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UNIVERSITI TEKNOLOGI PETRONAS

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TURN-MILL OPERATIONS

by

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STEP COMPLIANT APPROACH FOR TURN-MILL OPERATIONS

by

MESFIN GIZAW ZEWGE

A Thesis

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BANDAR SRI ISKANDAR

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FEBRUARY 2013

DECLARATION OF THESIS

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DEDICATION

I dedicate this thesis to my family, especially to my late Mother Tirunesh Manalebet for being the heart of my success to my late Father Gizaw Zewge for showing me the way to education, and
to my brothers & sisters for their constant encouragement

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Thanks GOD, the merciful and the passionate, for providing me the opportunity to step in the excellent world of science. To be able to step strong and smooth in this way, I have also been supported and supervised by many people to whom I would like to express my deepest gratitude

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ABSTRACT

Current machine tools have incurred challenges on limitation such as part programming complexity of G and M code, weak integration of digital machine tools and coverage of universal data modeling for product and manufacturing resources. In response to this manufacturing system requirement, Standard for Exchange of Product data (STEP) and its implementation on developing an interface for the next generation of machine tool controllers (STEP-NC) has become a concern of research interest and performed on basic manufacturing technology limited to a unit domain such as turning, milling or Wire EDM. Therefore; extending this STEP implementation on multipurpose machine tools such as turn-mill machines is mandatory since the machines are the main component in these industries. The research work offers a STEP-NC compliant interface supporting turn-mill machining environment identified as SCSTMO. SCSTMO is the programming system based on information model using ISO 14649 data model and object-oriented methodology with Visual Basic.Net as a binder programming platform for implementation development. The programming system supported generation of Part-21 file under ISO 10303 AP224 mechanical feature description representing an interactive machining feature extraction and process planning. Usability and testing of the programming system generates process plan file equivalent to ISO 14649-Part 12 file, a Part 21 file for a representative a case study component, Native STEP-NC file that include consideration of turn-mill specification and a suitable editor interfaces.

ABSTRAK

Alat-alat mesin telah melakukan cabaran batasan seperti kerumitan pengaturcaraan sebahagian daripada G dan M, kod integrasi lemah alat mesin digital, liputan data pemodelan sejagat bagi produk dan sumber pembuatan. Sebagai tindak balas kepada keperluan sistem pembuatan ini, Standard for Exchange data Produk (STEP) dan pelaksanaannya kepada pembangunan satu antara muka untuk pengawal alat mesin generasi akan datang (STEP -NC) telah menjadi kebimbangan kepentingan penyelidikan dan dilakukan pada teknologi pembuatan asas sepertiberpaling, pengilangan dan EDM Wire. Oleh itu; memperluaskan pelaksanaan STEP pada alat mesin pelbagai guna seperti mesin seterusnya-kilang adalah wajib kerana mesin adalah komponen utama dalam industri-industri ini.Kerja-kerja penyelidikan menawarkan STEP -NC patuh antara muka menyokong pula kilang pemesinan persekitaran yang dikenal pasti sebagai SCSTMO. SCSTMO adalah sistem pengaturcaraan yang berasaskan kepada model maklumat menggunakan ISO 14649 data model dan metodologi berorientasikan objekdengan Visual Basic.Net sebagai platform pengaturcaraan pengikat bagi pembangunan pelaksanaan. Sistem pengaturcaraan menyokong generasi Bahagian-21 fail di bawah ISO 10303 AP224 perihal ciri mekanikal yang mewakili ciri-ciri pemesinan pengekstrakan interaktif dan proses perancangan. Satu kajian kes telah dibentangkan pada kebolehgunaan, penyiasatan, dan ujian sistem pengaturcaraan. Ini termasuk generasi proses bersamaan file rancangan untuk ISO 14649-Bahagian file 12, generatif STEP -NC fail yang dibangunkan untuk komponen wakil, Bahasa STEP -NC fail yang mengambil pertimbangan spesifikasi turn-kilang dan antara muka editor yang sesuai.

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LIST OF ABBREVIATIONS

AAM	Application Activity Model
ABS	Abstract Base Class
ACS	Autonomous Control System
AIC	Application Interpreted Construct
AP	Application Protocols
AIM	Application Interpreted Model
ARM	Application Reference Model
ASCII	American Standard Code for Information Interchange
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CES	Code Editing System
CGS	Code Generating System
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
CAPP	Computer Aided Process Planning
CMM	Co-ordinate Measuring Machine
CORBA	Common Object Request Broker Architecture
DDL	Data Description Language
EDM	Electrical Discharging Machining
EPSRC	Engineering & Physical Science Research Council
ESPRIT	European Strategies Programm For Research In to Information Technology
FME	Feature Model Editor
FMS	Flexible Manufacturing System
GDLS	General Dynamics Land systems
GUI	Graphical User Interface
IGES	Initial Graphics Exchange Specification
IMS	Intelligent Manufacturing System
IP3AC	Integrated Platform for Process Planning and Control
IR	Information Requirement
ISW	University of Stuttgart
IDEFO	ICAM Definition Level 0
OMG	Object Management Group
ISO	International Standard Organization

ISD	Instruction System Design
ID	Instruction Model
IDM	Instruction Design Model
MASCAPP	Multi-Agent System for Computer Aided Process Planning
MCCM	Multi Channel Complex Machine Tool
MTS	Maximum Turnable State
NIAM	Nijssen's Information Analysis Method
NIST	National Institute of Standards and Technology
RAMP	Rapid Acquisition of Manufactured Parts
SCSTMO	STEP Compliant System for Turn-mill Operations
SMPS	STEP-enabled Manufacturing Planning System
STEP	STandard for the Exchange of Product model data
STEP-NCMtDm	STEP-NC Machine Tool Data Model
SFPS	Shop-Floor Programming System
UML	Unified Modeling Language
UMRM	Unified Manufacturing Resource Model
VMS	Virtual Manufacturing System
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Current global market competition scenario has demanded efficient utilization of flexible manufacturing facilities. It primarily needs higher electronic data exchange with smooth and efficient interlink among design, manufacturing and Numerical Control (NC) technologies. Its effectiveness predominantly depends on the degree of integration and interoperability attained among digital machine tools such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP) and NC technologies. Even though all hardware and software development of Computer Numerical Control (CNC) machine tools has reached a higher level of flexibility, the extent of their manufacturing capability utilization is the focus of research interest. In accordance to global market, collaborative manufacturing has become basic requirement with appropriate information exchange and data storage efficiency that brings uniform standard application with respect to product, manufacturing process and machine tools information.

In this respect, efficient machine tool programming and seamless data interface among the different phases of manufacturing becomes a crucial phenomenon. The effect was made by CAM software companies to plug in to STEP-NC [1] to cope with modern day agile manufacturing needs of digital machine tools integration and interoperability. It accounts the need for STEP compliant research with regard to crucial industrial facility such as turn-mill machine. The evolution of 60 years old NC technology from the primary hardwired conventional numerical control to today's high PC-CNC controls do not promise present day manufacturing integration.

This has been supported by utilization of modern day information technology advancement towards manufacturing industries for converging CAD, CAM and CAPP systems to a standard suite for implementation of concurrent engineering approach. It is mainly achieved by STEP-compliant approach that has been aimed at increasing quality with consistent manufacturing information and optimized efficiency accompanied with a reduced cost of production through customized manufacturing resource modeling.

1.2 Overview of STEP Implementation

The introduction of flexible manufacturing system is the result of hardware development in CNC machine tools, such as turn-mill centers, to overcome barriers of dedicated production lines. It promotes an increment on utilization of digital manufacturing tools. However; it has induced paradoxical challenge over synchronization of these two phase advancement. Wide span capabilities of machine tools acquired by hardware advancement against the need to adaptation between manufacturing execution and requirement of different level manufacturing information representation, integration and exchange complaint to digital manufacturing tools.

The need for information representation and integration of manufacturing modeling supports the acquired process capability of machine tools. That is to fulfill information sharing on vendor independent system platform which supports unit logical information base and relationship among different domains.

In current day manufacturing, a study of the information standard ISO 10303, STEP, STandard for the Exchange of Product model data, a STEP-NC i.e. a data model representing "workingstep", which stands for a library encapsulating specific technology and operations that might be performed by a CNC machine tool with manufacturing resource. These have been vital means for developing intelligent manufacturing workstations and efficient machine tool shop floor executions.

Many recent studies have focused on STEP product data representation, STEP-NC implementation model development and machine tool modeling which are extended to distributed manufacturing and universal manufacturing platform development for CNC Machining. However; a detailed study describing machining process or workingstep representation model of multi-task machining such as turn-mill machine has not been sufficiently addressed. Therefore; this research is to investigate and analysis an application of STEP-NC on the different configurations and additional capability of turn-mill machine over the traditional machine tools.

Specifications for feature based representation of product, machining and technology for turning and milling process capability and manufacturing resource model of CNC machine tools has been addressed on previous STEP, STEP-NC and related researches [2-4].

It is to develop a programming model that able to develop Generative and Native process planning documents. They can be used on a dual domain of turning and milling operations capability turn-mill manufacturing environment. In reference to supporting a simplified part programming and machining configuration of multi-purpose CNC machine tools and their manufacturing execution. This research specifically targeted to investigate analyzes and test a computational system demonstration on turn-mill manufacturing.

1.3 Importance of STEP Implementation on Machine Tool Level

STEP implementation is mainly important for advanced representation of product, manufacturing and manufacturing resource information. The representation has been intended to generate a process plan document applicable to the content of manufacturing technology specification towards new breed intelligent CNC controller. The emphasis on machining information modeling has two categories for interoperability: Model that describes:-

i. The cutting process and
ii. The machine tool resources.

The importance of cutting process model was to develop a Generative STEP-NC data model that established for achievements of an independent, interoperable and a neutral standard manufacturing data model regarding manufacturing data exchange and sharing. Whereas application of digital machine tools in building computer integrated manufacturing (CIM) draws the need for manufacturing resource modeling.

Since then researchers have been attempted towards a CAPP-CAM integration platform, process planning automation and resource modeling mainly aimed at alleviating CAPP requirements [5]. Recently the adoption of standard data model with regard to machine tool level STEP implementation was explained in unified manufacturing resource modeling for CNC[6] and STEP-compliant machine tool data model development[7]. It has been shown that the information regarding capability, specifications and components of the machines can be represented in EXPRESS model. This resulted in promoting establishment of Native STEP-NC data model. As shown in Figure 1.1 an EXPRESS representation ISO 14649 model with product and manufacturing model linked to Generic STEP-NC Program. This transferred to a Native process plan document with additional consideration of peculiar machining feature and machining configurations information that can be supplied by the EXPRESS Manufacturing Resource Model entities included in the flow chart. The implementation supported by binding program to generate these two stage process planning documents.

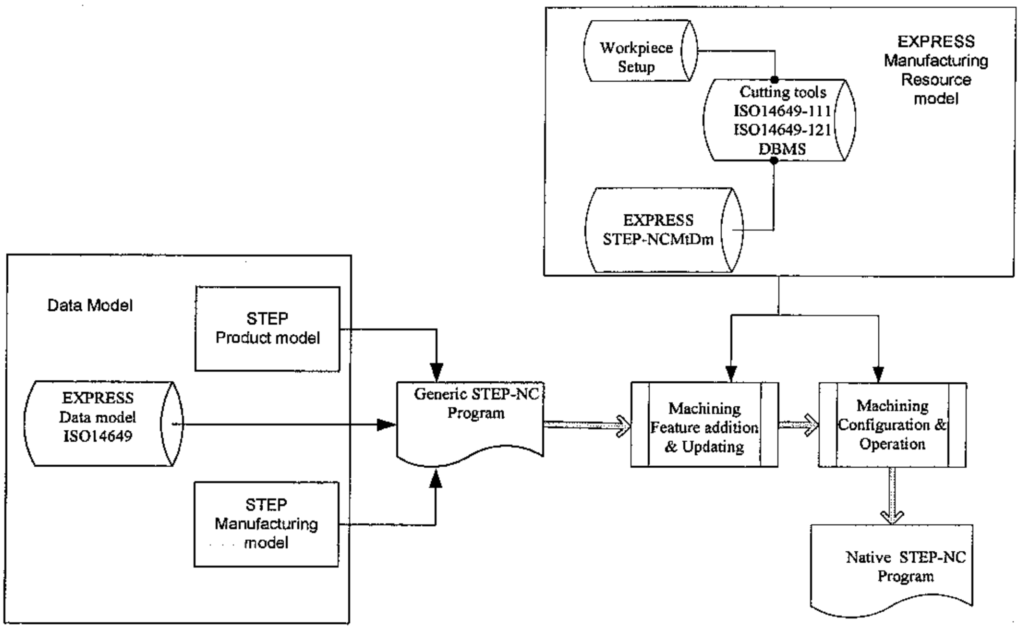


Figure 1.1 Flow chart of STEP implementation for Native STEP-NC generation [8]

1.4 Motivation of the Research

Currently, manufacturing companies are equipped with CNC machine tools providing multipurpose manufacturing service capabilities. This has been accomplished by the hardware advancement evolving these machine tools which brings a requirement of machine tool representation as significant area for manufacturing system modeling. The main purpose the machine tool representation significantly aimed to maximize utilization of acquired capability and consideration of machine kinematics information. In this regard, developing a machine specific level STEP-implementation using machine tool representation linking with ISO 14649 data model is a recommended means. It alleviates limitation of G and M code of ISO 6983 which has significant draw back on part programming complexity, manufacturing data sharing and dependent on post processor since these post processors provided by every machine tool vendors are specific to machine tools. The research is according to ISO TC184/SC4 standard and task force manufacturing towards next generation machine tool controller with an implementation of ISO 14649 data model for turn-mill machining.

In this research, the main intention is to investigate a machine specific STEP implementation. This focuses on contents of STEP product data and ISO 14649 data model such as machine tool representation, process and product model in STEP which is accomplished in the perspective of turn-mill manufacturing environment to address its various configurations.

1.5 Problem Statement

Currently manufacturing companies are working under a global competition, which forces them not only to acquire a hardware capability but also a suitable software interface that allows seamless integration and interoperability for a collaborative platform manufacturing. In the area of CNC machining, ISO 14649 standards [9], as high-level NC language based on the CNC data model of next generation machining system, has been researched separately on turning, milling and wire-EDM. The research in this thesis focuses on the use of the above concepts not only throughout the design (CAD) and manufacturing (CAPP, CAM and CNC) but also to maintain an interoperable and integrated turn-mill manufacturing. In accordance to this, the following research problems have been identified.

I. Currently working with the various option of machining configuration and machine tool orientation found in turn-mill machining are quite complicated, and significantly depends on CAM system or a postprocessor. This makes maintaining machining data compatibility among various machine tools impossible.

II. Current turn-mill machines are highly relied on low level G and M codes which have vendor formats and low level command programming. This limits the flexibility of the manufacturing environment. However; STEP-NC with full-fledged "what to make" and "how to make" machining information is considered suit to support today's global adaptability, integration requirement and moderate part program.

