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A Computer Integrated Manufacturing System for Low Repetitive and High Product-Mix Components

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ABSTRACT

This paper describes a strategy to fulfill the needs of the 21st century metalworking industry, especially for the industry that produces the low repetitive and high product-mix components using machining centres. The approach of strategy is emphasized in developing of computer integrated manufacturing (CIM) software technology. The designed software comprises of computer aided design (CAD) and computer aided manufacturing (CAM) modules, which is supported by common and working databases, run through dialogue box as the primary user interface inside AutoCAD·, and written in ARX (AutoCAD· Runtime eXtension, the C++ Application Programming Interface to AutoCAD·). The CAD module provides user with capabilities of designing product model by feature-based design and obtaining product data. The product model is displayed on screen in AutoCAD· environment, while the product data is maintained by the Database Management System (DBMS) before transferring it downstream to CAM module. The Structured Query Language (SQL) is used to link the CAM module to DBMS to provide a two-way flow data. Finally, the product data is entered to CAM module for process planning purposes, which is supported by machine tool and fixture databases. The ultimate goal of the software is to solve the CAD, computer aided process planning (CAPP), CAM integration and operation planning that consists of machining data generation and tool selection from the tool database, and NC program generation.

Keywords: CAD/CAPP/CAM integration, feature-based design, machining centre, soft technology.

ABSTRAK

Kertas kerja ini menerangkan suatu strategi untuk memenuhi keperluan industri kerja logam di abad ke 21, terutamanya untuk industri yang mengeluarkan komponen berulang yang sangat sedikit dan campuran-produk yang tinggi dengan menggunakan pusat pemesinan. Pendekatan strategi ditumpukan kepada pembangunan teknologi perisian berdasarkan pembuatan bersepadu komputer (CIM). Perisian yang dibangunkan terdiri daripada modul rekabentuk terbantu komputer (CAD) dan pembuatan terbantu komputer (CAM), disokong oleh pangkalan data dan kerja yang sama, dijalankan melalui kotak dialog sebagai antaramuka utama dengan pengguna didalam AutoCAD·, dan ia ditulis dalam ARX (AutoCAD· Runtime eXtension, aplikasi pengaturcaraan antaramuka C++ kepada AutoCAD·). Modul CAD menyediakan kepada pengguna kebolehan merekabentuk model produk dengan menggunakan rekabentuk berasaskan rupabentuk dan mendapatkan data produk. Model produk dipaparkan pada skrin dalam ruang lingkup AutoCAD·, manakala data produk dikekalkan oleh sistem pengelolaan pangkalan data

(DBMS) sebelum dihantar ke modul CAM. Bahasa baris-gilir terstruktur (SQL) digunakan untuk menghubungkan modul CAM ke DBMS bertujuan menyediakan satu aliran data dua hala. Akhirnya, data produk dimasukkan ke modul CAM untuk perancangan proses yang disokong oleh pangkalan data mesin perkakas dan pemegang. Matlamat utama perisian ini ialah untuk menyelesaikan masalah CAD, perancangan proses terbantu komputer (CAPP), integrasi CAM dan perancangan operasi yang terdiri penjanaan data pemesinan dan pemilihan mata perkakas daripada pengkalan data mata perkakas, dan penjanaan program kawalan berangka (NC).

Kata kunci: integrasi CAD/CAPP/CAM, reka bentuk berasas rupa bentuk, pusat pemesinan, teknologi perisian.

INTRODUCTION

The 21st century business environment in metalworking industry can be characterized by expanding global competition in producing the acceptable quality of components at the right time. The industry should be able to respond rapidly to changes in product design, demand, or product-mix. It can effectively serve both small customers requiring only a few parts and major customers requiring large quantities of many different parts. The mix can be made with consistent quality and minimum waste. For those purposes, adopting the computer integrated manufacturing (CIM), both the hard technology (robotics, CNC machines, AGV, etc) and the software technology (CAD/ CAM software), sounds perfect as the way out. However, there is no standard way for an industry to adopt CIM. All industries operate in different ways and in different market places, and each one must device its own strategy for success (Gunasekaran et al. 2000). With those in mind, it is urgent to design a system to solve the problem in implementing CIM.

