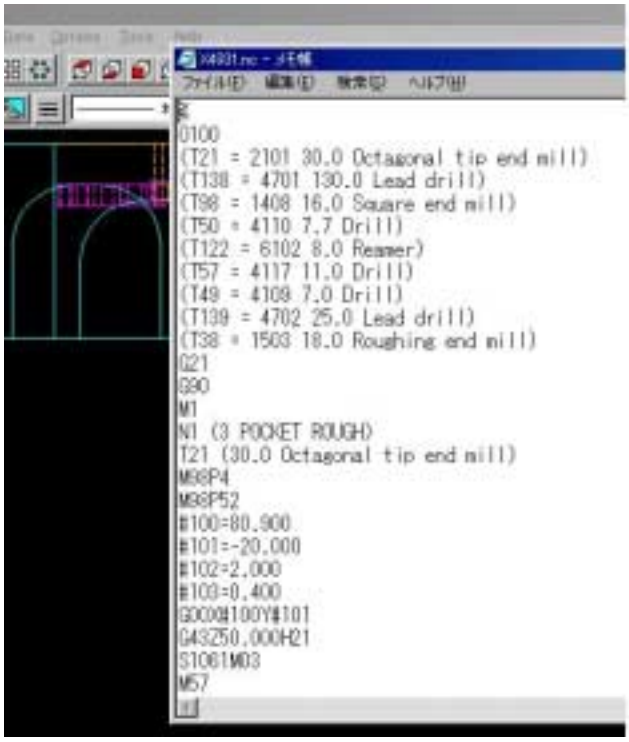


Fig. 9. Example NC program generated by P-CAD/CAM software and ready for uploading to the MC assigned for the job.

Before uploading to the MC, it is advisable for the user to simulate the tool motion of the NC program on the computer graphics as illustrated in Fig. 10 using commercially available simulation software.

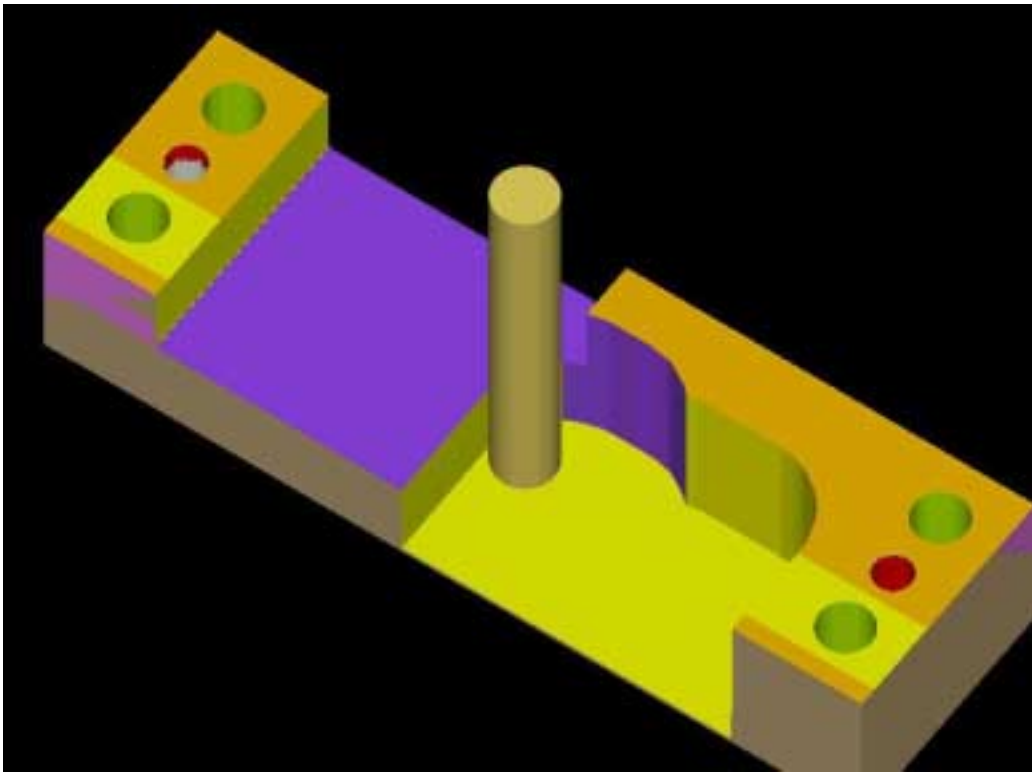


Fig. 10. Graphic simulation of the tool motion by commercially available software, Super Verify (http://www.aikoku.com/aec/index.htm)

