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Abstract :

Information systems in today's manufacturing enterprises are distributed. Data exchange and share can be performed by computer network systems. Enterprises are performing operations globally and e-manufacturing enterprises not only obtain online information but also organize production activities. The present manufacturing scenario demands the efficient database systems for manufacturing to perform the operations globally and to enable the e-manufacturing environment. Database systems are the key to implementing information modeling. Engineering information modeling requires database support. This paper proposes a manufacturing database system for STEP-NC data from EXPRESS entities. This manufacturing database mainly includes processing data, manufacturing data for milling and turning, tooling data for milling and turning.

Keywords: Database systems, STEP, STEP-NC, EXPRESS entities and e-manufacturing

1. Introduction

Engineering activities are generally performed across departmental and organization boundaries. Product development based on virtual enterprises, for example, is generally performed by several independent member companies that are physically located at different places. Information exchange and share among them is necessary. It is also true in different departments or even in different groups within a member company.

Information systems have become the nerve center of current computer-based engineering applications, which hereby put the requirements on engineering information modeling. Databases are designed to support data storage, processing, and retrieval activities related to data management, and database systems are the key to implementing engineering information modeling. Design and manufacturing companies eager to integrate their engineering processes around product databases, but engineering databases are expensive and difficult to create.

Integration around product databases can enable concurrent engineering, a process where multiple engineers work on different facets of a product concurrently. However, integrated product databases are yet to be common in industry in the STEP-NC and EXPRESS entities perspective. Engineering design objects and their components are not independent. Spatio-temporal data modeling is essential in engineering design.

The software systems are developed to share and exchange the product and production information in order to effectively organize production activities of enterprise. However, the systems are generally developed independently. In such an environment of distributed and heterogeneous computer-based systems, exchanging and sharing data across manufacturing units are very difficult. An effective means must be provided so that the data can be exchanged and shared among deferent applications and organisations.

2. STEP/STEP-NC

The contemporary product design and manufacturing environment requires a bidirectional and seamless data flow throughout all stages of data transactions. **St**andard for the **E**xchange of **P**roduct (STEP) Model Data, is a large and powerful set of ISO (International Organisation for Standardizations) standards, all under ISO 10303. The main objective of STEP is to provide a mechanism that describes a complete and unambiguous product definition throughout the life cycle of a product. STEP provides both broadly useful data modeling methods and data models focused on specific industrial uses. STEP is suitable for not only neutral file exchange, but also as a basis for implementing and sharing product data bases [1].

As an extension to STEP, STEP-NC provides the potential to finally close the gap between design and manufacturing in the drive for a complete, integrated product development environment. The STEP-NC data model is a long overdue improvement in the domain of computer numerical controls (CNC) where G-codes have been in use for more than half a century. STEP-NC brings richer information to CNCs presenting an opportunity for the development of more intelligent, interoperable and informative machining.

Two different ISO subcommittees are working towards such a STEP-NC standard with two different foci; ISO TC 184/SC1 is working on ISO 14649, termed the Application Reference Model(ARM) whereas ISO TC 184/SC4 is developing STEP AP-238, termed the Application Interpreted Model(AIM). Both models represent the data model information to program intelligent CNC controllers, but the AIM is fully STEP compliant, whereas the ARM contains the information required to program a CNC machine. The ARM is to be used in an environment in which CAM systems have exact information from the shop-floor, whereas AIM is more suitable for a complete design and manufacturing integration [2]. The ISO 14649 STEP-NC standards were developed and published by the above two sub committees under the different ISO standards such as ISO 14649-1, 14649-10, 14649-11, 14649-12, 14649-111 and 14649-121[3-8].

3. Current Database Models

Engineering information modeling in databases can be carried out at two different levels: conceptual data modeling and logical database modeling. Therefore, we have conceptual data models and logical database models for engineering information modeling, respectively. Database models for engineering information modeling refer to conceptual data models and logical database models simultaneously.