III. Appraisal of various mode of machining configuration in turn-mill, signified machine axis dependence of cutter center location (CL) imposes part programming difficulty that demands machining task data of ISO 14649 utilization as alternative.

IV. Current machine tool programming does not permit the transfer of high-level information through the digital chain steps: with human machine interface (HMI) the generic preparation of manufacturing is possible only until the CAM model.

1.6 Aim

The aim of the research is on developing data model of STEP implementation in supporting "manufacturing rich" STEP-NC file format for exchange of product and process data for turn-mill operations to support interoperable manufacturing.

1.7 Objectives

This work will provide STEP compliant product and manufacturing data model to support implementation of ISO 14649 turning and milling standards for a turn-mill center. It also delivers analyses on the application of STEP-NC machine tool model utilization at a workstation level implementation of STEP regarding turn-mill manufacturing environment. Specifically, it states a generic manufacturing information model to establish a STEP-NC interface for turn-mill machining based on previous research models developed in Loughborough University [10-12].The main objective of this research is on comprehensive representation and evaluation of a generic STEP-NC process data, machine tool level STEP implementation and interoperable environment.

I. To investigate the application of ISO 14649 requirement model for CNC machining of turn-mill parts in maintaining information exchange between "CAD" and "CNC" to develop an interoperable manufacturing environment.

II. Evaluation and synthesis of the programming system using a case study component. The STEP-NC compliant system for turn-mill operations will be evaluated against ISO14649-12 standard and other industrial components. This provides investigation on the requirements and realization framework of

STEP compliant information model comprised of a STEP-NC machine tool utilization supporting machine tool level STEP implementation on turn-mill component manufacturing.

III. To design a STEP implementation architecture that enables application protocol (AP) to share information at the integrated resource level of specific turn-mill machine utilizing application reference model (ARM) developed for turning and milling technologies.

The accomplishment of the above objectives are not intended to be full-fledged commercially viable STEP compliant for a fully automated turn-mill manufacturing systems. Instead, it is focused on the adoption of the new CNC controller data model (ISO 14649) for constructing STEP-NC file through concurrent engineering approach. The scope of this research is limited to cylindrical base shape supporting requirements of turn-mill manufacturing validated on a case study component. This programming system is able to generate a STEP based process plan supporting turn-mill manufacturing environment.

The programming system is established on data translation and sharing principles of STEP AP's and able to construct STEP implementation model for turn-mill manufacturing components. It ascertains design and manufacturing information integration, representation and adoption STEP compliant approach over turn-mill operations.

1.8 Organization of the Thesis

The thesis is organized as follows:

Chapter 1: provides main introduction of the research work, problem and motivation of the research with scope identification. It also summarizes and outlines the thesis structure.

Background and literature Review (2 and 3)

Chapter 2: A basic literature review on the evolution and role of manufacturing data standards with corresponding background importance of data archive representation, information exchange in computer aided process planning and computer aided manufacturing related to manufacturing features and resource modeling. Review on standard, motivation and STEP-NC researches

Chapter 3: This section presents the research methodology used to achieve the objective of this research. The proposed object-oriented architecture and implementation algorithm has been developed. It gives illustrate formulation of EXPRESS language translation of Serialization function. Review on methodology and structure of STEP process plan generation.

Theoretical View and System Design (4)

Chapter 4: STEP-compliant system implementation methodology and information models development for turn-mill operations. Framework design and specification analysis based on the literature review and current state of the art. Design and structure of STEP implementation methodology is included.

Prototype Development and Proposed System Output (5 and 6)

Chapter 5: This presents the architect of STEP-compliant system for turn-mill operations and the use of ISO 10303 AP224 components. Design of the system and corresponding functional model of the proposed system is constructed.

Chapter 6: This section covers implementation model and defines the data model. It also illustrates the mapping methodology. Prototype of the system and case study discussion are clearly drawn.

Chapter 7: Conclusion and Recommendations

This covers case study implementation of the system and description of the pros and cons of its utilization. The section summarizes the result and discussions with future work recommendations.

CHAPTER 2

LITRATURE REVIEW

2.1 Introduction

This review presents basics of STEP-NC, STEP-NC complaint process planning, comparison of STEP-NC with G-code, evolution and relation of feature based process planning with STEP and STEP-NC related research trend with their achievements. The literature review also stressed on integrated product development environment using STEP of CAD, CAM, CAPP and CNC chain representation has been covered in addressing process planning. This area achieved an implementation model in STEP with the perspective of comprehensive analysis and provision for integration. Finally, the structure of data model and its contents have been included along with feature based process planning researches related to turn-mill machining.

2.2 STEP-NC Compliant Manufacturing Process Planning

This section reviews the advantage, construct and structure of ISO 14649 standard informally known as STEP-NC, i.e. NC manufacturing information model with respect to substitute for the low-level machining instruction ISO 6983 and RS274D.

Manufacturing planning considered as the link between design and manufacturing activities [13].Manufacturing information model represent elements and methodology of process planning used for manufacturing. It includes process planning, process engineering and machine routing [13] . The standard defines a process plan as "the sequence of activities required to realize or produce a given product". In fact, it should be seen as way to create the instructions to produce a part. In the instructions the processes, parameters, machines and tools are selected to transform material from the raw material into a part according to the design information. According to Ham and Lu [14], Process Planning includes:- selection of:- machine tools, tool sets, set-ups, machine operation with sequence, cutting tools, design of jigs and fixture, cutting condition , tool paths and NC generation.

Manufacturing process planning activities are represented by digital machine tools, such as CAD, CAM and CNC. Bi-directional data exchange between CAM and CNCs accomplished by object-oriented STEP-NC programming interface, and enables integration of CNC to CAx systems. This gave raise to STEP-NC complaint CAD/CAM system. These systems mainly focus on closing the gap between design and manufacturing, for a distributed and collaborative manufacturing environment to sustain compliance to STEP standard. It also served as a means to define a new generation of NC programming language and that brings richer information to the CNC machine tools; hence intelligent machining and control are made possible. Its Web-enabled feature supports an additional dimension in that distributed manufacturing can be readily supported which leads to the foundation of STEP-NC interface. Some of the procedures for STEP-compliant process planning are outlined and patented in USA under such et al [15] consists of :

I. Geometric kernel data interpreting and generating a STEP physical file (ISO 14649 part program);

II. Manufacturing features extraction

III. Set a process plan on the ISO 14649 data manufacturing features;

IV. Edit the process plan;

V. ISO 14649 part program generation from the edited process plan;

VI. Tool path generation from feature information specified in ISO 14649 part program; and

VII. Tool path verification in a CNC (computer-based numerical control).

2.2.1 STEP-NC

STEP-NC is a data model provision for new breed intelligent CNC controllers. It uses continuously evolving specification of common standards specifically aimed at NC programming which is investigated by vendors, users and academics from across the world. Aachen and Stuttgart Universities, Siemens in Germany, Pohang University, and ERC-ACI in Korea, CADCAMation in Switzerland and NIST with STEP Tools in the USA are major academics and industrialists involved in this standard[16] . ISO Technical Committee TC184/ subcommittee SC1 introduced STEP-NC Draft International Standard (DIS) known as ISO 14649 in 1997 to ISO Working Group [17]. ISO 14649 Part 1 [9] provides an overview of the fundamental principles of the standard. The ARM of STEP-NC, i.e. ISO 14649 is made up of several Parts. The first set of Parts of ISO 14649 became international standards in 2004, adoption of ISO 14649 Parts as conceptual models by the ISO team resulted AIM of STEP-NC, i.e. ISO 10303-238 (or STEP AP238) in the early 2000s, and AP238 was published in 2007. ISO 14649 and STEP Part 238 investigations for development is still in progress. Currently both of them are commonly consigned as "STEP-NC".

STEP used as the exchange and sharing of product data in manufacturing, Whereas STEP-NC extends STEP for manufacturing, defines data representing "workingsteps", that is, a library encapsulation of specific operations that is applicable on a CNC machine tool. Its implementation is to address product data compatibility/interoperability and adaptable to CNC machines. In other words, it breaks down every machining operation with standards (represented as application protocols) into the steps necessary to perform the operation.

STEP-NC is the result of enabling standards underling the potential for using the digital product model as machine tool input. It allows a neutral database of machining information to be constructed. The database, then, dictates what capabilities must exist in the machine tool controller to execute the part manufacturing.

2.2.2 Structure of ISO 14649 Standard

Application of ISO 14649 is in representation of requirement model in manufacturing life cycle of a product regard to advance CNC machine tool and CAM system. It includes representation of CAD geometry data and part feature definition by ISO 103030-203 and ISO 10303-224 respectively[18]. Figure 2.1 shows hierarchical arrangements of ISO 14649 parts specification such as generation of resource requirements for part fabrication suit for Manufacturing execution system, manufacturing feature sets suitable for various processes, e.g. milling, turning, electrical discharging machining(EDM) , and inspection which also uses ISO 10303-219 [3].

The purpose of ISO 14649 covers requirements of current and future manufacturing data exchange; supports direct utilization of ISO10303 based computer-generated data, providing CNC machine tools an exchangeable, workpiece-oriented data model and ensures provision of CNC input data compatibility.

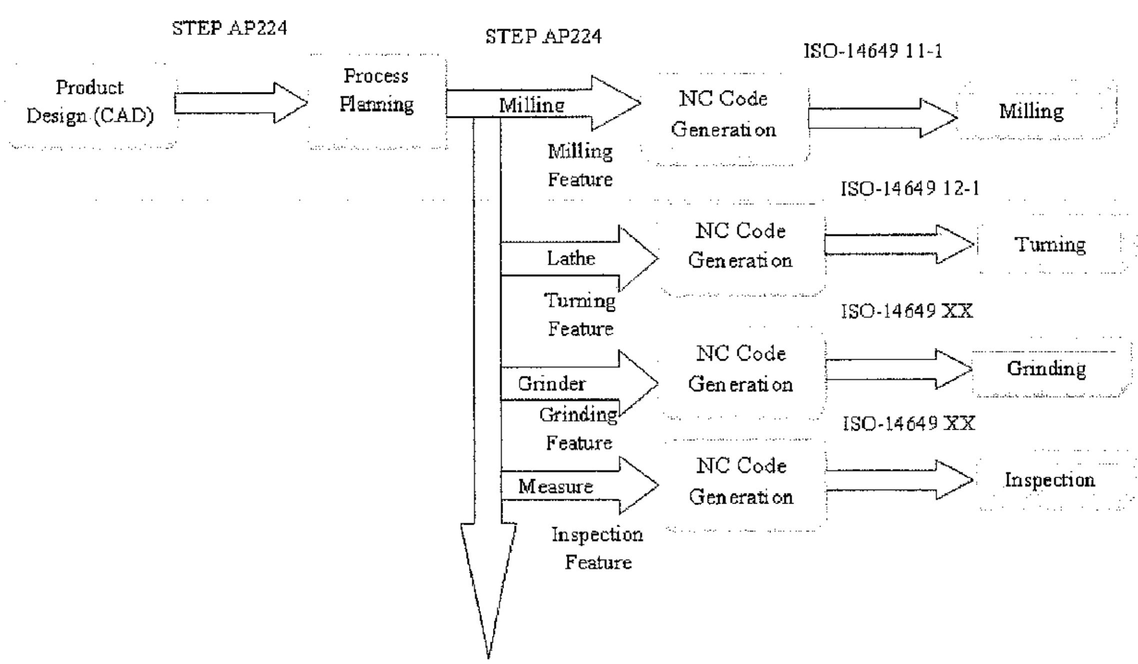


Figure 2.1 Manufacturing Life Cycle Representation by ISO 14649.

The standard follows the typical STEP structure where there is a general standard for guidelines and many parts which describe each branch of technology or process such as milling, turning, EDM (Electrical Discharge Machining), as shown in Figure 2.1

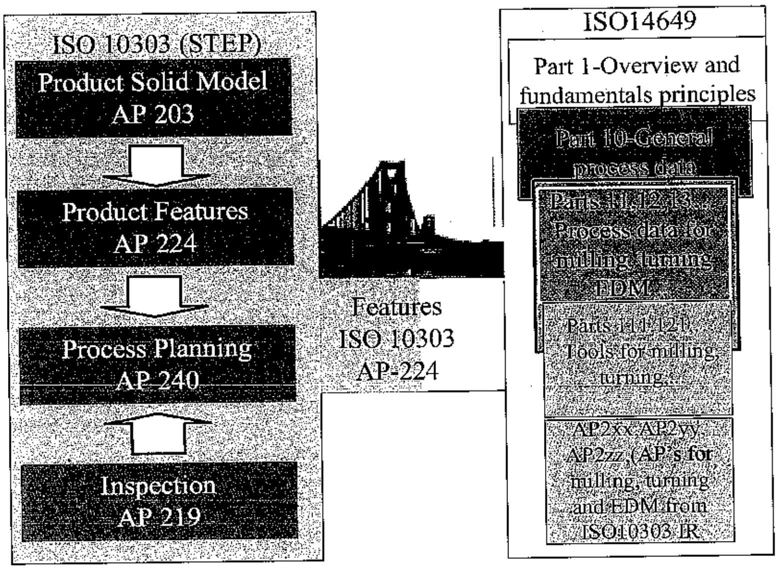


Figure 2.2 The Relationship between ISO 10303 and ISO 14649.[19]

Figure 2.2 also represents the relationship **between STEP AP's and ISO 14649 and** the actual structure of ISO 14649. Here, the features technology is used as the bridge to transform a product model in a machining program. Generation of STEP compliant NC program resulted in accordance to the product information model. If inspection is needed, AP 219 also should be included in the process[9, 20].

Part-21 files are used for describing the intent of ISO TC 184/SC1 in STEP data representation methods of ISO 14649 Parts on a specific domain or application. Part-21 files are based on ARM models. It is referred as Micro-level process planning information model representation by ISO 14649 attempting to replacing G-code high level data, Since G-codes is 60 years old and low level program for NC machine tools. In large scale Macro level machined products process planning information model is represented with ISO 10303-240.

2.2.3 ISO 14649 Fundamentals

ISO 14649 identified as new standard for transferring data between CAD/CAM systems and CNC machines. It works against shortcomings of ISO 6983 specifies machining processes rather than machine tool motion. A major benefit of using ISO 14649 renders total conformity to ISO10303. In fact, the standard that ISO 14649 defines is called STEP-NC, namely STEP extended to NC. Some major benefits of using STEP-NC are summarized underneath [17].

1) Both feature description and model structures in ISO 14649 are harmonized with ISO10303. So STEP-NC supports bi-directional information transfer between CAD/CAM and CNC. As a result, modifications for the information about machining tasks and technological data on the shop-floor can be saved and transferred back to the planning department.

2) Post-processors will be eliminated because the interface does not require machine-specific information.

3) Machine tools are safer and more adaptable because STEP-NC is independent from the machine tool vendor.

4) STEP-NC provides a complete and structured data model, linked with geometric and technological information, and avoids information loses between the different stages of the process.