The present work is aimed to respond the necessities as well as the problems in the above and the strategy taken is emphasized in developing CIM software technology. The concept of integration based on CIM is implemented to develop the CAD/CAPP/CAM software for producing the low repetitive and high product-mix components using machining centres. Feature-based design as a key factor towards CAD/CAPP integration is adopted and production planning is arranged to achieve the ultimate goal of automated CAM processing.

DESIGN OF THE COMPUTER INTEGRATED MANUFACTURING SYSTEM

PRODUCT DESIGN BY FEATURE-BASED MODELING

Currently two approaches are discerned on how to obtain application features such as manufacturing features from a product model. Firstly, the feature recognition where application features are automatically recognized from a model of the object under consideration (Joshi & Chang 1990). Secondly is the feature-based approach. In this approach, a product model is constructed by using features; thus, this approach is also known as design-by-features or feature-based modeling (Peklenik & Sekolonik 1990; Logar & Peklenik 1991). In this study, the second approach is selected since feature-based design is regarded as a key factor towards the integration of CAD/CAPP (Salomons et al. 1999).

The methodology in feature-based design is principally the parametric feature-based 3-D modeling. For the purpose of machining feature in this research (see Figure 1), the features are limited to certain geometrical shapes of manufacturing product that can be machined by using machining centre.

PRODUCTION PLANNING

There are two stages of production planning used to design CIM system in this study, i.e. process planning and operation planning. Production planning includes interpretation of product model that was designed based on those of machining features shown in Figure 1, selection of machine tools, selection of fixtures, calculation of cutting conditions, determination of tool path logic, and NC program generation. In performing those tasks, operation planning is used to execute the sequence of the process planning detail tasks as well as generating machining data and tool selection prior to NC program generation. Machining data is extracted from the product model automatically to fulfill the requirement of process planning automation. The detail of process planning and operation planning established in designing the CIM system in this study are given in Table 1 and Table 2, respectively.

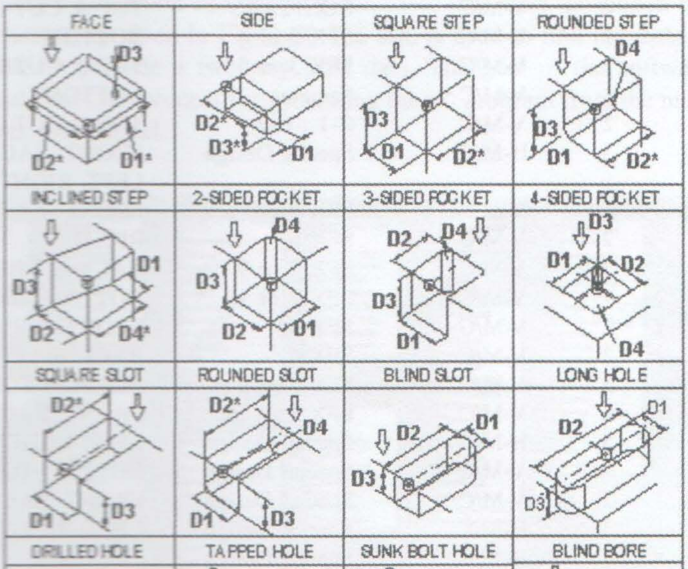

FIGURE 1. Machining features

TABLE 1. Process planning alternatives based on the product model

A	Standard Base Plate Square (400x400 mm) and (25 £ Thickness £ 60 mm).
B	Standard Base Plate Rectangular (600x400 mm) and (25 £ Thickness £ 60 mm).
C	Sides Cut-off From Standard Size Plate C-1. (25 £ Thickness £ 60 mm). C-2. (3 £ Thickness £ 25 mm).
D	Same as C but Side(s) later worked by Horizontal Machine.
E	Sides Trimmed by End Mill then work on Bottom and Top Face.
F	Same as E but Side(s) later worked by Horizontal Machine.
G	Two parallel faces first then four other faces.
H	Three faces first then three other faces.
I	Other Plans.