3.4. CAM Database

Advanced and user-friendly database viewing and editing capability is facilitated so that the operation details may be customized according to the preferences practiced at individual shop sites [3,4]. For example, the user may open the OPERATION DATABASE by clicking the button so marked in the main database dialog box, as shown in Fig. 11, to view a method of machining operation in detail among a number of alternative methods prepared for a machining feature. The user can modify the database by adding another method of machining, or changing the choice of operations currently defined for a machining method.

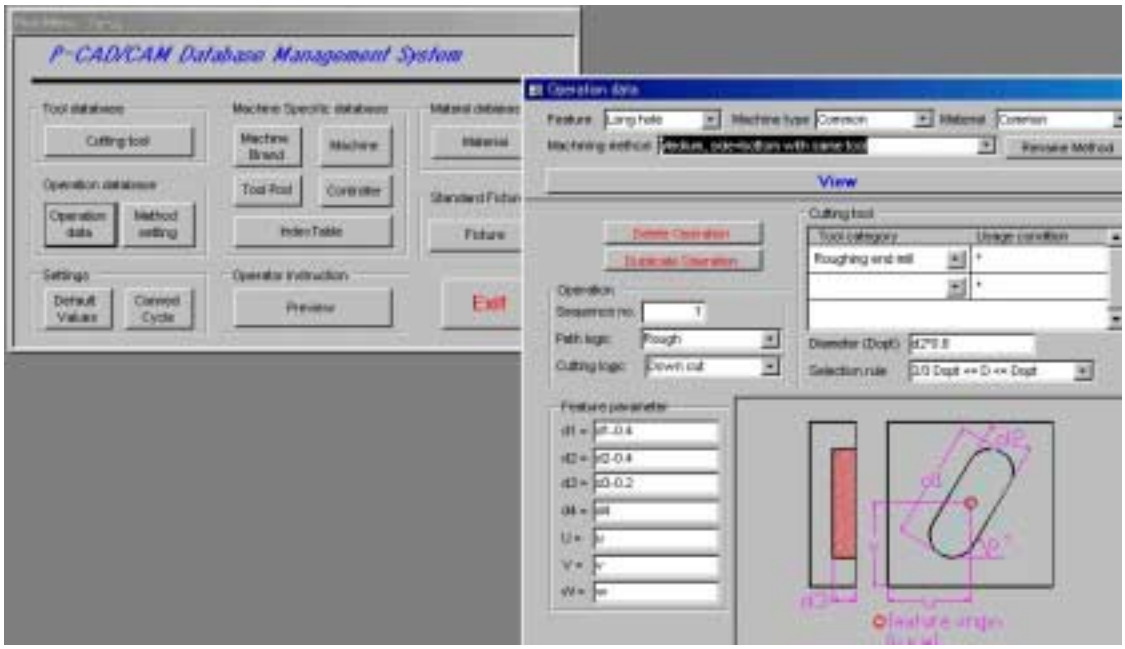


Fig. 11. Main database dialog box and the example viewing of the operation database.

Another example of the shop-adaptability of the CAM software is the CONTROLLER DATABASE in which the user may write according to the specific differences of each NC Controller used in the shop, therefore allowing them to automatically generate the G-codes specific to that controller.

3.5 Fully External Setup

The system features the capability of automatically calculating the machine co-ordinate of the workpiece datum point (termed as the NC Program Reference, NCPR) when the workpiece is mounted on a specified workpiece holding fixture on the MC to be used [5].