2.2.4 Components of ISO 14649

ISO 14649 component parts are used to cover machining data, process specific data and tool requirements for; milling, turning, wire and die-sink electrical discharge machining (EDM) and inspection[21]. A summary of ISO10303 and ISO 14649 related to this research can be summarized as follows;

I) Part 1: Overview and fundamental principles - includes a data model for computerized numerical controllers, an overview and fundamental principles [9].

II) Part 10: General Process Data - specifies the process data that is generally needed for NC programming within all machining technologies and describes the interface between a computerized numerical controller and the programming system [22].

III) Part 11: Process Data for Milling - specifies the data elements needed as process data for milling. General process data requirement is described in ISO 14649-10 this part of ISO 14649 constitutes the interface between a computerized numerical controller and the programming system [3].

IV) Part 12: Process Data for Turning - constitute a specification requirements of the data elements for process data of turning [2, 23].

V) Part 13: Process Data for wire-EDM - specifies the data elements needed by process data for wire-EDM.

VI) Part 14: Process Data for sink-EDM - specifies the data elements needed as process data for wire-EDM.

VII) Part 16: Data for touch probing based inspection - specifies the data elements needed as process data for touch probing based inspection.

VIII) Part 111: Tools for Milling Machines - specifies the data elements needed as tools for milling. These data elements can be used as the criteria for selecting one of several milling and drilling type tools, not to describe the complete information about a particular tool [24].

IX) Part 121: Tools for turning Machines - specifies the data elements needed as tools for turning. These data elements can be used as the criteria for selecting one of several turning type tools, not to describe the complete information about a particular tool[23].

In addition, ISO 10303-238, industrial data, is being under development using EXPRESS models, in ISO 14649 few modifications of domain requirement model (ARM), by ISO TC 184/SC4. It is mapped in to integrated resources to obtain an implementation model.

2.2.5 Comparisons STEP-NC with G-Code, Standards

STEP-NC addresses the requirement of NC process with object oriented data model using "workingsteps". "Workingsteps" includes description of information for manufacturing tasks of a specific operation, tool, or strategy. STEP-NC constitute high level information modeling which included various NC functions; machine functions; machining strategies; auxiliary commands; technological description extended from workpiece definitions to tool data representation.

In comparing STEP-NC describes "what to do", with G-code describes "how to do". STEP-NC describes tasks (pre and post machining operation) beyond normal tool movement description made by G-code. STEP-NC data are based on the machining features and architect as shown in Figure 2.3, so that the sufficient shop-floor information supported with higher level part program, the information about machining tasks and technological data on top of pure geometrical and topological information.

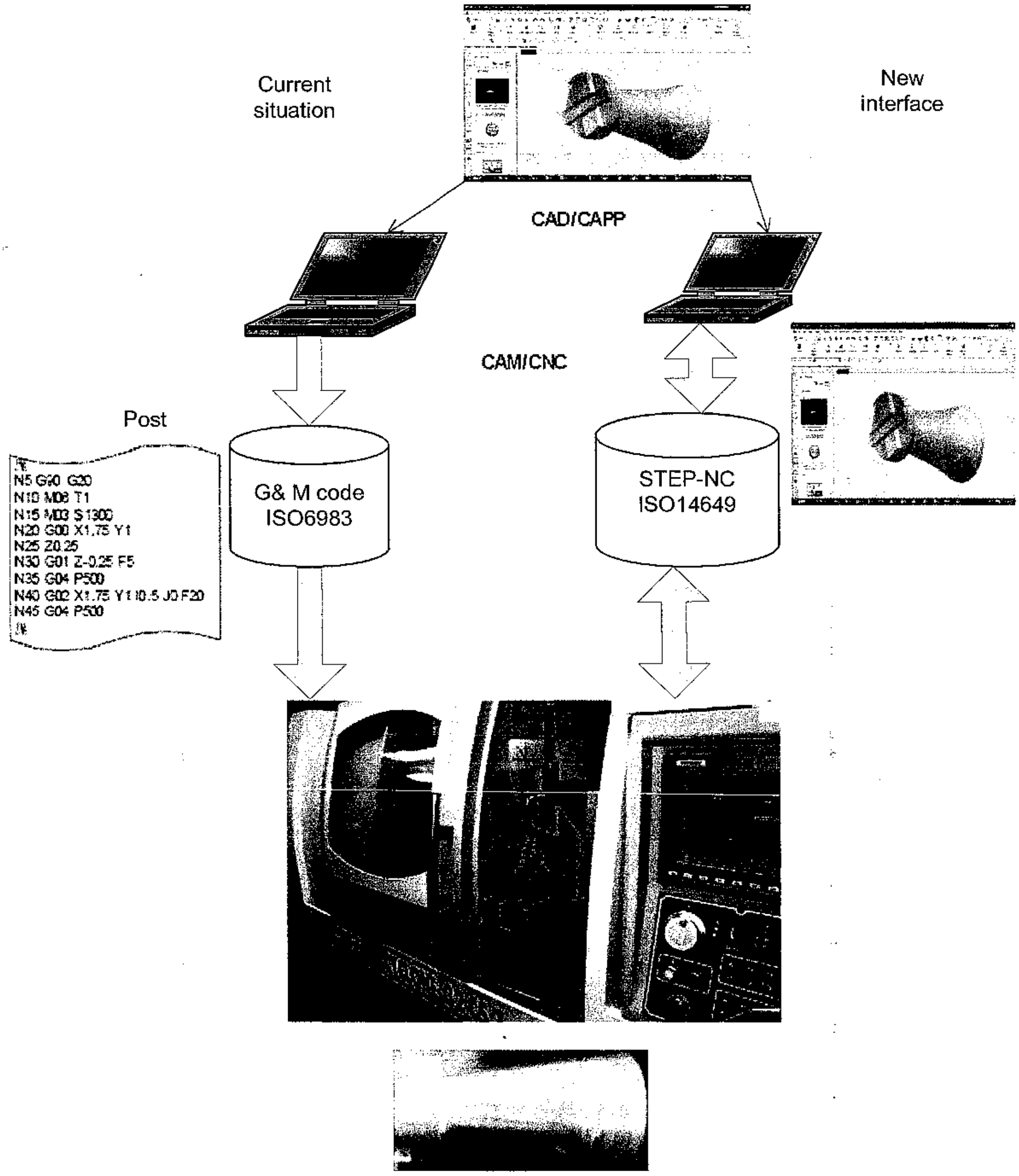


Figure 2.3 Comparison of G-Code and STEP-NC

As a result, modifications at the shop-floor can be saved and transferred back to the planning department that enables a better exchange and preservation of experience and knowledge. Some of the benefits with using STEP-NC are as follows[17] :

STEP-NC provides a complete and structured data model, linked with geometrical, technological information and enabled avoiding information loses between the different stages of the product development process.

STEP-NC provides sufficient data elements to describe task-oriented NC data.

STEP-NC constitutes data model which are extendable to further technologies and scalable (with Conformance Classes) to match the abilities of a specific CAM, SFP (Shop Floor Programming), or NC system.

A reduced machining time is achieved by intelligent optimization for medium-size job lots by using STEP-NC controller.

STEP-NC interface allow a universal data streaming and are machine independent which also allow eliminating post processor requirement.

CNC machine tools imparted adaptability since STEP-NC is independent from machine tool vendors.

Bi-directional information flow from CAD/CAM to CNC machine tool achieved and established fedback modification data transfer from shop-floor to design department

The system utilized XML files as a data carrier, hence enable web-based distributed manufacturing.

Rosso has forwarded detail comparison of STEP-NC and G and M code as shown in Table 2.1[19].

Table 2.1 Comparison Issues for STEP-NC and Previous Standards [19]

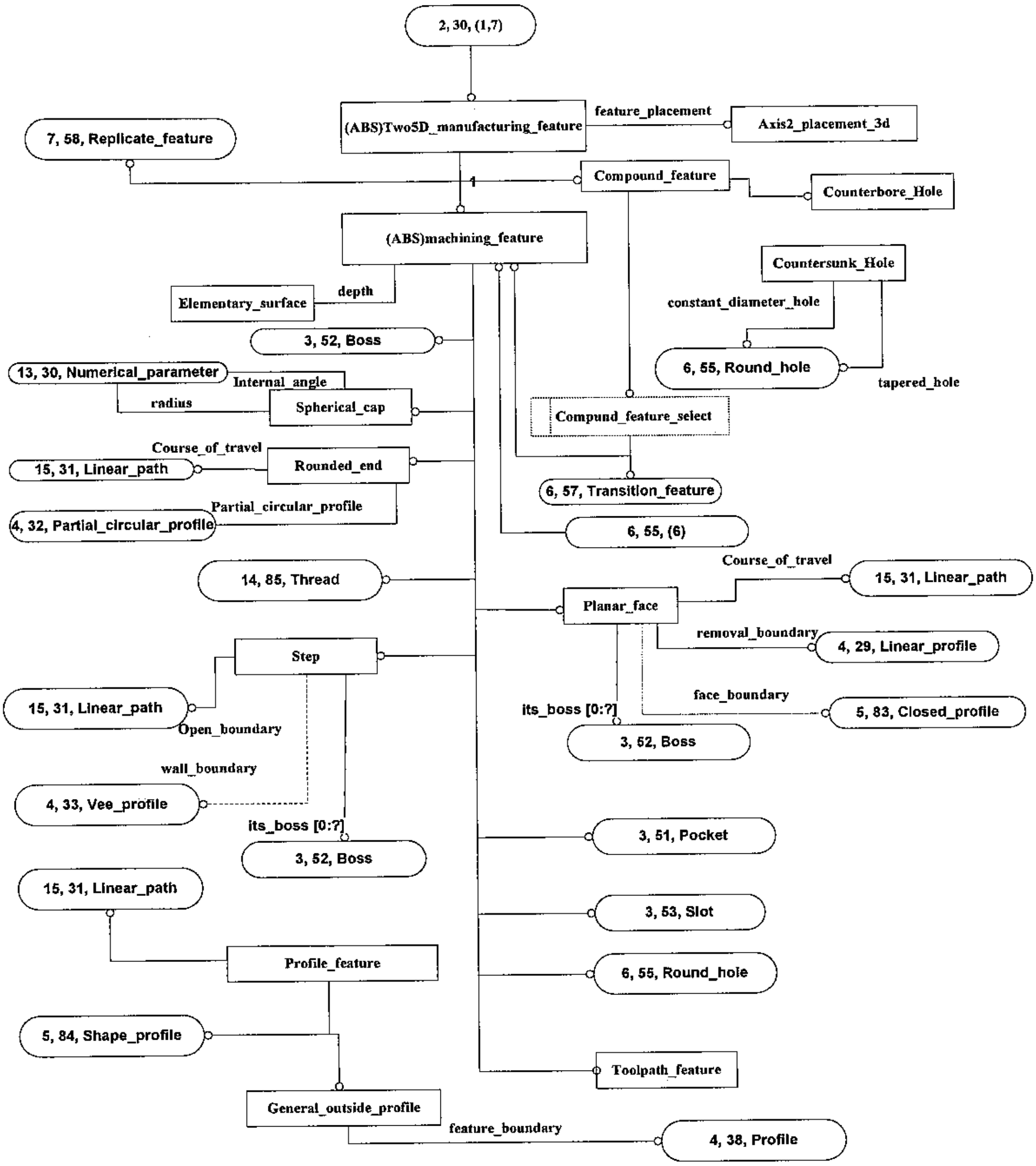
Comparison Issue	***STEP-NC***	***NC Part Programming System***	***Manual Programming***
Programming level	Highest level command	Highest level command	Lowes level command
Program length	Similar length to manual part program, but has different data	Not really applicable but data stored in CAM system format in software	Efficient for tool path when combined with learned cycle/sub, program very long for 3D parts
Part description	ISO Standards using geometric features	Software specific pseudo standard	No part geometry in code
Technological description e.g. tool definition and speed	Tool definition to ISO standard and cutting tool parameters	NC system holds database of tools and cutting parameters	NC tool description accept tool pocket or tool assembly code
Tool Paths	Not described left to intelligent controller	Tool paths simulated Shown and output through post processor	Tool path information based on tool center line
Readability	Easy to follow and read major process operations complex data statements	Easy to follow Operations and uses dialogs and high level language	Lower level commands With X,Y,Z and G and M codes
Surface/3D capability	Not defined as yet in detail	Based on 3D solid geometry, surface machining new standard	Possible but program needs processing from CAD/CAM system
Machine tool description	Little definition of machine and its intelligence	No definition	No definition

2.2.6 Data Structures of STEP-NC Complaints Systems

STEP-NC system is established on schemas. These are model definitions, which are used as mechanism for digging through its component parts. Object-oriented flavored explicit inheritance relationships of STEP-NC has been represented by EXPRESS

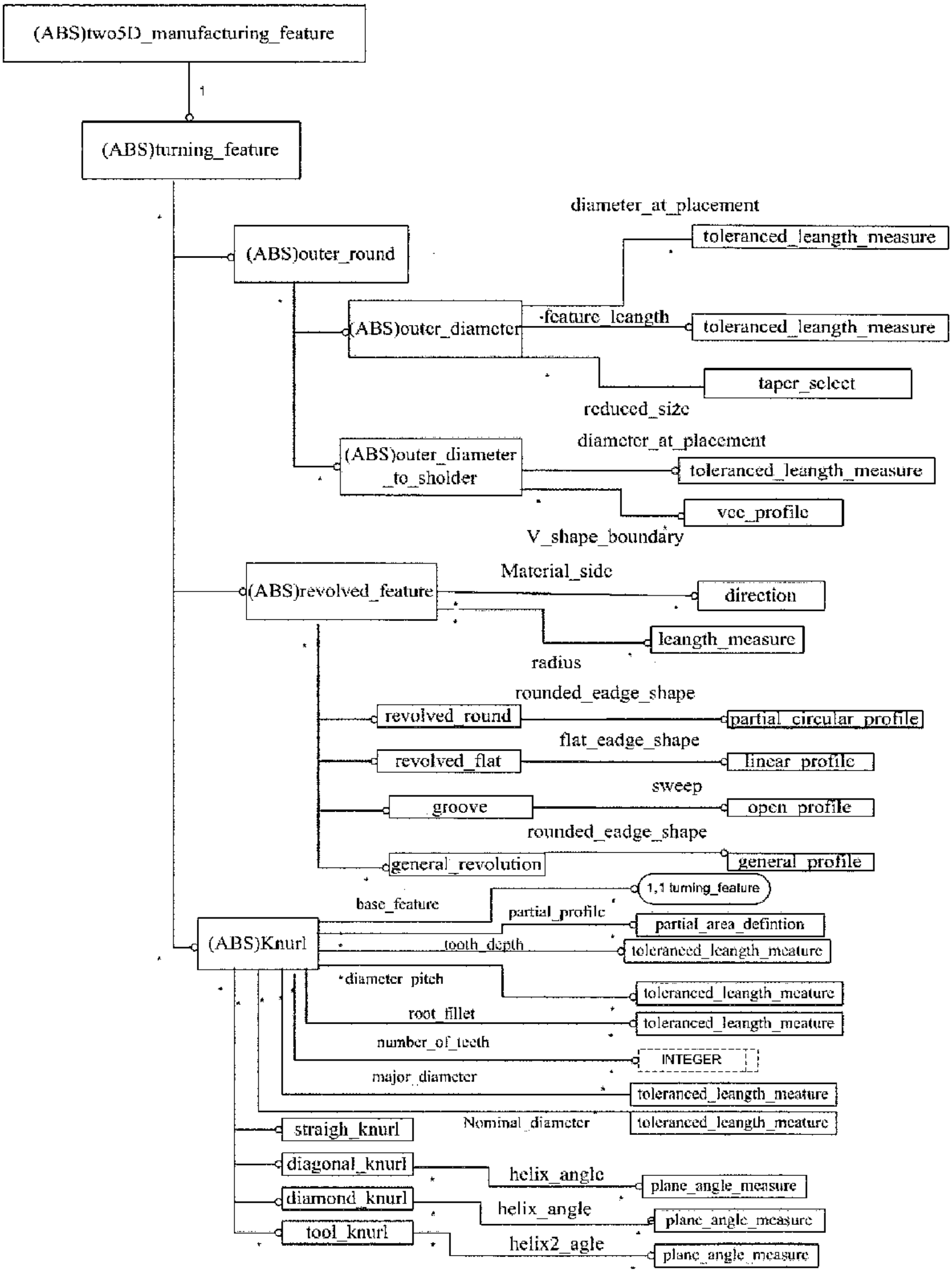
As illustrated in Figure 2.4(a) and (b) for [22] Abstract super class (ABS) Two5D manufacturing feature i.e. super-class consists of sub classes having feature placement entity. Its attributes are inherited by the "child" entities (machining, replicate, and compound features). The sub-type of machining features classes has an elementary surface for defining depth.