TABLE 2. Operation planning

Alternative	Process No.	Machine	Fixture No.	Surface
A & B	1	V-M/C	SFX 1	BOTTOM
	2	V-M/C	COUPLERS	TOP
C-1	1	V-M/C	SFX 1	BOTTOM
	2	V-M/C	COUPLERS	TOP & CUT-OFF
C-2	1	V-M/C	SFX 2 or 4	BOTTOM
	2	V-M/C	SFX 3 or 5	TOP & CUT-OFF
D	1	V-M/C	Same as	BOTTOM
	2	V-M/C	C-1 ; C-2	TOP & CUT-OFF
	3	H-M/C	Special Design	FRONT, BACK, LEFT, RIGHT
E	1	V-M/C	SFX 6	FRONT &
	2	V-M/C	SFX 6	RIGHT
	3	V-M/C	SFX 7 or 9	BACK & LEFT
	4	V-M/C	SFX 8 or 10	BOTTOM TOP
F	1	V-M/C	SFX 6	FRONT & RIGHT
	2	V-M/C	SFX 6	BACK & LEFT
	3	V-M/C	SFX 7 or 9	BOTTOM TOP
	4	V-M/C	SFX 8 or 10	FRONT, BACK,
	5	H-M/C	Special Design	LEFT, RIGHT
G	1	V-M/C	Special Design	BOTTOM TOP
	2	V-M/C	Special Design	FRONT, BACK,
	3	H-M/C	Special Design	LEFT, RIGHT
H	1	H-M/C	Special Design	Three faces
	2	H-M/C	Special Design	Three other faces
I	Other Plans (the other combinations besides those alternatives)			

V-M/C: vertical machining centre
H-M/C: horizontal machining centre
SFX: standard fixture (1-10)

To support the process planning in solving the complexity of fixture due to the unlimited combination of machining process and rapid fixture preparation to reduce production time, a number of fixtures have been designed based on the requirement of the machining process for all of the machining features.

PRODUCTION CONTROL AND PROCESSES: DATABASE DEVELOPMENT

In order to control those processes in producing the product design, the developed CIM system is supported by a DBMS. The database is developed by utilizing the relational database concept and supported by the object oriented database approach. The relationship among those objects in process planning as well as operation planning is arranged and shown in Figure 2.

IMPLEMENTATION OF THE COMPUTER INTEGRATED MANUFACTURING SYSTEM

THE OVERVIEW OF SOFTWARE SYSTEM CONFIGURATION

The methods and algorithms established in designing of the CIM system in this study are implemented for software development. The developed software is run through dialogue box as the primary user interface inside AutoCAD·, and written in ARX (AutoCAD· Runtime eXtension, the C++ Application Programming Interface to AutoCAD·). The software is designed for the application in personal computer (PC).

As the overview of the software system configuration which is given in Figure 3, the software comprises of two modules (CAD and CAM) and supported by common and working databases that were developed based on the relationship given in Figure 2. The SQL is used to link the CAM module to DBMS to provide a two-way flow data. The goal of the software is to automate the CAM process for generating the NC program from the machining features CAD model.

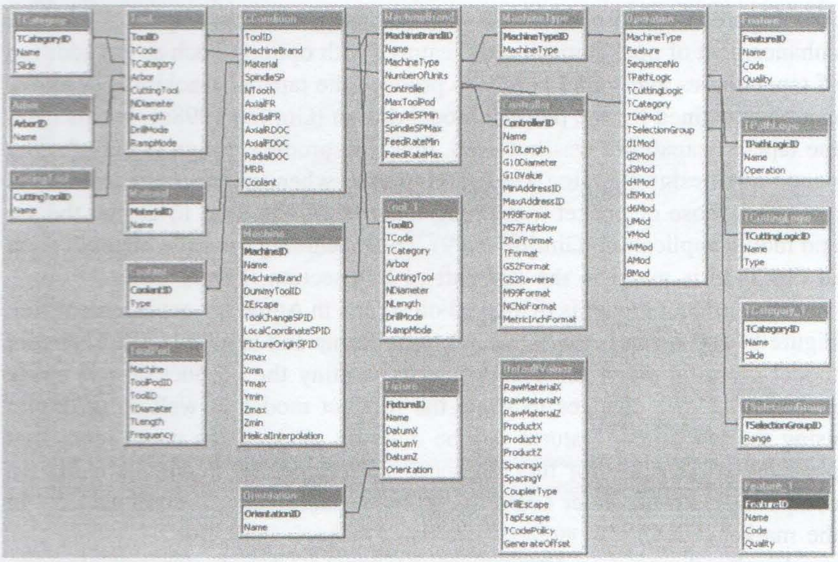

FIGURE 2. The relationship among the objects used to develop the database management system (DBMS).