For instance, in machining three adjacent design surfaces of a workpiece in one process using a horizontal MC, a vise-type universal fixture can be prepared for clamping a block-like workpiece by the upper and lower vise jaws. Key principle is to machine the three surfaces using the B-axis rotational indexing of the machine table of the horizontal MC as illustrated in Fig. 12.

In the database supporting the CAM software, there is an object “FIXTURE Database” in which user registers the coordinate values of the Work Piece Origin (WPO). WPO position, as previously shown in Fig. 12, has to be measured only once on the machine when the fixture was originally made. Fig. 13 illustrates a set of the FIXTURE data for an example fixture named Vise 90-H. This fixture is placed on the machine table in an index angle $B=90^{o}$ as indicated by the value entered in a data box located at one line above the bottom. It is assumed that the user always places the block workpiece in the fixture symmetrically across a vertical centerline at X=0 when the fixture is indexed to its own index angle. Next adjacent design surfaces are oriented to the machine spindle by rotating the machine table by $+90^{o}$ and -90^{o} from that index angle. Each of the three design surfaces to be worked has its own NC Program Reference (NCPR) point at a

location specified by the user.

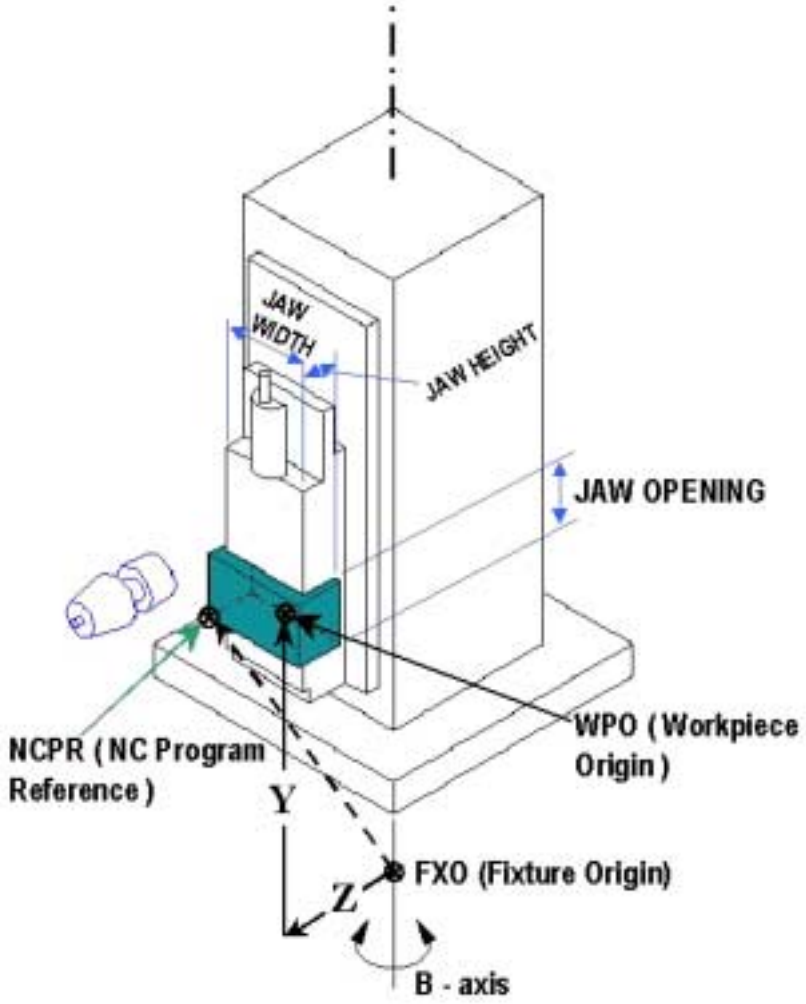


Fig 12. Three faces machining by horizontal machining center.