The STEP-NC data structures represented under the basic abstract class such as (ABS) machining feature require binding programming language like Visual basic dot net. Object oriented methodology support the sub class being interfaced through similar attributes under the ABS super class. As abstract class is the one that is not used to create objects, it is designed to act as a base class (to be inherited by other classes). The design concept in program development and provides a base upon which other classes are built. Abstract classes are similar to interfaces. After declaring an abstract class, it cannot be instantiated on its own, it must be inherited. Like interfaces, abstract classes can specify members that must be implemented in inheriting classes. Unlike interfaces, a class can inherit only one abstract class. Abstract classes can only specify members that should be implemented by all inheriting classes. This allows the given elements in the EXPRESS model representing the data structure to construct the required process plan information element. Here the data structure is formulated by the programming language as to be illustrated on the design and testing in chapter 6. This is constructed on the contents of individual machining feature class formulating the machining library class. It has been represented by the universal modeling language under the information model constructed in chapter 5. The flow of the system adopted integrated platform for process planning and control (IP3AC) [25].



2, 30, (1,7)
(ABS)Two5D_manufacturing_feature
feature_placement
Axis2_placement_3d
7, 58, Replicate_feature
1
Compound_feature
Counterbore_Hole
(ABS)machining_feature
Countersunk_Hole
Elementary_surface
depth
constant_diameter_hole
3, 52, Boss
6, 55, Round_hole
tapered_hole
13, 30, Numerical_parameter
Internal_angle
radius
Spherical_cap
Compund_feature_select
Course_of_travel
15, 31, Linear_path
Rounded_end
6, 57, Transition_feature
Partial_circular_profile
4, 32, Partial_circular_profile
6, 55, (6)
Course_of_travel
14, 85, Thread
15, 31, Linear_path
Planar_face
removal_boundary
4, 29, Linear_profile
Step
face_boundary
15, 31, Linear_path
its_boss [0:?]
5, 83, Closed_profile
Open_boundary
3, 52, Boss
wall_boundary
4, 33, Vee_profile
its_boss [0:?]
3, 51, Pocket
3, 52, Boss
15, 31, Linear_path
3, 53, Slot
Profile_feature
6, 55, Round_hole
5, 84, Shape_profile
Toolpath_feature
General_outside_profile
feature_boundary
4, 38, Profile

(a)



(b)

Figure 2.4 EXPRESS-G Illustration of STEP-NC Manufacturing Features

2.2.7 STEP-NC Implementation Physical File Formats

STEP-NC data model is in conformance with ISO10303-21 since it is an input standard for CNC system, extended from STEP for establishing instruction of NC processes. The file constituted basic structure and functionality of a part program by two sections assigned by keywords HEADER and DATA respectively [17]. Figure 2.5 HEADER section is first part of the program and describes general information and comments such as filename, author, date and organization. The DATA section includes all manufacturing and geometry information in a PROJECT entity. It is composed main Executable objects initiate actions on a machine that are arranged in a pre-defined but changeable order. NC_function, program_structure and Workingstep constitutes the three types of the executable objects. NC functions describe switching operations and other non-interpolating machine functionality, typically singular events. Program structures are used to build logical blocks for manufacturing operations and related machining features under workingsteps super class.

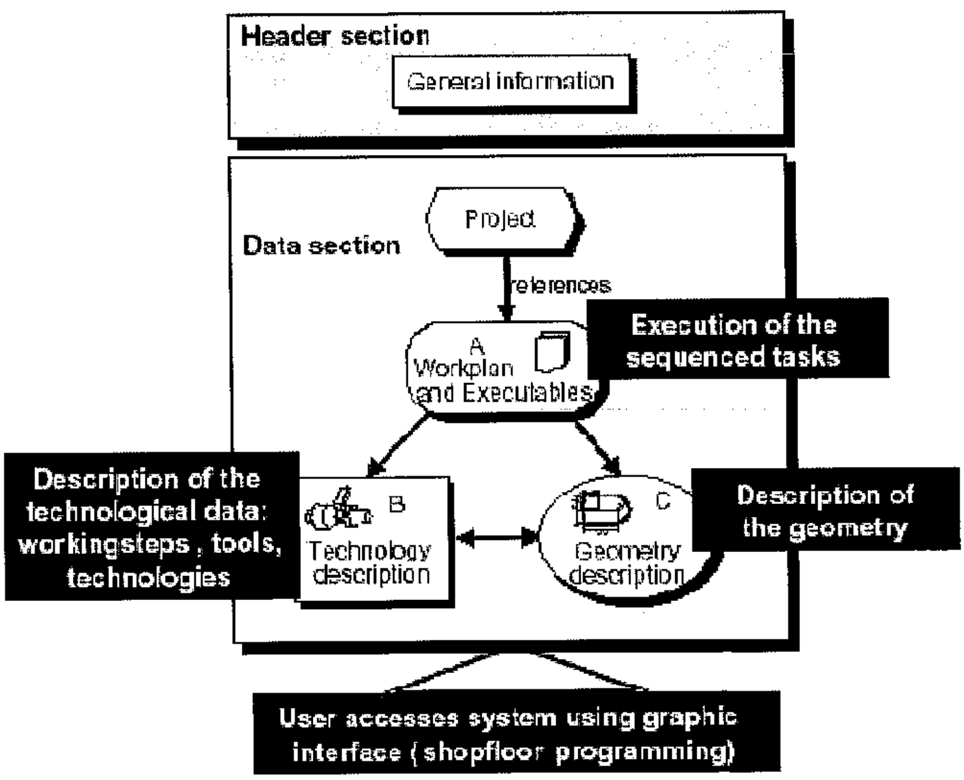


Figure 2.5 STEP-NC Physical File Structure [26]

An EXPRESS representation can summarize two parts of workingstep hierarchy, namely Technology description and Geometry description as in Figure 2.6 Executable is the Super-class having a sub-class of Workingstep which in turn has got a sub-class of Machining_Workingstep. It is this executable unit to act on process a part, by axis movements and material removal during NC execution. Moreover, it has been linked information about technologies and geometric semantics along with machining requirement. The execution sequence of the NC program is determined using the entity Workplan that has an ordered set of the Executables.

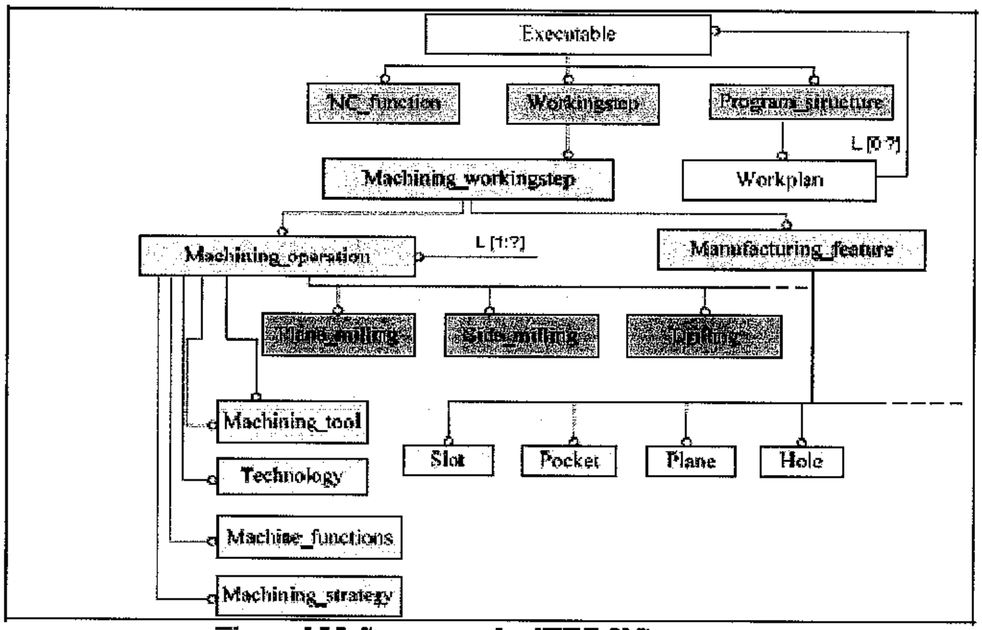


Figure 2.6 Structure of a STEP-NC Program[8]

A Manufacturing_feature constitutes most of the manufacturing features defined in STEP AP224 and included geometric information. For example, a Closed_pocket is one of manufacturing_features, has a boundary curve data and depth of bottom with one more planar bottom condition.

A *Machining_operation* is the abstract base class for the process specific operations.It specifies the tool to be used (*Machining_tool*), and a set of technological parameters: machining parameters (Technology, e.g. feed-rate, spindle speed), machining conditions (*Machine_functions*), and *Machining_strategy* (e.g. contour parallel, contour spiral).

2.3 Manufacturing Information Modeling

Manufacturing information modeling efforts have been focused on manufacturing resource capability modeling, process plan modeling, and manufacturing cost modeling. Several manufacturing models have been developed, but product model for design was primarily engaged in to standardization stage in IS0 10303 (informally known as STEP) includes representations of geometry, topology, dimension, tolerance, feature, material, product configuration, and so on. NIST in DPPI project established an open neutral manufacturing process object modeling using object oriented technology for achieving software interoperability between design and manufacturing [27].

Process planning and machining process planning activity model representation, definition on scopes, functional requirements contents had been described by IDEFO diagram in assessing to overcome barriers in data exchange and sharing sustainability on integration of process planning system [28]. This methodology used in the next section to display sub-division and functionality of integrated STEP-compliant manufacturing environment.

In this thesis the review started on fundamental of STEP, STEP-AP and implementations structures. Then the review proceeds on discussing researches on the significance of geometric and feature representation under feature based CAD/CAM since they are the basis of proposed methodology on interlinking design with process planning [29].

2.3.1 Integrated STEP-Compliant Manufacturing Environment

It has been presented as a combination of two sub-systems shown in Figure 2.7

I. primary system is for generating a native program which retains all part machining requirement information with regard to specific machine tool

- Inputs are CAD geometric data and AP-203 as output

- Information in STEP files interpreted in to AP-224 manufacturing features.
- These features are input for process planning.
- Workingsteps are formed from defined common production requirements and manufacturing resources for generic part programs in STEP-NC.

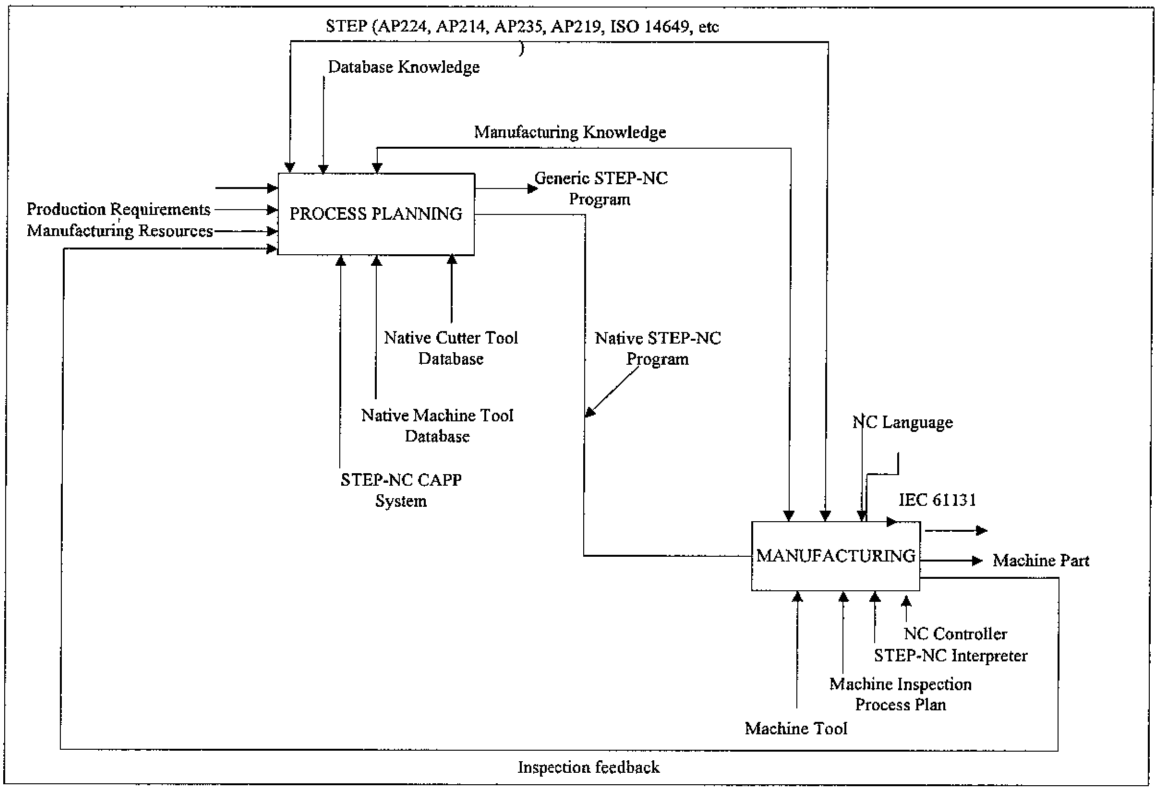


Figure 2.7 IDEFO Diagram for Process Planning and Manufacturing[8]

Generic STEP-NC is an input of resource driven process plan interacting with machine tool database on EXPRESS. It can be converted to Native STEP-NC program Figure.2.8.