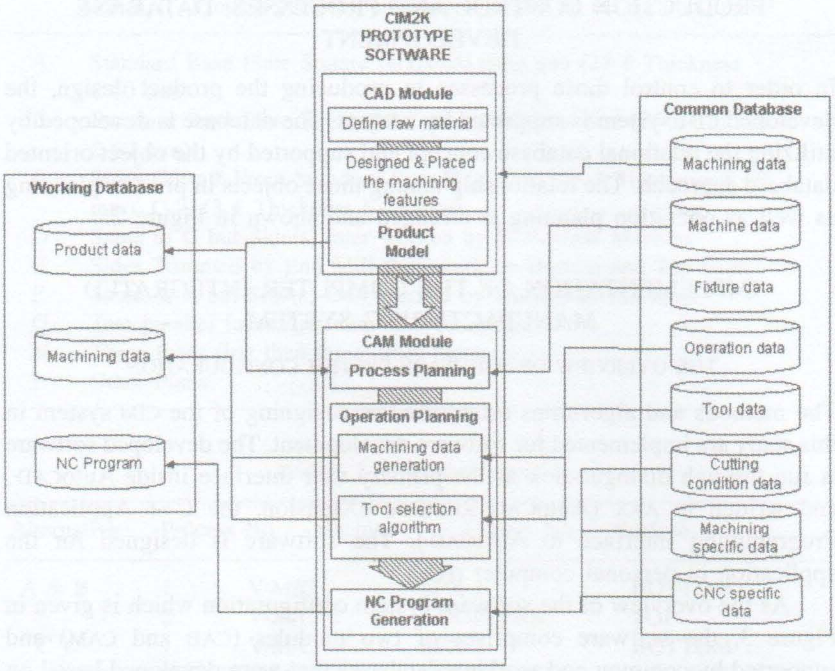

FIGURE 3. The overview of software system configuration.

CAD MODULE

The CAD module provides user with capabilities of designing product model by feature-based design and obtaining product data through the dialogue box (see Figure 4). Those of machining features shown in Figure 1 and the enhancement of pocket machining features with options, such as the addition of taper angles and round corner to produce the tapered machining features, can be combined for the product model design (Ginting 1998a). In this case, the tapered capability was not used, thus, the product design is only for the parametric design (Ginting 1998b). However, when the tapered capability is activated, those of pocket machining features can be used to design the die and mould application (Ginting 1999). The machining example of application in this field is given in the last part of this section (Figure 10).

The product model is displayed on screen in AutoCAD· environment (see Figure 5) and it can be in 2D or 3D (wire frame and solid model). The solid model is useful when the user wants to scrutiny the product design in the real view. Those changes to show the product model as well as to design using the machining features can be done by clicking the menu icons that provided specifically for this software. This capability makes the software competing with the other CAD/CAM software that available commercially in the market today.

Finally, the product data is entered to CAM module for process planning that supported by machine tool and fixture databases, operation planning that consists of machining data generation and tool selection from the tool database, and NC program generation as the ultimate goal of the software to solve the CAD/CAPP/CAM integration.