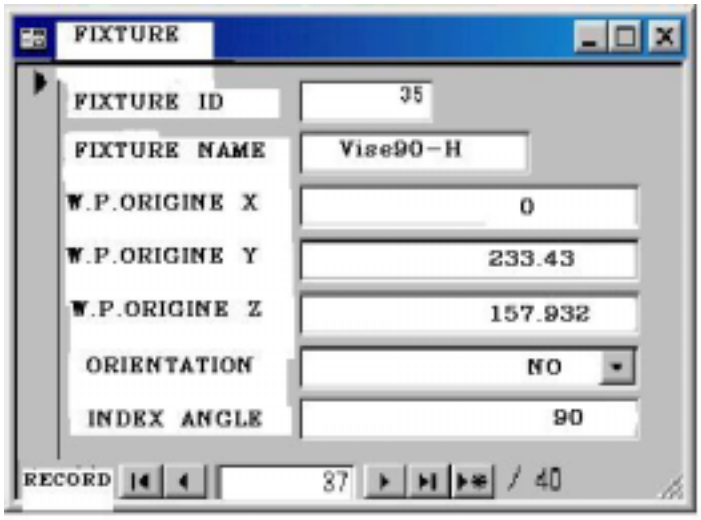


Fig. 13. FIXTURE DATA for an example fixture VISE 90-H

CAM system, upon referring to the FIXTURE DATA and the size of the workpiece model, automatically generates three sub-programs for the MC to find the location of the NCPR points of the respective three design surfaces to be machined as illustrated in Fig. 14. Coordinate values

VZOFX, VZOFY and VZOFZ correspond to those of the NCPR of the respective design surfaces with respect to the Fixture Origin (FXO). As previously illustrated in Fig. 12, FXO is set on the centerline of the B-axis rotation so that its position does not change with the B-axis rotation. VC111, VC112 and VC113 are X, Y and Z co-ordinate values of the FXO, which are set by calling a sub-program O55 found in the second block. The block G15H52 commands that a local co-ordinate system to be established referencing to an origin having the VZOF co-ordinate values calculated in the preceding three blocks.

```
O52(LOCAL COORDINATE SHIFT -> LEFT)
CALL O55
VZOFX[52]=157.932+VC111
VZOFY[52]=233.430+VC112
VZOFZ[52]=35.000+VC113
G15H52
G90G00X0.Y0.
RTS

O51(LOCAL COORDINATE SHIFT -> FRONT)
CALL O55
VZOFX[51]=-35.000+VC111
VZOFY[51]=233.430+VC112
VZOFZ[51]=222.932+VC113
G15H51
G90G00X0.Y0.
RTS

O50(LOCAL COORDINATE SHIFT -> RIGHT)
CALL O55
VZOFX[50]=-222.932+VC111
VZOFY[50]=233.430+VC112
VZOFZ[50]=35.000+VC113
G15H50
G90G00X0.Y0.
RTS
```

Fig. 14 Three NCPR finding sub-programs O52, O51 and O50 for three design surfaces, LEFT, FRONT and RIGHT respectively of an example workpiece measuring width 70mm, and depth 65mm, clamped by Vise90-H example fixture.

```
N1 (FACING ROUGH)
VC110=90
CALL O7(SETUP -> FRONT)
T21 (30.0 Octagonal tip end mill)
CALL O4
CALL O51
VC100=-21.500

N2 (FACING ROUGH)
VC110=0
CALL O7(FRONT -> LEFT)
CALL O52
VC100=60.000

N3 (FACING ROUGH)
VC110=180
CALL O7(LEFT -> RIGHT)
CALL O50
VC100=55.000
```

Fig. 15 Three parts of main NC Program automatically generated for calling NCPR finding sub-programs O52, O51 and O50 after indexing B-axis to three design surfaces LEFT, FRONT and RIGHT respectively.

The CAM system automatically writes in the main NC program, a block for calling respective NCPR finding sub-program, either O50, O51 or O52, each time after rotational indexing (B-axis) of the machine table is performed as illustrated in Fig. 15. In the example NC program listed, VC110 is a common variable where wanted B-axis orientation values, either 0^o, 90^o or 180^o is entered. O7 is a sub-program for indexing the machine table to B-axis orientation designated by VC110.