3.1. *Conceptual data models*

Much attention has been directed at conceptual data modeling of engineering information [9]. Product data models, for example, can be viewed as a class of semantic data models (i.e., conceptual data models) that take into account the needs of engineering data [10]. Recently, conceptual information modeling of enterprises such as virtual enterprises has received increasing attention [11]. Generally speaking, traditional ER (entity-relationship) and EER (extended entity-relationship) can be used for engineering information modeling at conceptual level [12].

3.2. *Logical Database model*

Generic logical database systems used in engineering information modeling such as relational databases, nested relational databases, and object-oriented databases. Ahmed [13] proposed in his paper a KSS (Kraftwerk Kennzeichen System) identification and classification system was used to develop database system for plant maintenance and management. Arnalte and Scala [14] were built on top of a relational DBMS, an EXPRESS oriented information system for supporting information integration in a computer-integrated manufacturing environment. Goh et al [15] have studied Object-oriented databases for STEP/EXPRESS. Based on the comparison with relational databases, the selections and characteristics of the object-oriented database and database management systems (OODBMS) in manufacturing were discussed in Zhang [16]. Also, the formal transformation of EER and EXPRESS-G was developed in Ma et al. [17]. The present work propose a tool which separates the manufacturing data from STEP-NC file based on EXPRESS entities and stored in the STEP-NC manufacturing database.

4. STEP-NC Manufacturing Database

STEP-NC can develop a high-level data model that contains primarily design and manufacturing information independent of machine tools. This makes it fundamentally different from G-code which is a rather low-level NC data model. The high-level data in the STEP-NC data model contains information such as workpiece, machine tools, set-up information, cutting tools, machining functions and strategies, all of which are defined based on a set of schema in EXPRESS. In the following subsections describes the different databases.

4.1. *Material (workpiece) Database*

The material information in STEP-NC is organized into two groups: material property and geometric information. Material No. is the unique identifier for the raw material in the database. It is an important data used for searching purposes. The geometric information of the workpiece includes definitions of block, cylinder and complex shape. Complex shape caters for workpieces such as castings or forgings. Once a workpiece is defined or loaded, it can be displayed in a GUI (**G**raphical **U**ser **I**nterface). Material property contains information about the material type and its parameters. All the material-related information is grouped and reorganized to be used to define STEP-NC entities such as security plane, clamping position, cutting tools, machining_technolgy and machining_strategy.

4.2. *Set-up Database*

The set-up database includes the information related to the machining feature, machine tool and set-up coordinate system. It is possible to load and modify an existing set-up file to suit a new set-up.

4.3. *Machine Tool Database*

The CNC machine tools database is divided into two categories. One is physical data such as mechanical components of a machine tool i.e. the physical configuration of the machine tool. The other one is performance data of the machine tool i.e. the elements of a machine tool that can be controlled, and the data that is needed to control them. The database of the physical configuration of a machine tool consists of Workspace, Travel, Axes and Accessories data of the CNC machine tool. The machine Workspace is defined as a bounded plane or volume in which the tool and workpiece can be positioned and through which controlled motion can be invoked. It is one of the basic pieces of information for defining the maximum size of a workpiece. Travel designates a maximum distance which the cutting tool(s) can reach in X, Y and Z directions, respectively. Together with workpiece, it is one of the basic pieces of information for defining the maximum machining size of a workpiece. Only linear axes are considered in the database. Linear axes denote the relative linear motion of the tool (and/or workpiece) provided by the machine's independent mechanisms. Accessories of a machine tool contain all the hardware that is necessary for a machine to be robust, efficient, reliable and accurate. Some examples are, the pallet loading system, tailstock in a lathe or fixtures for a milling centre. The control and data components of a machine tool contain information about the maximum spindle speed, feed-rate, coordinate system and tool change parameters. The coordinate system defines a 3D special base for a machine tool. When an NC instruction is generated, the geometry of the workpiece is transformed into this coordinate system. The tool change parameters include information such as the tool-changing times and tool-changing sequences. The machine tool database is built for representing different CNC machines.

4.4. *Cutting tool Database*

The cutting tool database is composed of cutting tool parameters and cutting tool dimensions. Cutting tool parameters include tooth_number, coolant and material information, all affecting machining_technolgy and machining_function as defined in STEP-NC. Cutting tool dimensions include the basic geometric information of a cutter such as the angle of the insert, edge radius, diameter, etc.