II. Secondary system able to execute machining parameters optimization using information from the former Native STEP-NC program i.e. performing two activities

- generating tool path and interpreting commands such as G-code or any other NC languages (low-level machining)
- Manufacturing execution followed by inspection activities

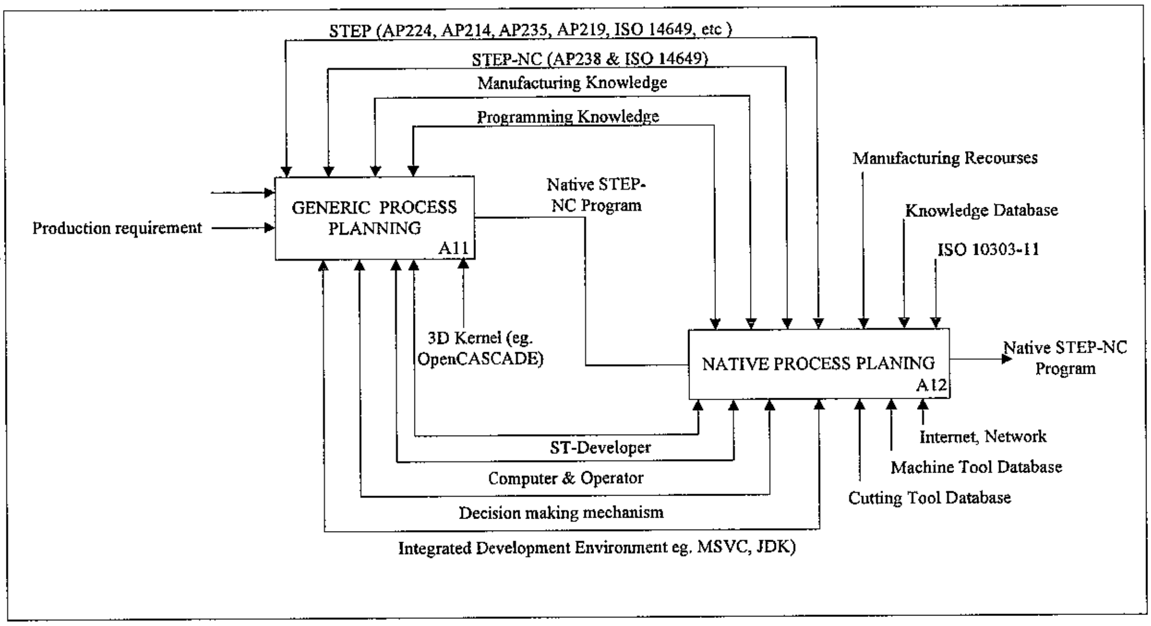


Figure 2.8 IDEF0 Diagram for Integrated STEP-NC Process Plan[8]

2.3.2 Feature-Based CAD/CAM

Features are forms found in feature-based design or means for design by features that are known as "feature-based design provides designers with a feature library in which a number of features are predefined and when designers design a part, they can select different features to form the parts". It is helpful for establishment of concurrent engineering environment [30].

Recognition of ISO 10303 AP224 features from AP 203 has been active research since Bhandarkar et. al [31] which allows integration of CAD/CAPP/CAM data. Specifically in STEP related researches feature recognition has a key role in generating AP-224 or AP238 data from AP 203.

Syntactic pattern recognition, rule-based search, graph-based matching, volume decomposition, hint-based geometric reasoning, Neutral network and generic algorithm are some of proposed methods for feature recognition.

Feature based approaches have been used in developing a commercial CAD/CAM prototype unit capable of extracting machining feature model known as CAFÉ [32]. Other feature-based design presented which had an incremental extraction of machining feature for part modeling [33]. An automatic process planner and NC-code generator specific to prismatic parts constructed as extended feature-based system [34]. STEP-FM is also one STEP-based feature recognition system as prismatic parts process planning based on STEP features. It is among the recent STEP-based proposed system to associate feature extraction and neural-network cutting tool parameter optimization[35].The evolution of feature recognition and process planning researches and their association with STEP standards has been given on Table 2.2.

Feature recognition systems are governed by domain of AP224 description of mechanical parts. That makes requirement of STEP standards provide data structure supporting machine configurations and technology capabilities. A universal machine tool resource data model developed can be used to map a generic STEP-NC program to a native one in place of machine tool resource database. It is suggested that the use of AP-238 ascertains bi-directional data flow through design and manufacturing which is suitable for provision of manufacturing process feedback.

Table 2.2 Summary of Researches on Feature Recognition and Process Planning

Summary of Research on Feature Recognition and Process Planning				
	System	Capability	Standard I/O	Region
Feature Recognition	Feature Recognizer	B-rep geometry abstraction/ conversion (simple features only)	CAD data/ISO 10303 part 21	UK
	Feature Recognition Processor	Feature interaction, detection, and extraction (simple features only)	CAD data/ISO 10303 part 11	Singapore
	AP-203 interpreter	Feature interaction, detection, and extraction (simple features only)	AP203/AP224	S. Korea

	Modeling-feature recognition system MASCAPP	B-rep geometry abstraction/ conversion, modeling feature extraction (simple prismatic features only)	CAD data/ISO10303 part 21 Design features/ ISO10303 part 21	UK
	AB-CAM system	Features interaction/inter-relating detection (closed pocket and round holes only)	Design features/ ISO10303 part 21	UK
Process planning system	IP3AC system MASCAPP system	Resource, cutting-tool, machining parameters selection and determination	Product design features/ISO10303 part 21 and NC code	UK
	EDM system	Machining feature detection/ sequencing, machining operation, tool and parameter selection determination, NC code generation		
	STEP-compliant process planning agent	Machining feature detection/ sequencing, , NC code generation	ISO14649, ISO10303 part 21 and NC code	Switzerland
	Sheet metal CAPP	Machining operation, cutting tool, machining parameter selection and determination	ISO14649, ISO10303 part 11	China
	CyberRP system ST-FeatCAPP system	Machining features detection/ sequencing, machining operation selection, NC code generation. Machining feature detection/ sequencing, machining operation, tool and parameter selection and determination	ISO 10303 part 21/NC code STL/ISO 10303 part 11 Design features/AP 224 XML	New Zealand S. Korea Turkey

2.3.3 Turn-mill Manufacturing and Feature Based Researches

A feature based geometric reasoning used to evaluate a manufacturability analysis for efficient and flexible utilization of part design representation in turn-mill machining process plan generation. Convex decomposition and mapping system to machining process classes on turn-mill parts used for feature recognition and a geometric based machining precedence relation recommended for machining feature decomposition on determining machining process sequence and assigning multiple spindles and turrets machines[36]. Feature recognition methodology further utilized on the domain of interacting rotational and prismatic parts for machining volume generation method development by Tseng and Joshi [37].

A rotational C-axis features process planning module presented to determine feasible sequencing. The system followed the regular NC co-ordinates system and features. Features are categorized as primary (face, cylinder and cone) and secondary(groove, chamfer, thread and C-axis features) which also included consideration of spindle orientation with rotating tool as in CNC turning for generating machine dependent module of process plan.[38]

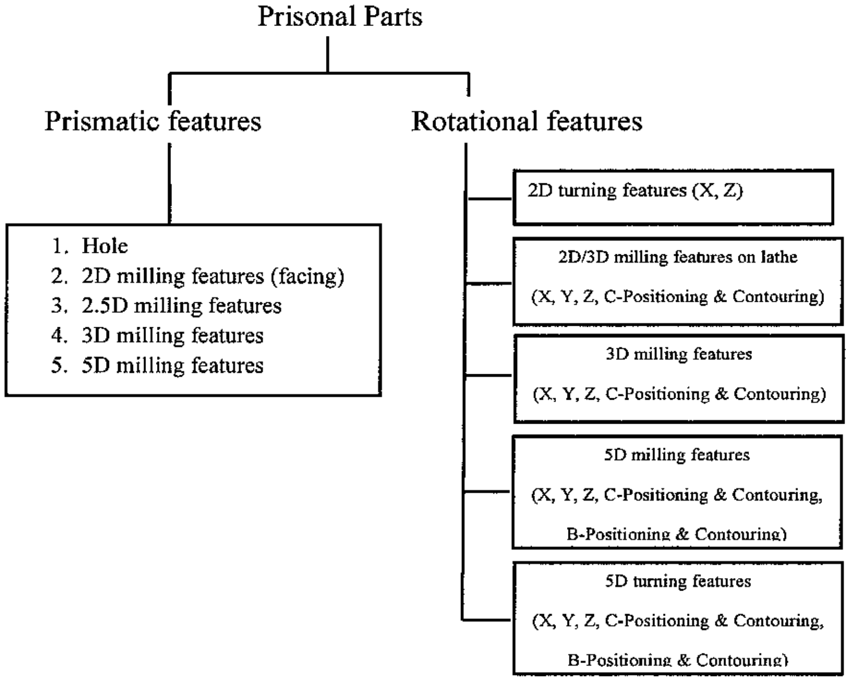


Figure 2.9 Prisonal Parts

A proposal of new machining feature model made describing both prismatic and rotational features as Prisonal shown in Figure 2.9. The model accounts aspects of geometric, manufacturing and machining process with knowledge-based rules for process planning system on five-axis lathe.

The drawback of multiple setups resolved by turn-mill machine tool since it is the combination of five-axis capability, twin-turrets and multiple spindles. Derek Yip- et al. primarily suggested a proposed computational technique for determining Maximum Turnable State (MTS). It is similar to turning machine with five-axis milling capability including X, Z, C, Y and B axis. It has the additional rotary milling axis called B-axis. The B-axis is defined as the rotation about the Y-axis. The B-axis makes cuts with compound angles possible and gives a machine full support for 5-axis simultaneous freeform milling. When the B-axis equips with dual spindles, the B-axis enables to perform milling and turning operations on both front and back of a workpiece.

Table 2.3 Comparison between Number of Axis and Capabilities of Mill-Turn machine

Number of axis	Capabilities of turn-mill machine
X-Z	Milling operation only such as simple slots, drilling and tapping holes located on machine's centerline
X-Z-C (positioning)	The main spindle holding a workpiece can be indexed called C-axis Milling a keyway or drilling off the machine's centerline is possible
X-Z-C (contouring)	The C axis enhances the abilities to make profiling cuts, spiral cuts, contours or other relatively complex interpolated geometries.
X-Z-C-Y	Normal turn-mill can move linearly only in two axes of motion. Any feature on the workpiece that is not along the centerline or perpendicular to the spindle centerline, it can't be directly accessed to the rotating drill, mill or tap. By adding a third linear axis called Y-axis enables rotary cutters to machine across the spindle centerline. So, off centerline geometric features can be perfectly machined.
X-X-C-Y-B	The B-axis makes cuts with compound angles possible. Grooved at compound angles, milled features at compound angles or multi-faces parts can be completely machined in a single set-up.

A proposal of intelligent process planning system for five-axis mill-turn parts mainly identified as Prisonal parts has been developed. It has three main features [39].

Novel machining features classification based on machining processes and number of simultaneously controlled axes of five-axis lathe; a special group code was proposed.

Machining feature definition with representation; this model not only includes geometric and manufacturing data in the open layer but also includes machining processes and machining knowledge viewed as production rules of expert systems.

Process plan generation model; a process plan is generated based on machining features and rules. The developed system ascertains fast and accurate process plan generation with new group code system combining the variant and generative approaches. Feature based design approach is useful for interlinking design and manufacturing but its application has not been fully compliant with STEP and not extended to turn-mill process planning.

2.4 Major Executions of STEP-NC Projects

2.4.1 Intelligent Manufacturing Systems

Intelligent Manufacturing Systems (IMS) is a multinational collaboration which includes European ESPRIT STEP-NC project, the American "Super Model Project" and Rapid Acquisition of Manufactured Parts (RAMP). This section discussed about the primary target, related achievement and contribution made by the research partners under Intelligent Manufacturing Systems.

IMS is the culmination of regional project, endorsed in November 2011 was linked with Super Model Project. Academic institutions and manufacturers of CAM systems, controller, OEM and end–users are presented in Table 2.4. The table displays the regional, technology scope and distribution of partners.

Table 2.4 Participants and Regions Involved in the IMS project[17]

Region	EU	Swizerland	Korea	USA
Technologies covered	Milling			
	Milling, turning wood/glass cutting stone	Wire/sink EDM	Milling Turning Rapid Prototyping	AIM for milling and Turning (STIX)

	machining inspection		XML-formatted STEP-NC data structure	
Orginal equipment Manufacturer (OEM) & End-user	• Daimler Chrysler • Franci(Italy) • Progetti	• Derendinger • Wyss	• Sam sung	IRB (including • Boeing • Lock head Martin • General Electric • GDLS • General Motors.)
Machine-tool manfacturer	• CMS(Italy)	• AGIE • Starrag		
Control manufacturer	• Siemens* • OSA(Italy) • Fidia			
CAM manufacturer	• Open Mind • Dassult	• CADCAMation*	• Cubictk	• Step Tools • Gibbs & Associate • BA solution • Numerical Control services
Research institute	• WZL (RWTH AACHEN) • ISW (University of Stuttgart) • KTH	• EPFL • EIGI-tech	• ERC-ACI* • KIST • NRL-SNT	• Louisiana Centre for manufacturer services • Lawrence Livermore national laboratories
Associations	• CE CIMO (Belgium)	• AMT		• NIST Departement of Energy • Army's National Automotive Centre (NAC)

In this project Siemens, CADCAMation, STEP Tools (USA) and ERC-ACI (South Korea) were referred as regional co-coordinators where as Siemens's referred as the inter-regional coordinator. Their research focused on technologies implementation and development of STEP-NC standards on different NC applications such as milling, turning, inspection etc. At the final review of IMS, Aachen

University (Germany) forwarded a demonstration of fully integrated inspection planning in to STEP-NC information flow [40]. But in all the cases described, the studies are limited to single domain applications which trigger the need for turn-mill implementation.

2.4.1.1 European STEP-NC Project

A global collaborative project among EU, Korea, Switzerland and the USA were formed to exploit former STEP-NC research outputs in the line of intelligent manufacturing systems (IMS). Their main activities were validation and improvement on the existing data model for milling and constructing data models for additional technologies such as turning and wire-EDM (Electrical Discharging Machining), wood and glass cutting. In October 2001, Aachen ,Germany project achieved in setting up demonstration facility on STEP-NC compliant system for milling . In the demonstration system Catia V5CAM modules was used and the STEP-NC program demonstrated capacity in generation high level CAD geometry data, operation data and sequencing information. The generated part program file was transferred for shop floor using shopMill through a Sinumeric 840D control of Siemens that can adopt the part program file with shop floor oriented NC programming tool.

STEP-NC EDM at CADAMation realized STEP-NC driven scenario for wire-EDM on Age Charmilles machine tool. CAM output for Contour Cutting was realized by the control (Siemens, OSAI) and machine tool of CMS. OSAI was also able to control machine tool for wood machining using STEP-NC information. In the second phase of the project, enhancement of formerly developed system and development of feedback mechanisms of STEP-NC has been performed.