4. Setup Free Technology

4.1. Standardized work Plan

Using the capabilities of the P-CAD/CAM in modeling relatively complicated geometry, and referencing the workpiece origin for the fully external setup, the user can develop new strategies of integrating work process. Therefore the low-repetitive machining of prismatic components are possible to be totally automatic using only machining centers within minimum number of processes, as well as minimized through-put time and amount of works for preparing the work setup.

A standardized work plan has been developed for machining six design surfaces of a block-like prismatic component in first two processes. As illustrated in Fig. 16, the first process covers only facing of three design surfaces using horizontal machining center (MC) whereby no feature machining nor hole making is performed. This is because, even if some features or holes have been machined in the first process, there is no way to establish their locations with accuracy in the second process. Only chamfering of edges among the three design surfaces may be included in the first process.

Feature machining and hole making will be performed in the second process as much as no tool interference occurs with the vise jaws, in which the other three design surfaces are machined by the horizontal MC. Those features and holes that could not be machined in the first two processes will be worked in the third or subsequent processes where horizontal or vertical MC will be used. Edge chamfering may be included as needed in the second and subsequent processes.

4.2. Process Example and Work Time Data

Work time data are listed in Fig. 17 for machining two pieces of an example workpiece BRACKET in four processes. For preparing the work, total of modeling (CAD process) and CAM processing time were 93minutes in which the user is working with the computer. Time for machining two pieces was 126minutes. Machining time included the net machining time by the automatic CNC operation, and the time for manual stopping, and checking the correctness of the tool motion when the first workpiece was being made. After the NC program was proven through the work on the first piece, the second piece could be worked fully automatic. The extra time spent for the manual checking could be estimated by subtracting the fully automatic machining time for the second piece from the working time for the first piece.

Including two other example workpieces which have been made by two pieces, summary of time data in detail only for the first piece has been broken down as illustrated in Fig. 18.

It is shown that more than 80% of the total work time is spent for preparatory tasks whereas the net NC machining time is less than 20% when only one piece is to be made. Furthermore, when only one piece is made, the work time, which does not engage the machining center, is almost equal to the work time that ties up the machine. For the second repeat, only the workpiece setup time and NC machining time are necessary which is only 32% of the total time spent for the first piece.

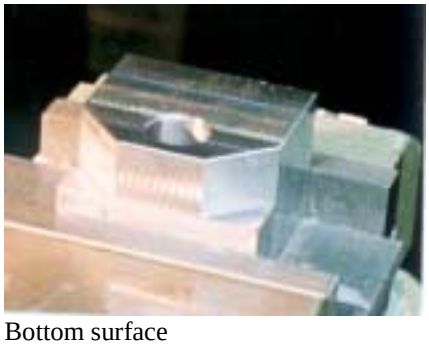
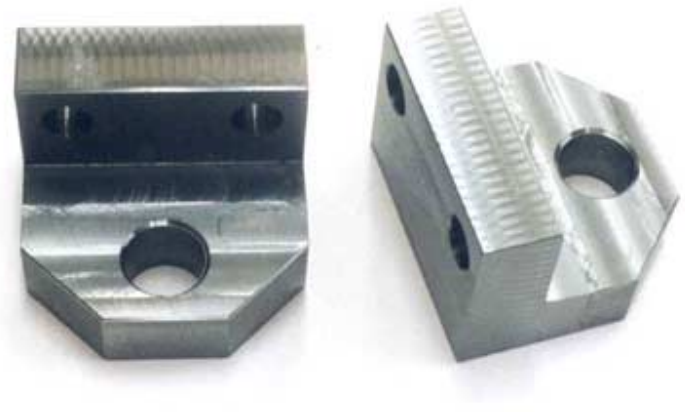
<table>
<tr><td colspan="3">WORK PROCEDURE</td><td rowspan="2">Example: BRACKET
size: 70x65x50</td></tr>
<tr><td>MACHINE</td><td>SURFACE</td><td>OPERATIONS</td></tr>
<tr><td colspan="3">[1st Process]</td><td rowspan="2"> 
Left, Front and Right surfaces</td></tr>
<tr><td>HORIZONTAL
Machining Center</td><td>working on Three Design Surfaces</td><td>Only FACING roughing and finishing 3 surfaces.
<u>No FEATURE</u>
<u>No HOLE</u>
should be machined.
CHAMFERING
if appropriate.</td></tr>
<tr><td colspan="3">[2nd Process]</td><td rowspan="2"> 
Top, Back and Bottom surfaces</td></tr>
<tr><td>HORIZONTAL
Machining Center</td><td>working on Three Other Design Surfaces</td><td>FACING
3 surfaces.
<u>FEATURES</u> and
<u>HOLES</u>
are machined as much as no interference occurs with fixture.
CHAMFERING</td></tr>
<tr><td colspan="3">[3rd and Subsequent Process as needed]</td><td rowspan="2"> 
Bottom surface
 