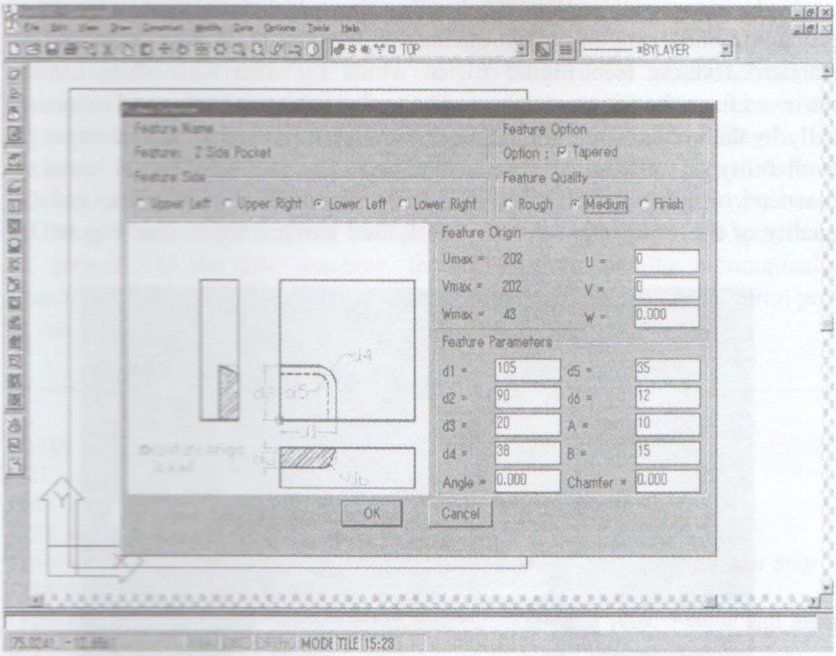

FIGURE 4. The dialogue box in designing product model using the machining features.

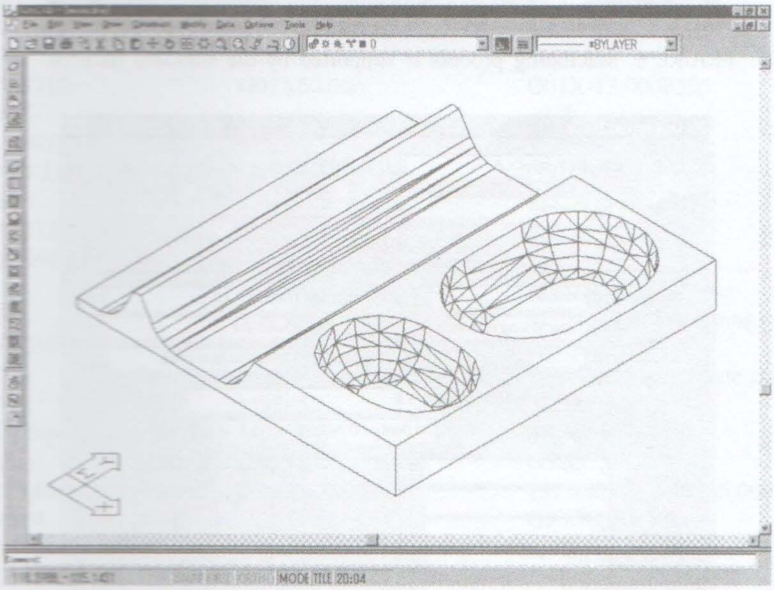

FIGURE 5. Product model displayed on screen in the AutoCAD· environment.

CAM MODULE

After completing the design of product model, the product data is entered to CAM module automatically for production planning. This stage, as mentioned previously, includes the process planning, operation planning (machining data generation and tool selection) and NC program generation.

In the operation planning, holding the raw material that to be cut in producing the component by the machining centre is supported by the standard fixtures (see Figure 6), in which the data for fixture can be retrieved from the fixture database. The tool selection is performed automatically by the system since certain algorithm has been established based on the availability of tools in certain machine tool. The tool selection is based on the need of cutting tool types in cutting the machining features, and the quality of the component due to the desired surface finish (see Figure 7).

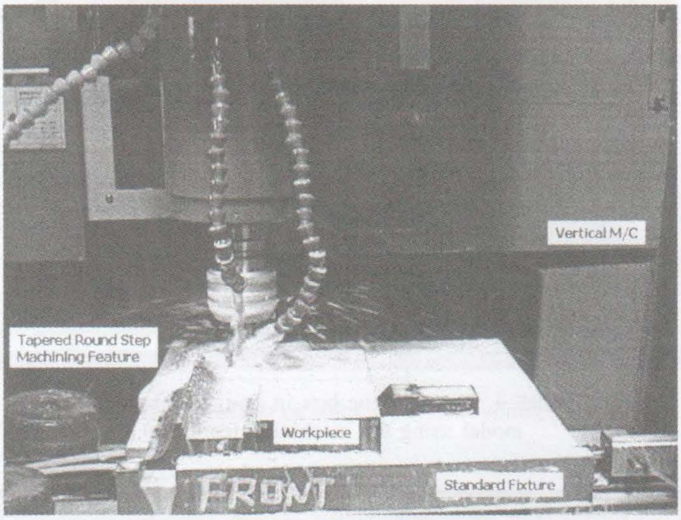

FIGURE 6. Machining process is supported by the standard fixtures.