2.4.1.2 The Super Model Project

The Super Model Project is the Model Driven Intelligent Control of manufacturing project commenced in October 1999 by STEP Tools, Inc. Its objective was on building a database for the entire information requirement to make a part. General Dynamics Land systems (GDLS), General Motors, Daimler-Chrysler, Gibbs and Associates and Department of Energy were industrial review board as subcontractors[41]. XML has been used as a means in the interfaces link manufacturing strategy, tool path generation and tool selection information to geometry, features and machining steps in the database interfaces. A ST-Plan, first software package for STEP-NC and e-manufacturing, was a STEP-NC enabled CAPP tool which was a CAPP system with machine independent CNC control files from STEP (AP203 or AP204) data utilized open source code library of STEP-NC.

2.4.1.3 STEP Manufacturing Suite (SMS) project

In this project, prototype system designated as STEP-enabled Manufacturing Planning System (SMPS) established, which uses harmonized key elements machining features semantics i.e. combined definition of profile shape and path shape with geometric and tolerance used in Feature Model Editor (FME) and design of process planning that support process plan document generation from ISO10303 AP224. South Carolina Research Authority introduced suit of STEP-Application Protocols with implementation architecture of STEP part production for commercial and defense application.

2.4.1.4 The Rapid Acquisition of Manufactured Parts (RAMP) Project

The Rapid Acquisition of Manufactured Parts (RAMP) Project:-since 1986 addressing standards driven applications for the manufacturing of mechanical and electrical parts and assemblies. Its main achievement is development and implementation of STEP standard ISO 10303 AP224 as a part of the RAMP program. UKRAMP is as UK implementation of RAMP technology. RAMP project suggested lead time reduction of spare part procurement by using APP-224 [42].

2.4.1.5 Intelligent Manufacture on STEP-NC compliant

Engineering and Physical Science Research Council (EPSRC) started since 2004, led by AMST center of Loughborough University. It mainly aimed to extend in process measurement of CNC machine and exploring application of integration of STEP-compliant NC standards between the CNC machine and a Co-ordinate Measuring Machine (CMM). Application of artificial intelligence to CAD/CAM/CNC process with application of agent technology using data mining is as second major theme. The project was supported by a number of industrial partners namely Renishaw, Siemens, LSC Group, Delcam and Rolls Royce [12]. The achievements of this project were STEP enabled process control measurement feedback for machine tools, application of STEP-NC information with intelligent agent technology on CNC controller integration with LOCAM process planner system i.e. CAPP system developed by the LSC Group in the UK [42], Power Mill/ Inspect and Fixture products were developed using STEP compliant knowledge and information models by Delcam and finally the research proved capability achievement for STEP-NC approach effectiveness through Rolls Royce case study parts.

2.4.1.6 STEP-Compliant System Development and Implementations

This review outlines specific areas of STEP-compliant system development and implementation researches related to various CNC manufacturing process. The STEP-compliant research activities mainly focused on machining technology, processes, inspection and related manufacturing resources. Reviews on the functionality and limitation of prototype systems on STEP-compliant principles are also included.

2.4.2 Milling STEP-Compliant Manufacturing

In case of milling technology, two PC-based retrofitting schemes had been performed. The former was an attempt of enhancing free-form surface manufacturing capacity of NC machine to acquire economical benefit [43]. The latter was an integration research allowing graphical simulation and direct machining without G and M code [44]. Both systems are limited to free surface milling and don't support bi-directionality with being specific prototype of CAD/CAM integration to NC execution. These systems had been enriched by the preview of methodologies such as modular conceptual framework of design and implementation of intelligent CNC system, Shop-Floor programming system framework and extended implementation methodology on milling machine controller. Earlier lessons on developing protocols for virtual industrial Enterprises supported primary outlook of STEP-NC compliant manufacturing which had been solely dedicated to milling operations as prescribed by Hardwick [45].

The modular design relied on CORBA facilitator for in internal information exchange was developed by Korean. The tool path generator was presented as a flow chart that checked resource capabilities while enabled in interpreting the STEP-NC code automatically but limited to ISO14649-11. This implementation was then realized in the form of a STEP-NC compliant prototype-milling machine [46]. Even though it had design and complete implementation of Shop-Floor programming system construct of STEP-NC architecture, its feature in AP203 [23] file and generation of ISO 14649 process document was limited to milling features. Therefore; process plan generated in STEP-NC file output of the system was not applicable to other than milling.

Boeing and NIST jointly accomplished illustration of interoperable scenario on utilization of tool centered programming (TCP) on different configuration 5-axis milling machine by AP238 with ISO 14649-11. Hardwick and Loffredo reported this implementation as demonstration of interoperability with single AP238 file interpreted cutter center location for two machines of four CAM vendors and two CNC controls for 5-axis milling machine only. Therefore the research indicated the need of extension study for deployment of feature based implementation method [47-48] such as turn-mill machine .

Newman et al. [49] provided a perspective of how ISO 14649 and ISO10303-238 standards could be used in manufacturing by possible generic frameworks displaying their effect in CAD/CAM systems evolution. An agent-based CAM system capable of generating STEP-NC milling code was used to demonstrate the capability of STEP-NC in manufacturing prismatic parts.

A successful prototype system developed on five-axis milling machine. It has been driven by STEP-NC in XML [50]. Due to the increase in number and importance of STEP-NC prototypes developed, test and validation methods which have specific description of operational scenarios were provided for testing the data and test cases [51].

AB-CAM system representation illustrated the major activities within a STEP compliant structure through IDEF0. It proved capability of interfacing on three operating modules automatic, semi-automatic and manual. Thus providing the flexibility to manufacture parts automatically if all manufacturing data is known to manually generating tool paths when new or specialized NC machining is required. The agents can be programmed to accomplish various planning activities such as selecting machine types, cutting tools and cutting parameters to machine specific geometries or features [52]. Fichtner et al. used suitable manufacturing feature representation for NC planning and manufacturing process and to serve as information carriers. This also created milling machining prototype agent based system for data management and neutral self-learning modules to retrieve planning data and for interpretation of STEP-NC part program. The system based on cooperative agents can monitor information on the shop floor while machining is taking place and represent information from different local knowledge bases [53].

Multi-Agent System for Computer Aided Process Planning (MASCAPP), prototype on milling technology, was developed employing provision of STEP-NC ability to store and utilize high level and detail information from CAD system to intelligent STEP compliant CNC controller. It was an object-oriented process planning system design for prismatic components in a STEP-NC compliant environment. Two test components have been designed, process planned, simulated on the machine controller and finally machined, to demonstrate the capabilities of the system and illustrate the activities required to implement STEP compliant manufacturing. The system also demonstrated the potential of intelligent agents and AI capability in breaking down the process planning into smaller planning problem and the possibility of robustness the process planning. As STEP-NC architecture holding class hierarchies and complex geometry, AI systems served for knowledge base. Among the two types STEP-NC data storage structure namely flat files and databases, XML was suggested since the need for computer power is less than object oriented database system [54].

Advances in AI technology and integration of STEP leads to CAD/CAM/CNC automation which was extended to application of mobile agent on distributed artificial intelligence techniques. A prototype mobile-agent system has been developed using agents to demonstrate the applicability of mobile-agent systems in achieving interoperability within the STEP-NC manufacturing context. It focused on coupling tool information in execution of workingsteps required to manufacture a simple prismatic components. It was demonstrated that the layers of manufacturing information of STEP-NC with AI provided platform capability serving as data libraries for Multi-Agent systems and mobile agent systems since interoperability enabled working with distributed systems [55]. However; the importance of AI application with regard to machining configuration of turn-mill has not been investigated.

Prototype of adaptive global manufacturing system presented applicability of interoperable STEP-NC standard. Application Reference Model (ARM) for STEP-NC has been formalized in ISO 14649 which provided various level information requirements. It supports implementation of process control through CAD/CAPP/CAM/CNC chain with bidirectional information exchange of interoperable STEP-NC process plans. An illustrative system on ISO14649-11 example part using feature based ShopMill for GandM code generation with resource specific implementation had been constructed. An information tree of entities on predefined hierarchy of manufacturing model created STEP-NC structures which was loaded into the adaptive manufacturing system utilized a Multi-Agent System for shop floor control of CMM system [56].

An outline of framework for implementation of STEP-compliant CNC systems on milling machines was presented with representation blocks for manufacturing workstations. An interpretation module, a planning module, a simulation module are incorporated within an open CNC kernel, where an AP238 file is used as input to the machine controller. It was also demonstrated that interpretation of an AP238 file and the major issues in using AP238 for STEP-compliant manufacturing was the potential for an intelligent CNC system with both planning and control abilities for STEP compliant manufacture. The implementation tools and methods for interpreting the AP238 file are outlined to demonstrate the STEP-NC conversion process. It is noteworthy that only the ISO 14649 data elements were actually populated in the native data structures [57].

An intelligent process planning system based on ISO 14649 which was enabled to map STEP ISO 10303 AP224 XML data file. It was utilized without using a complex feature recognition process and produced the corresponding machining operations generate the process plan and corresponding STEP-NC in XML format. This system was equipped with optimized tool selection algorithm based on Fuzzy logic and ruled-based decision-making systems utilized hybrid artificial intelligence and neural network approach. ISO10303-224 format compliant manufacturing features taken as in put and an ISO 14649 compliant XML process plan was generated[58]. However; the system is limited to milling operations.

2.4.3 Turning and Turn-mill STEP Compliant Manufacturing

A comprehensive record presented the progress of complete integration of CAD/CAPP/CAM/CNC on STEP-NC. At the beginning, it was on deployment of STEP-NC for turning application and description of methodology illustrated for implementing a standard CAx system process chain for rotational asymmetric parts based on ISO14649-12 [59]. The achievement issued were focused on intelligent and autonomous controls of NC machine for e-manufacturing, data sharing throughout the product life cycle, adaptability of XML for STEP data and its web application scenario.

STEP-compliant researches were aimed at interoperability and adaptability for customizing manufacturing needs and setting up basis for next generation CNC machine in accordance to volatile global market. A recent proposal on a framework for turning machining using ISO standard 14649 provision of data exchange format come up with prototypes supporting data interoperability between various CAx systems shown in Table 2.5. It can be observed on the reviews that the systems addressed either turning or milling operations. This brings the requirement of current day manufacturing for simultaneous utilization by turn-mill machine. Therefore; extending the above research implementation with regard to this machine is the main objective of this research.

Table 2.5 Reviews on STEP-Compliant Manufacturing for Turning Operations

Author(s)	issue
Xu and Wang, 2004	Developed a STEP-NC Converter and a retrofitted CNC lathe realizing a G-code free machining scenario
Wei et al., 2005	Proposed a framework for a CNC turning system based on STEP-NC with eighteen functional modules, involved in the software-based framework of a STEP-NC control system. As a result, the study provided the high potential for the development of new CNC turning systems
Shin et al., 2007	Presented development of a prototype G2STEP system to convert G-codes to a STEP-NC file
Choi et al., 2006	Introduced the development process for TurnSTEP using structured and object oriented methodology to provide a part program.
Suh et al., 2006	Presents a STEP–CNC system for turning, named TurnSTEP, and demonstrated the potential and power of STEP-NC based CNC systems compared with conventional CNC systems
Heusinger et al., 2006	A prototype methodology using technology based on ISO14649-12 for implementing a standardized CAx process chain for rotational asymmetric parts has been discussed
Yusof, Case et al., 2007	CAPP and CAM systems related to STEP-NC created by other researchers and the development of a STEP-NC compliant CAD /CAPP /CAM are summarized

A primary investigation made on STEP-NC implementation method to combine turning and milling operation for complete machining of asymmetrical components on single turning machine indicated the needless for new STEP schema specific to asymmetrical parts [60]. Since ISO14649-10 is capable of supporting the case, an outline of manufacturing resource model and its importance were presented. This gave the foundation of STEP-NC researches towards turn-mill operations attempted by this thesis.

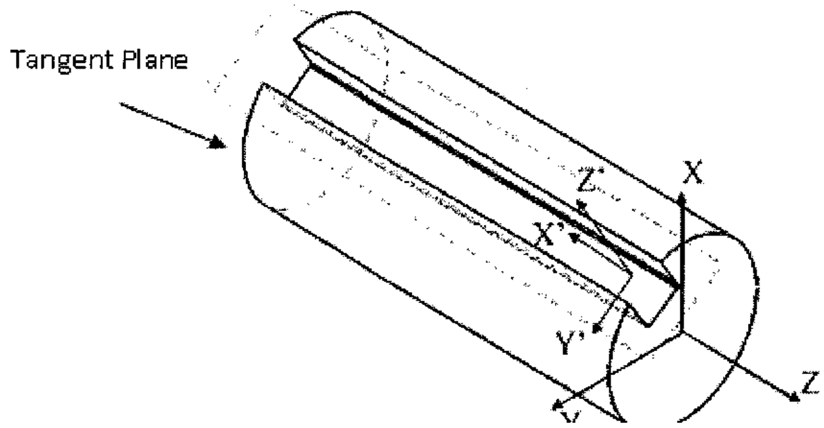


Figure 2.10 Translation and Rotation of the Feature's Co-ordinate System[11]

Figure 2.10 displays the adoption of ISO14649-Part 10 translation and rotation function over feature co-coordinate system regarding C or B-axis features of a cylindrical bases shape. Where X, Y and Z are workpiece coordinate system and X', Y' and Z' are feature co-ordinates system[11]. Recently, STEP-NC implementation on turn-mill operations was investigated for developing STEP-NC compliant CAM system [61]. The investigation used the above method for rotational asymmetric component process planning i.e. translation of feature co-ordinate to workpiece co-ordinate. STEPTurn programming system also has been employing similar approach for developing Shop floor system by text encoding of component with respect to machine tools.

2.5 Previews and Progresses in STEP-Compliant Systems

Current manufacturing system configuration evolved from dedicated transfer lines to flexible manufacturing system (FMS) and manufacturing cell (MC), where CNC machine are the vital component; however the functions of CNC machines are predominantly depends on ISO6938 standard programming which imposed limitation in the flexibility of this system. STEP-NC research activities have attempted to resolve the impediments of CNC by addressing product compatibility/interoperability and adaptability of machine tools through customized product model [59]. ISO10303 and ISO 14649(STEP and STEP-NC) are ISO standards established accounted for interoperable issues of changes in business environment to the extent of globalization. The recent approaches provided platforms for the future of global interoperable manufacturing. That is based on the new standards which are capable of maintaining opportunities of current CNC machines in global market, in spite of the hardware/software obstacles [16]. STEP-NC compliant systems such as the shop-floor Programming system (SFPS).

STEP Turn, G2STEP and G-code free are prototypes used to prescribe achievements and technical progress previews. In addition, research reports about extra functionalities on these demonstrative systems are given on the next section. Some of SFPS and others related works to STEP compliance has been developed by academia all over the world are shown in Table 2.6.