5. STEP-NC Manufacturing Database Design

Conceptual data models are generally used for engineering information modeling at a high level of abstraction. However, engineering information systems are constructed based on logical database models. So at the level of data manipulation, that is, a low level of abstraction, the logical database model is used for engineering information modeling. Here, logical database models are often created through mapping conceptual data models into logical database models. In this conversion we used conceptual design for stores the manufacturing data from EXPRESS entities.

5.1. *Database Systems*

The strength of relational database systems is the ability to store large amounts of data in a highly normalized, tabular form, and to perform efficient queries across large data sets. Relational systems use Structured Query Language(SQL) for both data definition and data manipulation. In the present work the database is developed using MS Access. This database can be easily migrated into other advanced RDBMS.

5.2. *Mapping Manufacturing Data To Ms Access*

The MS Access implementation uses the mapping the manufacturing data from EXPRESS entities to the relational model. Each entity is mapped to a table with columns for attributes. Each table has a column with a unique identifier for each instance. Attributes with primitive values are stored in place, and composite values like entity instances, selects, and aggregates are stored as foreign keys containing the unique instance identifier.

The MS Access primitive data types are not as extensive as those of EXPRESS. Booleans and logical are approximated as Yes/No values; enumerations are stored as Text; the corresponding EXPRESS and MS Access types are shown in Tables I, II, III.

5.3. *Design of EXPRESS Entity Database*

This database is important in this storage management of manufacturing data from STEP-NC data. This EXPRESS Entity database is designed with the help of EXPRESS schema supported by different designs. EXPRESS schema entities are developed and maintained by National Institute of Standard and Technology (NIST, US). Design of EXPRESS Entity database is shown in the below Table I, Manufacturing database design and data is shown in the Table II and Table III.

Table 1. EXPRESS Entity databse design

EXPRESS_Entity

Field Name	Data Type
entiry	Text
data1	Text
data1_type	Text
data2	Text
data2_type	Text
data3	Text
data3_type	Text

Field Properties

Table 2. Manufacturing Database Design

Milling_Data

Field Name	Data Type
Entity	Text
data1	Text
data1_type	Text
data2	Text
data2_type	Text
data3	Text
data3_type	Text
data4	Text
data4_type	Text
data5	Text
data5_type	Text
data6	Text
data6_type	Text
data7	Text
data7_type	Text
data8	Text
datatype8	Text

Field Properties

Table 3. Manufacturing Data

Milling_Data

Entity
MILLING_TYPE_OPERATION
MILLING_TYPE_STRATEGY
MODIFIED_GEOMETRIC_TOLERANCE
MODIFIED_PATTERN
PLACEMENT
PLANAR_SHAPE_REPRESENTATION
PLANE
PLANE_ANGLE_MEASURE_WITH_UNIT
PLANE_ANGLE_UNIT
PLANE_MILLING_OPERATION
PLUS_MINUS_TOLERANCE
POCKET
POCKET_BOTTOM
ROUNDNESS_TOLERANCE
SLOT
SLOT_END
THREAD
THREAD_RUNOUT
THREADING_TURNING_OPERATION
TIME_MEASURE_WITH_UNIT
TIME_UNIT
TOLERANCE_VALUE
TOLERANCE_ZONE
TOLERANCE_ZONE_DEFINITION
TOLERANCE_ZONE_FORM
TOPOLOGICAL_REPRESENTATION_ITEM
TOROIDAL_SURFACE

Record: 1 of 54 No Filter Search

6. Implementation

In the present work an interface program is developed to extract STEP-NC manufacturing data from STEP-NC file using VB language [18]. EXPRESS Schema entity definitions for manufacturing data are stored in MS Access and these are used in backend for validation. The manufacturing data i.e., workpiece material, set-up data, manufacturing working steps, cutting tool data etc., are extracted from STEP-NC file as per the EXPRESS Schema entities in database. The extracted data is entered into the manufacturing database. Template is designed using front end language (VB) for the execution of interface program shown Figure 1.