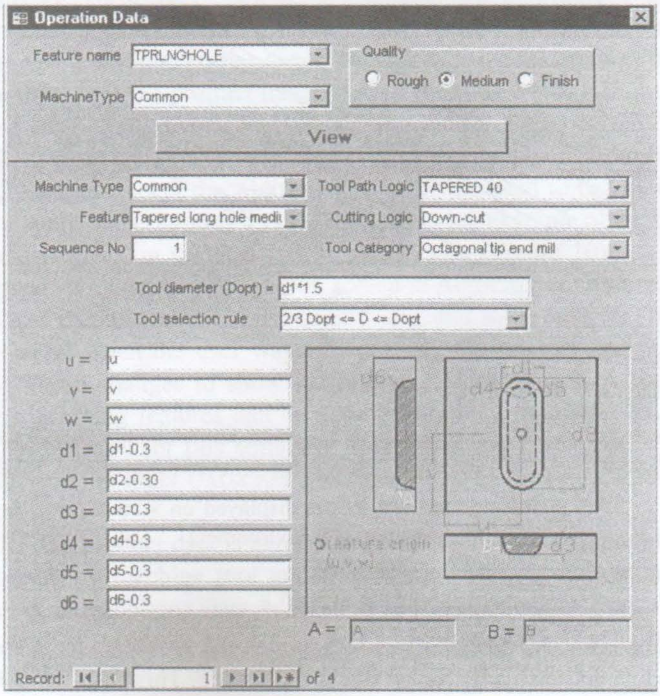

FIGURE 7. Operation planning dialogue box (submenu of Figure 9).

By executing the CAM process, the software prepares machining data, tool-path logic, tool selection and cutting conditions for the NC program generation. In the final stage, those tools to be used are measured and the dimension, on both length and diameter, is input by the user to the appropriate dialogue box during completing the CAM tasks. Finally, NC program is automatically generated and saved in specific file with *.NC extension. The sample of the NC program generated by this software based on the product design is given in Figure 8. To avoid key-in of the generated NC program to the CNC machine, the NC program can be automatically transferred to the machine tool by linking its RS-232 port with the serial port at the personal computer where the software is run.

```
%
O1111
G21
G90
(T38 = 1503)
(T94 = 1404)
(T98 = 1408)
(T27 = 1201)
M1
N0 (Tapered Square Step scallop)
T38 (18.0 Roughing end mill)
M98P4
M98P52
M03S710
G00X-14.000Y0.000
G43Z-3.000H38
M8
Y35.171
G01X64.000F170
...
M9
G91G30Z0.
M5
M1
N1 (Tapered Square Step walls)
T27 (10.0 Ball end mill)
M98P4
M98P52
M03S1061
G00X-10.000Y45.000
M03S1077 (Tapered Surface tool-path logic.down-cut.amg2k.)
G43Y40.076Z-4.132H27
M57
G01X60.000F215
...
(Rounded Surface tool-path logic.down-cut.amg2k.)
Y36.941Z-21.904
M03S1077
G01X60.000
...
M9
G91G30Z0.
M5
M1
N2 (Tapered Square Step bottom)
T94 (10.0 Square end mill)
M98P4
M98P52
M03S1496
G00X-10.000Y0.000
Y22.150
G43Z-29.850H94
M8
G01X60.000F473
...
M9
G91G30Z0.
M5
M1
N3 (Tapered Square Step bottom)
T98 (16.0 Square end mill)
M98P4
M98P52
M03S935
G00X63.000Y0.000
Y19.124
G43Z-30.000H98
M8
G01X-13.000F395
...
M9
G91G30Z0.
M5
M1
T145
M98P4
M30 (end of machining code and process)
O52(Local coordinate shift -> TOP)
M98P55
G52Q2X-137.500Y87.500Z35.000
G90G00X0.Y0.
M99
%
```

FIGURE 8. Sample of NC program generated by the software.