Table 2.6 Some of STEP-Compliant System Prototypes

No.	Systems	Input	Output	Domain
1	SFPS (Milling)[62]	STEP AP203 and AP214	Part program physical file (text)	Prismatic
2	STEPTurn [60]	STEP AP203	Part program physical file (text)	Rotational
3	TurnSTEP [63-64]	STEP AP	ISO 14649 physical file and extensible markup language	Rotational
4	G-Code Free for lathe[65]	STEP AP 203	Native CNC language program	Rotational
5	G2STEP (2-axis turning machining)[66]	G-codes	STEP-NC part program	Rotational

2.5.1 Shop-Floor Programming System (SFPS)

It is South Korean prototype which has been considered as fully compliant with STEP-NC and comprehensive in fulfilling user's requirement. This computer assisted part programming tool proposed for prismatic components and interfaced with new CNC controller i.e. STEP-CNC (STEP compliant CNC) [62]. It has been also the first patented STEP prototype in USA as show in Figure 2.11 generated ISO 14649 part program based on the ISO Parts 10, 11,111 and ISO10303 Parts 21, 22, 23, 42,203 and 224. Suh et al. provided a useful definition of architecture and functionality composed of five modules which govern the part program generation and its accomplishment given below.

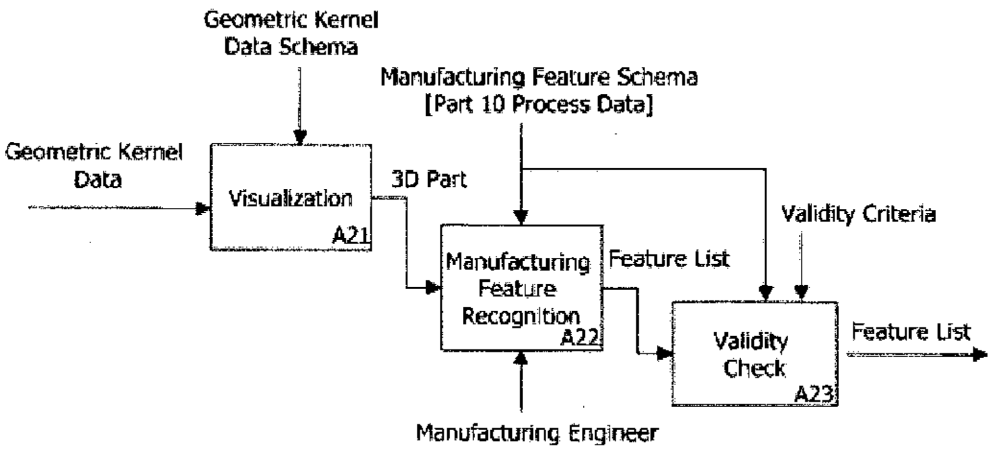


Figure 2.11 Machining Feature Recognition for SFPS [62]

1) C++ classes of interpreter for ISO 14649 and ISO10303 physical file instanced in Part-21 schema representation.
2) Feature recognition on the provision of ISO 14649 definitions using geometric kernel inputs.
3) Process planner composed of activities such as
    i) Assigning machining operation to each machining features
    ii) Setting up process data for activity
    iii) Wokingsteps set up for feature and operation tuples
    iv) Classify the workingsteps in to set ups and Sequencing the workingsteps
4) ISO 14649 part program generator developed using entity instances and
5) ISO 14649 code viewer a GUI for visualization and identification of workingsteps.

SFPS has been seen as successful on its primary accomplishment of generating a part design program which is in either AP 203 or AP 214 file format and basic platform improvement made on milling operations. Its architecture was derived from systematic analyses aiming to fully support the STEP-NC interfacing and exploiting its practical gains. The IDEF modeling and implementation methodology were given in detail. Based on the architecture, a prototype system called PosSFP was developed and integrated with Korea STEPNC for milling operations with a possible provision appropriate for turning operations Figure. 2.12. [46, 62, 67].

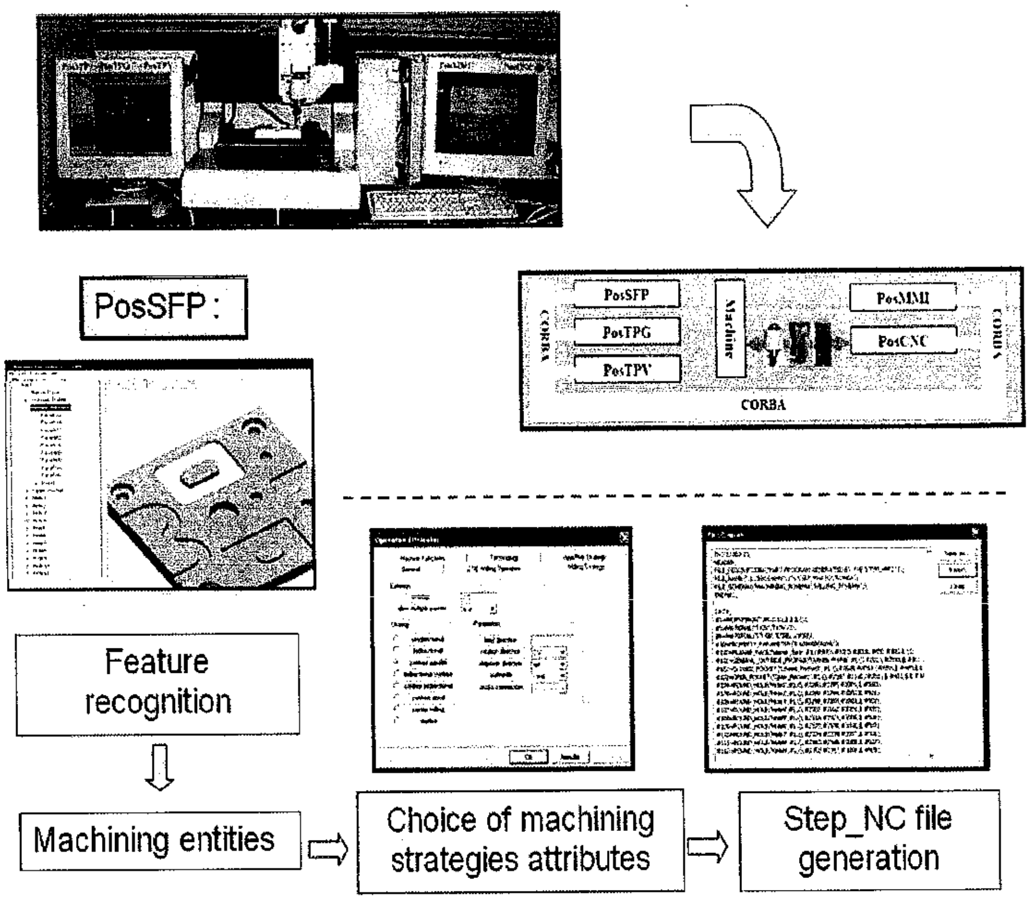


Figure 2.12 Modular Representation of the Korean Prototype of STEP_NC Numerical Chain

2.5.2 STEPTurn

Institute for Control Engineering of Machine Tools and Manufacturing Units at the University of Stuttgart (ISW), Germany adopted the STEP and STEP-NC standards for turned parts and have been successful on developing STEPTurn [60, 68].

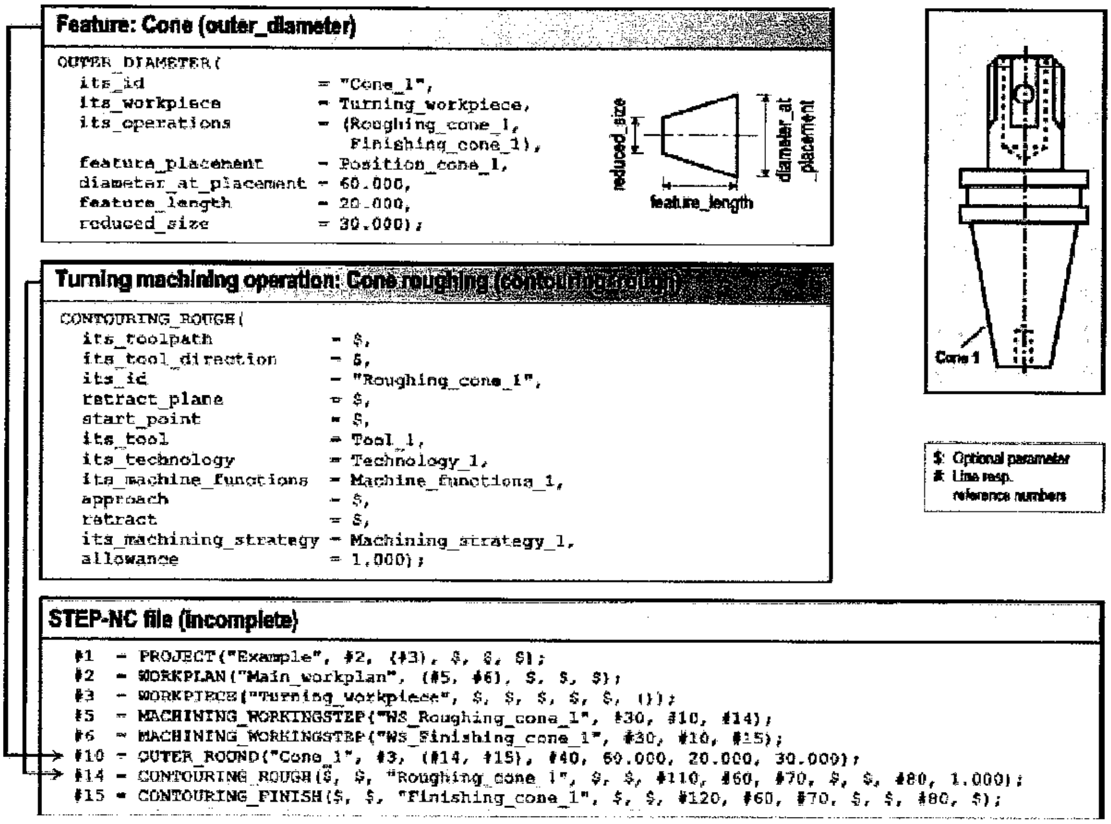


Figure 2.13 Workpiece and STEP-NC File Representation[60]

The detail contents of technology-oriented process model for turning and importance of feature based process chain devised in STEP-NC implementation has been illustrated Figure 2.13 based on STEP-NC workpiece representation given in Figure 2.12. STEPTurn constituted primarily a CAPP system capable integrating CAD and CAM system by reading geometry data from a STEP AP-203 Part 21 file, and performing process-planning tasks such as feature recognition preceded by Workingstep sequencing a STEP-NC physical file generation [60].

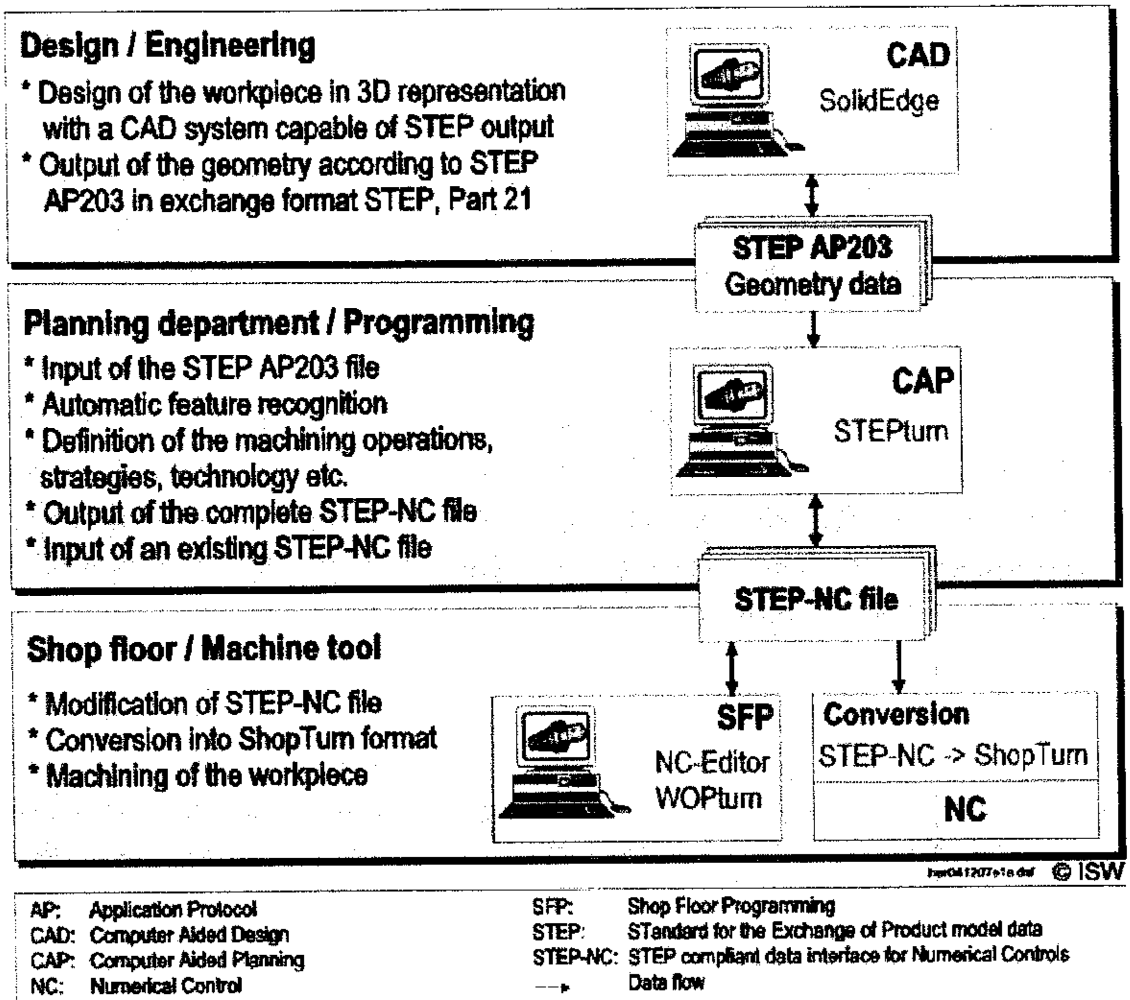


Figure 2.14 Implemented Process Chain For Turning[60]

ShopTurn data format enabled data file conversion of Siemens to the internal STEPNC data representation which served as input format generated tool paths on NC Siemen 840 of the Boehringer machine tool. The respective conversion tool consists of the soft keys dialogue of machine interface representing the control system. Finally a suggestion drawn for extension of STEPTurn system for mill-turn components representation and with XML schemas based on identification of the requirement web-base applications, since it was limited to machining cylindrical base components and utilization ISO14649-12 of turning machining standard[60].

2.5.3 TurnSTEP

TurnSTEP is third generation type capable of intelligent and autonomous functions through non-linear process planning. Choi and et al. presented the architecture, development process and data management capability of TurnSTEP. TurnSTEP mentioned as a primary STEP-compliant system for turning machining, claimed as fully compliant to ISO 14649 suit and supported e-manufacturing using XML schemas. It described as three sub-systems namely; i) CGS (Code Generating System) to generate neutral independent STEP-NC code based on ISO 14649, ii) CES (Code Editing System), to edit or customize machine tool data to be used for execution of STEP-NC code and iii) ACS (Autonomous Control System) as shown in Figure 2.15.