Top surface</td></tr>
<tr><td>HORIZONTAL
or
VERTICAL
Machining Center</td><td>One Design Surface in One Process</td><td>FEATURES
<u>HOLES</u> and
<u>CHAMFERING</u>
that have not been worked in previous processes.</td></tr>
</table>

Fig. 16. Standardized Work Plan for Process Integration

Product Name: BRACKET



Number of pieces made: 2

WORKING TIME DATA, min (%)					
Modeling (CAD Process)			23	(7.8)	
CAM Processing			70	(24.0)	Total
Tool Preparation			10	(3.4)	292
Work Piece Setup			63	(21.6)	(100)
Machining			126	(43.2)	
	Process 1	H-MC	38	(13.0)	
	Process 2	H-MC	49	(16.8)	
	Process 3	V-MC	12	(4.1)	
	Process 4	V-MC	27	(9.2)	

Fig. 17. Time data for making two pieces of example workpiece BRACKET

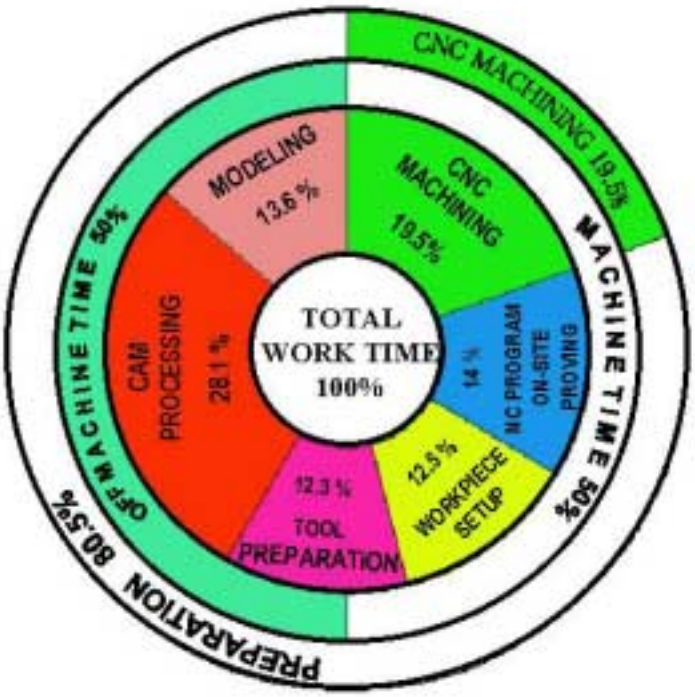


Fig. 18. Percentage share of work time among preparatory and machining tasks for making a first piece of a product component.

5. Global User Support Framework

5.1 P-CAD/CAM INTERNATIONAL (PCI)

For the purpose of providing technical supports to the worldwide P-CAD/CAM users, a new organization named P-CAD/CAM INTERNATIONAL (PCI) is under preparation to be founded in April 2002 by the following four members:

1. Tetsutaro HOSHI, Professor of Toyohashi University of Technology (Toyohashi City, Japan). Dr. Hoshi has been serving as the academic leader for the Setup Free Research Consortium for six years since 1993. He is presently engaged with efforts of spreading practical use of the P-CAD/CAM software, which was one of the research results of the consortium. Dr. Hoshi will be serving as the representative of PCI.
2. Tokushi NISHIJIMA, Representative and Chief Executive Officer of Nishijima Co. Ltd. (Toyohashi City, Japan). Mr. Nishijima was serving as the chairman of the Setup Free Research Consortium. He is promoting practical use of the P-CAD/CAM software in his factory.
3. Yoh IMADA, Factory Director of Sanei Seiki Industrial Co. Ltd. (Ohta-ku, Tokyo, Japan). As a member of the Setup Free Research Consortium, Mr. Imada participated in the development of the P-CAD/CAM Software and became the first successful user of the software.
4. Anas MA'RUF, Lecturer, Department of Industrial Engineering, Institut Teknologi Bandung (Bandung City, Indonesia). During his five years study at Toyohashi University of Technology, Dr. Anas Ma'ruf was the principal researcher who developed the P-CAD/CAM software. After returning to his home university, he has organized a CAD/CAM Research activity and represents the Research Group of PCI.

PCI will be a non-profitable organization whose function will be first to make the P-CAD/CAM software including the User's Manual accessible for any user in the world free of charge through INTERNET.

5.2. Dissemination of P-CAD/CAM Software

The software and manual of P-CAD/CAM are presently available from either one of the following URLs: namely, http://pcadcam.lspitb.org (in English), http://cherry.tutpse.tut.ac.jp or http://www.nishijima.co.jp (in Japanese).

Although the P-CAD/CAM is downloadable for free, the user must hold the user license of AutoCAD software authorized by the Autodesk Company. P-CAD/CAM needs currently Auto CAD r13 version for its operation. A new version of P-CAD/CAM operational with AutoCAD 2000 or 2000i is under development, and will be released in the near future. It is advisable for the user of P-CAD/CAM to be equipped with another software for proving the NC program written in G-code only by executing simulated operation in the computer. One such Simulation Software is the Super VERIFY, commercially available from the Aikoku Alpha Engineering Company (http://www.aikoku.com/aec/index.htm).

5.3 Take-off Support Service (TSS) and User Training

It has been a common experience that a new user needs certain technical supports in starting up the use of P-CAD/CAM for installation of the software in the computer, adjusting database with respect to the specific machining centers to be used, and setting the Fixture Origin (FXO), etc.

Although detailed instruction for all of those Take-off procedures are given in the user's manual which is downloadable from either one of the URLs mentioned formerly, it practically takes substantial work load for a new user to self-study those and try oneself.

Take-off Support Service for a new user is eventually a necessity, and should be available on commercial and profit-raising basis from any one who is already experienced with the procedure.

Training of new user in operating the P-CAD/CAM software is also necessary. Hopefully those who have become experienced would provide the User Training for others.

5.4 User Member Support

The second function of the newly organized PCI will be to respond to technical inquiries, and trouble reports submitted by the User Members. Among those who use the P-CAD/CAM software, one may become a User Member of PCI by paying annual membership fee. PCI will be committed to its User Members in providing following services:

1. Responding inquiries
   Technical inquiries submitted by User Member are responded on individual basis.
2. Trouble shooting
   Technical solutions for troubles reported are notified to the User Member at earliest possible on individual basis. In cases where modification of P-CAD/CAM software is found necessary, PCI will work with the Research Group and the outcome will be notified to User Members concerned.
3. Proposing individual research plan
   When the problem is specifically related only to a User Member, and the solution is found to need further research development of a scale beyond regular trouble shooting, PCI proposes to the User Member to consider an individual research contract with the Research Group.

PCI will be using the membership fee paid by User Members for conducting following activities:

1. Communication Services
   a) Communication with User Members
   b) Communication with the Research Group
   c) Operation and maintenance of the INTERNET homepage
   d) Operation of a bureau for conducting the communication services
2. Research and Development services
   a) Support for the research and development of P-CAD/CAM software conducted by the CAD/CAM Research activity of Institut Teknologi Bandung.
      - Research and development necessary for quickly removing troubles reported by User Members.
      - The mid- and long-range research and development for upgrading the P-CAD/CAM software in response to the future evolution of computer technology and software environment.
      - Scholarship for supporting education of personnel capable of research and development of P-CAD/CAM software.
   b) Editing the user's manual of P-CAD/CAM software.