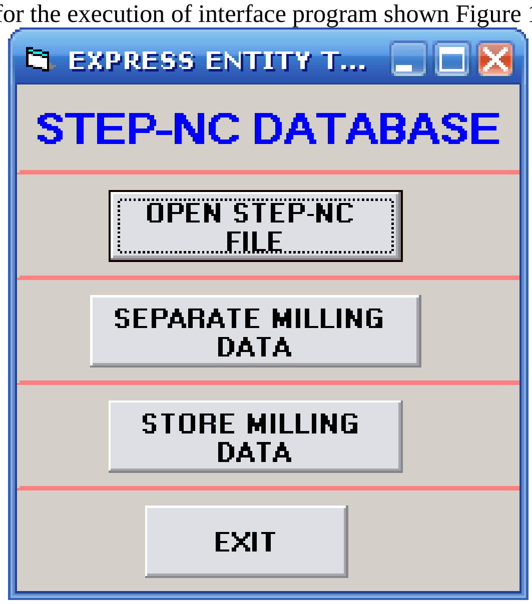

Fig 1. The tool seperates the milling data

7. Implementation procedure

Step1: Choose the STEP-NC FILE
Step2: Open the file STEP-NC FILE in read mode
Step3: Read a line from STEP-NC FILE into variable STEP-NC LINE
Step4: If STEP-NC LINE equals to null GOTO Step 8
Step5: Separate the entity, entitydata1,entitydata2,…., entitydatam from STEP-NC LINE in following manner.
- i Read character by character from STEP-NC LINE
- ii Extract the entity to variable ENTITY
- iii Extract the entity data to variable ENTITYDATA1
- iv Extract the next entity data to variable ENTITYDATA2
- v And So on extract next entity data to variable ENTITYDATAM until end of the STEP-NC LINE

Step6: Search the EXPRESS entity database for ENTITY in column "entity".
Step7 : If found store the ENTITY along with the ENTITYDATA1, ENTITYDATA2, . ., ENTITYDATAM in the Database "Manufacturing Database".
Step8: Otherwise increment the counter in STEP-NC FILE and GOTO Step 3
Step9: STOP

In the present work the following model is considered as an example to separate the manufacturing data from STEP-NC file using the tool developed.