THE DATABASE MANAGEMENT SYSTEM

As shown in Figure 9, the relationship given in Figure 2 is implemented to develop a DBMS in order to support the production control for the processing of product design. As mentioned previously, the database is developed by utilizing the relational database concept and supported by the object oriented database approach. The product data from CAD module is maintained by the DBMS before transferring downstream to CAM module. The SQL is used to link the CAM module to DBMS in order to provide a two-way flow data.

The main menu shown in Figure 9 consists of 4 main groups of databases, i.e. tool database, machine specific database, material database, and operation database. Besides, the standard fixture database is also provided to support the operation database in preparing the NC program. Those instructions of processes as well as the NC program can be viewed on screen or printed.

MACHINING EXAMPLE

The product design shown in Figure 5 has been fabricated from prismatic billet raw material by using the 3-axis vertical machining centre and the result is shown in Figure 10. This sample has been designed using the tapered pocket machining features for the die and mould application.

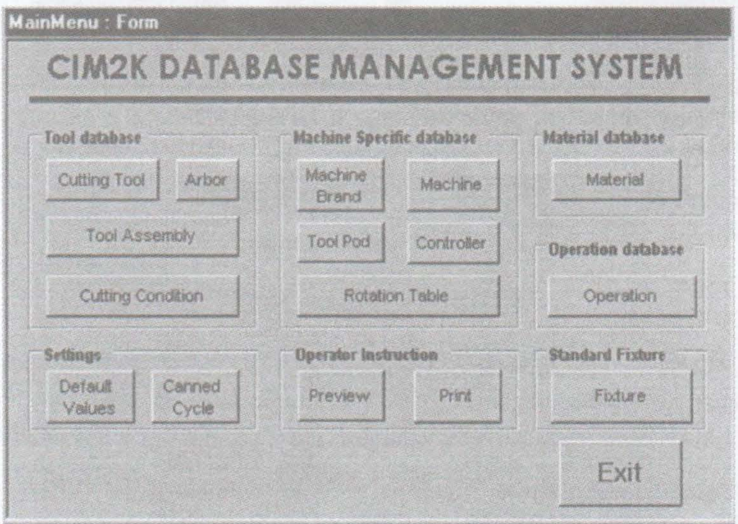

FIGURE 9. Main menu of the DBMS.

CONCLUSIONS

1. A new computer integrated manufacturing soft technology has been developed based on the machining feature-based approach and supported by production planning as well as the database management system for machining process.
2. The software shows a new design method for fully automated CAD/CAPP/CAM processing and demonstrates the needs of the 21st century

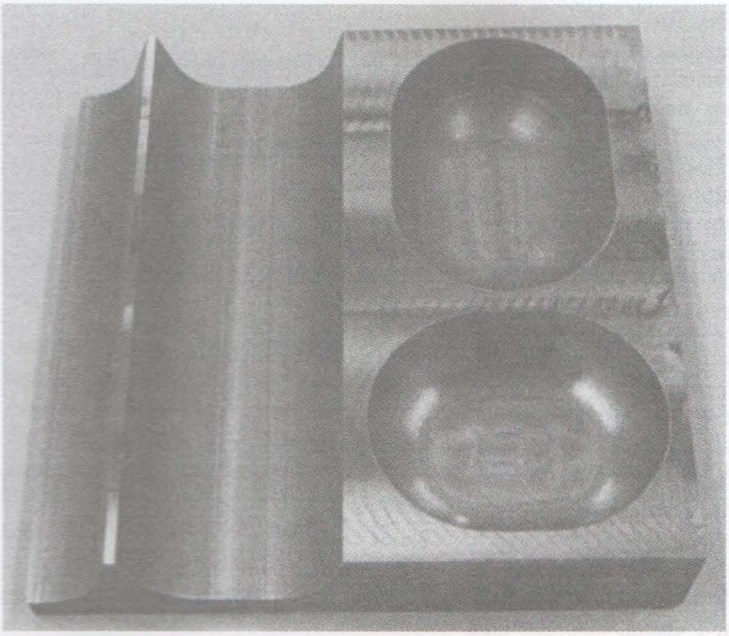

FIGURE 10. Machining example for die and mould application.

metalworking industry that is the global competition in producing the acceptable quality of components at the right time.

3. The high-efficiency manufacturing in extremely low repetitive and high product-mix components can be achieved by the software.

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