6. Concluding Remarks

Historically, CAM technology has been developed for CNC machining of 3D free-form surfaces specifically to the need of dies and molds fabrication. Low-repetitive and discrete production of regular mechanical components that does not include the free-form surfaces, has not been much covered by the CAM technology up to the present time, although it is practiced to far greater extent than the production of dies and molds.

Study collaboration between ITB in Indonesia and TUT in Japan was conducted in recent years and has been successful in the development and industrial implementation of new CAM software referred to as the P-CAD/CAM.

The P-CAD/CAM software is characterized as a CAM system that helps the user in creating correct NC program and the set of cutting tools to be used for 2.5 Dimensional CNC machining tasks by vertical and horizontal machining centers.

By using the Machining Feature Based Design, the user may input the feature model to be machined by means of the Parametric Feature Base methodology, which is the latest technology of 3D feature modeling.

Also by the automatic Feature Recognition, the user has another option of inputting the feature model based on 2D mechanical drawing, which is imported through the DXF file format. In this case, a specially developed Feature Recognition software is activated for semi-automatic modeling of the feature to be machined.

The system is featured with Automated Operation Planing capability by which operation details are automatically selected by the software, and presented to the user for confirmation or modification such as the tool to be used, cutting conditions and tool paths.

The system includes Advanced Database that facilitates user friendly database viewing and editing capability so that operation details may be customized according to preferences practiced at individual shop sites.

Also, the Fully External Setup capability automatically calculates the machine co-ordinate of the workpiece datum point (termed as the NC Program Reference, NCPR) when the workpiece is mounted by specified workpiece holding fixture on the MC to be used.

Those advanced capabilities of the system are expected to serve as a platform on which users can develop their own original programs of creating innovative process plans and manufacturing systems. Those are important factors that will realize the substantial savings in cost, man-hour, through-put time, and work spent for correct setup preparations in job shop type manufacture.

Global user support is intended to encourage any organizations and / or individuals to develop their own business on commercial and profit-raising basis in using and/or promoting the P-CAD/CAM software.

P-CAD/CAM International (PCI) will be founded that will be responsible in disseminating the software as a freeware through the INTERNET.

Hopefully the new users of P-CAD/CAM will obtain the Take-off Support Services by those who are already experienced with the procedure of setting up the software system in computer, as well as setting up the CAM connection to the MC at the shop site. Mutual provision of User Training is expected in the similar manner. For the users who routinely use P-CAD/CAM in their commercial production, PCI will be providing technical supports to its User Members with annual membership fees.

PCI will be managed as a non-profitable organization, and use the membership fees collected from User Members mainly for supporting technical research of CAM technology specifically in support of User Members for solving technical problems that may arise in using P-CAD/CAM software at their shop sites.

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REFERENCES

1) Shakeri M., 1999, *Automatic feature recognition from 2D engineering drawing*, Proceedings of The 2nd International Workshop on Intelligent Manufacturing Systems, pp. 525-534, Belgium.

2) Shakeri M., 1999, *CAD/CAM Linkage by automatic feature recognition for 3D CAM model construction from 2D engineering drawing*, Proceedings of The International Workshop on Emergent Synthesis, Japan.

3) Ma'ruf A., 1999, *Object-oriented/relational database design applied for automated operation planning in a machining center CAM software*, CIRP-Journal of Manufacturing System, Vol. 29, No. 3.

4) Ma'ruf A., 1999, *Implementation of a CAD/CAM software for job shop machining center work with external setup capability*, Proceedings of The 9th International Flexible Automation and Intelligent Manufacturing Conference, pp. 1171-1180, The Netherlands.

5) Ma'ruf A., 1999, *Direct Generation of NC Program Supporting External-Setup Machining Center Work*, International Journal of Japan Society of Precision Engineering, Vol. 33, No. 22, pp. 143-148.