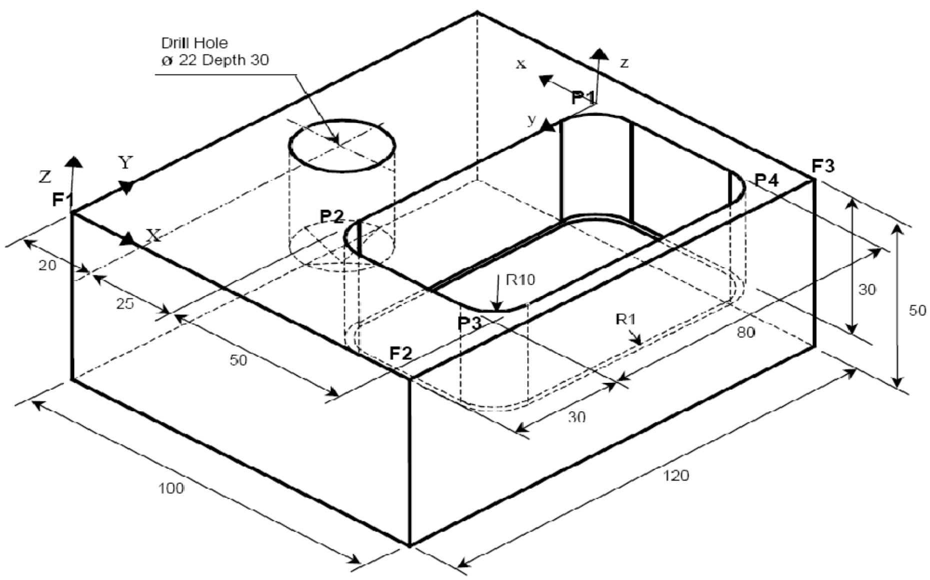

Fig 2. Block having a pocket and a drill hole

The following is the STEP-NC file for the above figure.

```
HEADER;
FILE_DESCRIPTION(('ISO 14649-11 EXAMPLE 1',
'SIMPLE PRORGRAM WITH A PLANAR_FACE, A POCKET, AND A ROUND_HOLE'),'1');
FILE_NAME('EXAMPLE1.STP',('YONG TAK HYUN','JOCHEN WOLF'),('WZL, RWTH-AACHEN'),$,'ISO
 14649',$);
FILE_SCHEMA(('MACHINING_SCHEMA','MILLING_SCHEMA'));
ENDSEC;
DATA;
#1= PROJECT('EXECUTE EXAMPLE1',#2,(#4),$,$,$);
#2= WORKPLAN('MAIN WORKPLAN',(#10,#11,#12,#13,#14),$,#8,$);
#4= WORKPIECE('SIMPLE WORKPIECE',#6,0.010,$,$,$,(#66,#67,#68,#69));
#6= MATERIAL('ST-50','STEEL',(#7));
```

```
#7= PROPERTY_PARAMETER('E=200000N/M2');
#8= SETUP('SETUP1',#71,#62,(#9));
#9= WORKPIECE_SETUP(#4,#74,$,$,());
#10= MACHINING_WORKINGSTEP('WS FINISH PLANAR FACE1',#62,#16,#19,$);
#11= MACHINING_WORKINGSTEP('WS DRILL HOLE1',#62,#17,#20,$);
#12= MACHINING_WORKINGSTEP('WS REAM HOLE1',#62,#17,#21,$);
#13= MACHINING_WORKINGSTEP('WS ROUGH POCKET1',#62,#18,#22,$);
#14= MACHINING_WORKINGSTEP('WS FINISH POCKET1',#62,#18,#23,$);
#16= PLANAR_FACE('PLANAR FACE1',#4,(#19),#77,#63,#24,#25,$,());
#17= ROUND_HOLE('HOLE1 D=22MM',#4,(#20,#21),#81,#64,#58,$,#26);
#18= CLOSED_POCKET('POCKET1',#4,(#22,#23),#84,#65,(),$,#27,#35,#37,#28);
#19= PLANE_FINISH_MILLING($,$,'FINISH PLANAR FACE1',10.000,$,#39,#40,#41,$,
#60,#61,#42,2.500,$);
#20= DRILLING($,$,'DRILL HOLE1',10.000,$,#44,#45,#41,$,$,$,$,$,#46);
#21= REAMING($,$,'REAM HOLE1',10.000,$,#47,#48,#41,$,$,$,$,$,#49,.T.,$,$);
#22= BOTTOM_AND_SIDE_ROUGH_MILLING($,$,'ROUGH POCKET1',15.000,$,#39,#50,#41
,$,$,$,#51,2.500,5.000,1.000,0.500);
#23= BOTTOM_AND_SIDE_FINISH_MILLING($,$,'FINISH POCKET1',15.000,$,#39,#52,
#41,$,$,$,#53,2.000,10.000,$,$);
……………..
…………….
#38= PLUS_MINUS_VALUE(0.100,0.100,3);
#39= MILLING_CUTTING_TOOL('MILL 20MM',#29,(#125),80.000,$,$);
#40= MILLING_TECHNOLOGY(0.040,.TCP.,$,12.000,$,.F.,.F.,.F.,$);
#41= MILLING_MACHINE_FUNCTIONS(.T.,$,$,.F.,$,(),.T.,$,$,());
#42= BIDIRECTIONAL(5.000,.T.,#43,.LEFT.,$);
#43= DIRECTION('STRATEGY PLANAR FACE1: 1.DIRECTION',(0.000,1.000,0.000));
#44= MILLING_CUTTING_TOOL('SPIRAL_DRILL_20MM',#31,(#126),90.000,$,$);

#45= MILLING_TECHNOLOGY(0.030,.TCP.,$,16.000,$,.F.,.F.,.F.,$);
#46= DRILLING_TYPE_STRATEGY(75.000,50.000,2.000,50.000,75.000,8.000);
#47= MILLING_CUTTING_TOOL('REAMER_22MM',#33,(#127),100.000,$,$);
#48= MILLING_TECHNOLOGY(0.030,.TCP.,$,18.000,$,.F.,.F.,.F.,$);
#49= DRILLING_TYPE_STRATEGY($,$,$,$,$,$);
#50= MILLING_TECHNOLOGY($,.TCP.,$,20.000,$,.F.,.F.,.F.,$);
………………….
…………...........
#125= CUTTING_COMPONENT(80.000,$,$,$);
#126= CUTTING_COMPONENT(90.000,$,$,$);
#127= CUTTING_COMPONENT(100.000,$,$,$);
ENDSEC;
```

The following manufacturing data(in the form of flat file) is separated from the STEP-NC file by using the tool developed

```
#10= MACHINING_WORKINGSTEP('WS FINISH PLANAR FACE1',#62,#16,#19,$);
#11= MACHINING_WORKINGSTEP('WS DRILL HOLE1',#62,#17,#20,$);
#12= MACHINING_WORKINGSTEP('WS REAM HOLE1',#62,#17,#21,$);
#13= MACHINING_WORKINGSTEP('WS ROUGH POCKET1',#62,#18,#22,$);
#14= MACHINING_WORKINGSTEP('WS FINISH POCKET1',#62,#18,#23,$);
    ……
#44= MILLING_CUTTING_TOOL('SPIRAL_DRILL_20MM',#31,(#126),90.000,$,$);
#45= MILLING_TECHNOLOGY(0.030,.TCP.,$,16.000,$,.F.,.F.,.F.,$);
#46= DRILLING_TYPE_STRATEGY(75.000,50.000,2.000,50.000,75.000,8.000);
#47= MILLING_CUTTING_TOOL('REAMER_22MM',#33,(#127),100.000,$,$);
#48= MILLING_TECHNOLOGY(0.030,.TCP.,$,18.000,$,.F.,.F.,.F.,$);
    ……
```

After completion of this process above empty database filled with manufacturing data as shown below Table V. This information is useful for further processing.

Table 4. STEP-NC manufacturing databse

Milling_Entity_Database

id	entity	entity_data0	entity_data1	entity_data2	entity_data3
_10	MACHINII	'WS FINISH PLANAR FACE1'	_62	_16	_19
_100	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_101	CARTESIA	'WORKPIECE1:LOCATION '	0.000	0.000	0.000;\
_102	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_103	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_104	CARTESIA	'PLANAR FACE1:LOCATION '	0.000	0.000	5.000;\
_105	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_106	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_107	CARTESIA	'PLANAR FACE1:DEPTH '	0.000	0.000	-5.000;\
_108	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_109	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_11	MACHINII	'WS DRILL HOLE1'	_62	_17	_20
_110	CARTESIA	'HOLE1: LOCATION '	20.000	60.000	0.000;\
_111	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_112	CARTESIA	'HOLE1: DEPTH '	0.000	0.000	-30.000;\
_113	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_114	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_115	CARTESIA	'POCKET1: LOCATION '	45.000	110.000	0.000;\
_116	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_117	DIRECTIOI	' REF_DIRECTION'	-1.000	0.000	0.000;\
_118	CARTESIA	'POCKET1: DEPTH '	0.000	0.000	-30.000;\
_119	DIRECTIOI	' AXIS '	0.000	0.000	1.000;\
_12	MACHINII	'WS REAM HOLE1'	_62	_17	_21
_120	DIRECTIOI	' REF_DIRECTION'	1.000	0.000	0.000;\
_121	CARTESIA	'P1'	0.000	0.000	0.000;\

Record: 1 of 48 No Filter Search

8. Conclusions and Future Work

This paper concentrates on the extraction, storage and management of manufacturing data from STEP-NC file using EXPRESS schema entities are in the backend. This implementation provides flexible environment to the people, who are using STEP-NC data and manage the EXPRESS entity data. Further Database can be used in the e-manufacturing.

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