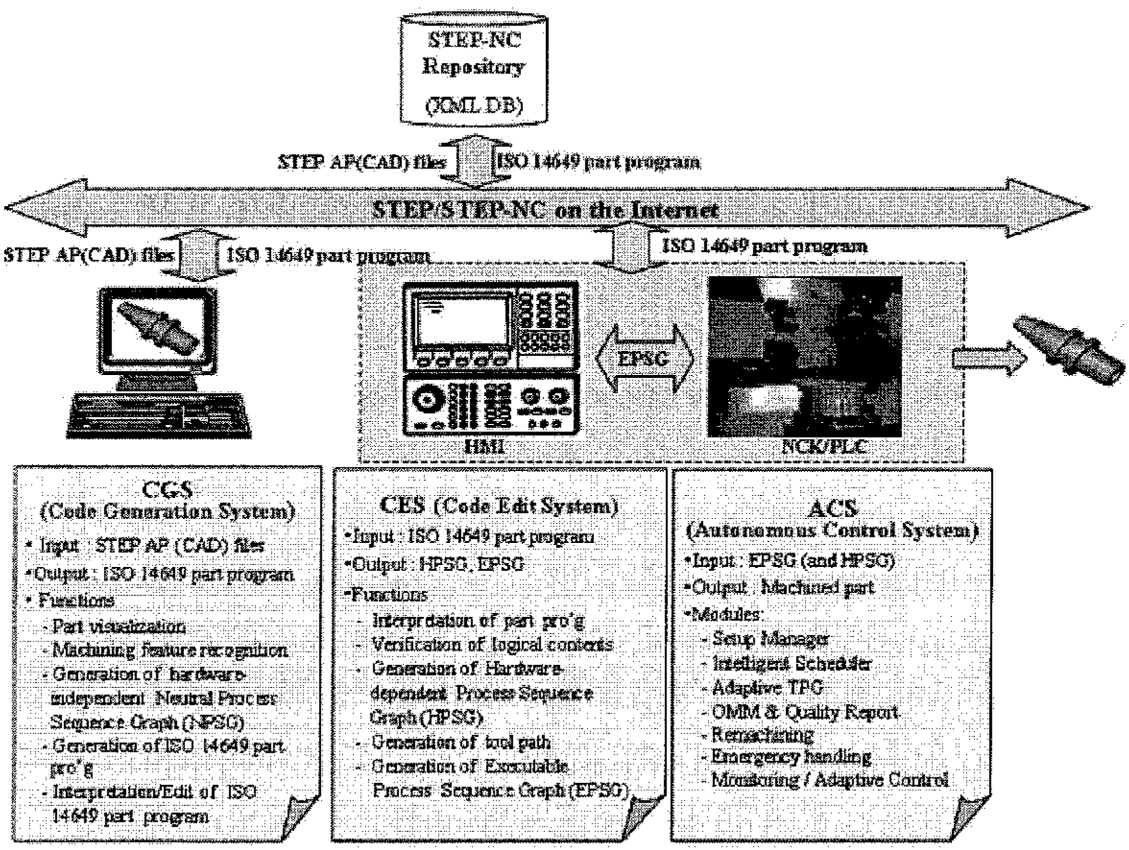


Figure 2.15 Three Subsystems of The TurnSTEP [63]

TurnSTEP Workingstep supported propositions of optimization for non-linear process planning and demonstrated by complete machining of turned parts on

MCCM. Since its design philosophy has ascertained provision of distributed architecture for e-manufacturing with a physical file and XML translation, full utilization of STEP-NC information for execution of NC machines, support automated and interactive generation of process plan, feature recognition, generation and alternative process sequences cutting conditions [63, 69].

TurnSTEP development architecture considered seamless and intelligent CAD-CAM-CNC chain on e-manufacturing paradigm. TurnSTEP system has been demonstrated capability of generation and mapping of machine independent format of process plan from AP203 geometric format by using a simple example component in ISO 14649 Part 12. The prototype system loads an AP 203 file from a CAD system via the internet and visualizes the part geometry. The blank part material is then defined, followed by determination of the number of set-ups and finally it generates a virtual machining simulation and machined part [64].

2.5.4 G2STEP

G2STEP objective was to derive comprehensive information of STEP-NC from low level G-code information. The primary step was to identify available and required information which was followed by constructing algorithms that enabled deriving STEP-NC information. A demonstration had been developed for turning application and the system contributed for time and cost reduction since it was an automated conversion of G-code in to STEP-NC. The developed algorithms were implemented and tested on G-code part programs used in actual practice. The system has been considered as indispensable tool for implementation of a STEP-NC application and repository but its application has met limitation through legacy code induced by vendors.

This prototype has been developed based on ISO 14649 data model. It required additional real machining data supplement from skilled operator and only used for turning operations. The part program generation functions steps summarized:

- on pre-processing function which is mainly for available data structure and identification, then followed by
- machine tool identification and defining with ISO 14649 Part 111
- feature recognition function and
- Operation attributes identification and elaboration i.e. technology, machining operation, machining strategy which are the main contents constructing workingsteps included in a unit workplan entity constituting a unit project first interpreted entity in the STEP-NC data model. This information is instanced in the STEP-NC schema and is printed in a physical file format according to the ISO 10303 Part 21 rule [70].
- Finally part verification was constructed based on visualization of feature profile and a wokingstep editor used for accommodation of any correction measures.

G2STEP developed for 2-axis CNC Turning using the C++ language and worked on a Windows platform used a geometric modeling kernel and OpenGL for the GUI [66]. Further application development for milling, multi-axis and complex machining with algorithm extension to enhance robustness mentioned as future issue intended to be addressed with regard to G2STEP system.

2.6 Machine Tool Resource Modeling in Support of STEP-NC Manufacturing

So far the reviews emphasis on machine independent manufacturing data representation and data model development using STEP and STEP-NC. These data models are suitable for data exchange and sharing, however; there has been quite significant requirement for machine tool capacity and component data representation for mapping STEP-NC data in a specific facility or manufacturing environment. This leads to an inevitable requirement for machine tool resource representation regarding machine specific process planning in STEP-compliant. Since the enriched standards of STEP and STEP-NC format are best vehicle for neutral file format exchange in machine tool resource functionality. This scenario has been covered by unified manufacturing resource model (UMRM) for CNC machine tool and machine tool data model compliant to STEP known as STEP-NCMtDm [71].

2.6.1 UMRM

UMRM data model various components of resources are specified along with their use to decision support system in computer integrated manufacturing (CIM). It is mainly a representation of machine tool functionality and consequential process capability in object-oriented approach. Formerly, machine information models representing CNC lacks comprehensive methodology to derive unified capability and they are basically standards established for exchange of geometrical and functional information indicated in Table.2.7. Those are specific to particular technology but not interchangeable.

Table 2.7 Established International Standards for Exchanging Geometrical and Functionality Information[71]

		CNC machining system resources				
		Machine tools	Cutting tools	Fixtures	Material handling devices	controllers
Resource specific viewpoints	Geometric information	STEP, IGES STL,VDA	STEP, IGES STL,VDA	STEP, IGES STL,VDA	STEP, IGES STL,VDA	-
	Functionality information	ASME B5.59-2	STEP-NC ISO 13399	-	-	ISO6983 STEP-NC

Currently description of machine tool cutting process and machine tool resource model are under development by NIST[71]. The models are basically intended to clarify constraints of Virtual manufacturing system (VMS) and to manage resources of FMS. Since UMRM presents diverse spectrum of machine tool configurations, functional aspect of machine tool not limited to classified machining technology or application group and suitable for multi-process machine tool configuration. Machine tool considered as assembly of various mechanical machine elements and structures such as tool and workpiece holder assembly, turret holder which are suitable to develop customized representation.

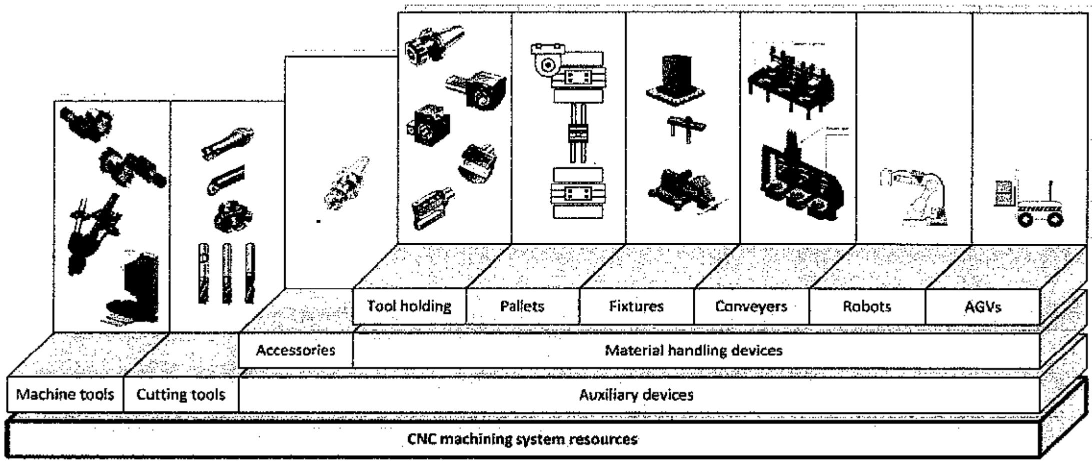


Figure 2.16 Resource Domains of CNC Machining [6]

Manufacturing resource information models used for integrated manufacturing provided only object-oriented representation of machine tools for shop floor execution system. They are limited to the capability of the machine but can't avail how to derive that capability associated with its elements as shown in Figure 2.16. Therefore; process capability representation the main objective for machining system resource model as a potential area for future research.

A Proposal of a flexible modeling approach representing elements of CNC machining in STEP compliant framework has been done against reviews of existing standards for classification of the elements and verification of parent class "mechanical_machine_element" as unified means for constructing UMRM. It mainly aimed at machine specific process-planning stage and addressing the shortcomings in using turn-mill machines in the manufacturing industry without a kinematics model of the machine under consideration [71].

2.6.2 STEP-NC Compliant Machine Tool Data Model

Machine tool model is a conceptual representation of the real machine tool and a provision for logical framework representing its functionality in manufacturing system. A novel STEP-NC compliant machine tool data model known as STEP-NCMtDm has been developed to realize STEP-NC based process planning and manufacturing as a comprehensive machine tool database. It addresses two aspects of manufacturing i.e. machine tool and tool assembly. The goals of STEP-NCMtDm are to meet the data requirements for implementing STEP-NC data model in process planning and scheduling, and to support the distributed manufacturing. Functionally, it provided capability and mechanism of addressing the central issue of STEP-NC implementation i.e. "How to do" information for CNC with "What to do" information of STEP-NC program as shown in Figure 2.17.

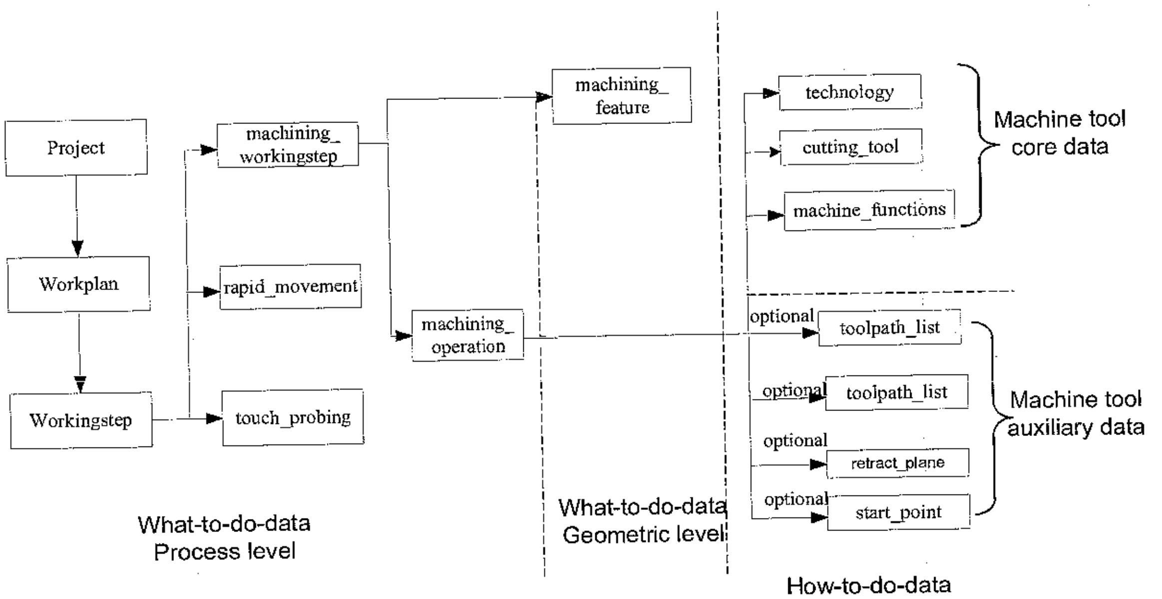


Figure 2.17 What-to-do and How-to-do Data in STEP-NC [7]

It models various machine tool data i.e. machine tool general information, components information, performance data, machining capability and cost information. These data meet the requirements of STEP-NC compliant process planning and manufacturing activities. A comprehensive manufacturing resource data model can be achieved when STEP-NCMtDm coupled with cutting tool data models in STEP-NC standards.

EXPRESS modeling language used to construct an object-oriented data structure which has been also converted to XML schema in the demonstration. It also showed that clear text data format (i.e. STEP Part 21 file) or an XML document representing machine tool data. Thus, it was confirmed that STEP-NCMtDm implementation is possible in computer integrated and web-based manufacturing environment. Machine tool data are classified as either 'Static data' or 'Dynamic data'. This classification reflects the nature of different machine tool data, and their different acquisition and updating methods. The former is more related to vendor capacity and specification where as the latter is suitable for adaptability by capturing shop-floor environment ever changing data.

EXPRESS language is used for constructing the data model, and provides a web-based data model supporting distributed manufacturing scenarios using corresponding extensible markup language (XML) schema. EMCO Concept milling 105 milling machine was used to evaluate the proposed data model. It demonstrated that STEP-NCMtDm can provide sufficient information for STEP-NC programming [7]. STEP-NCMtDm application was limited to turning and milling machines only.

2.7 Review Discussion

According to the reviews made STEP-NC implementations, all researches were mostly focused on turning or milling operations independently, other than the proposals made by Yusir and Russo [16]. Whereas the popularity and the importance of turn-mill machines in shop floor prevails the limitation of G and M code as significant setback for efficient utilization of machines capacity and part programming difficulty.

As explained in the literature reviews the demonstration system of turning are STEPTurn, TurnSTEP and G2STEP. These are specific domain limited to cases of turning and drilling operations. A clear cut coverage regarding the systems extendibility to milling operation not yet presented other than the system's ability addressing non-linear process planning. Specifically, TurnSTEP could not generate a process plan for thread features automatically. The systems are demonstrated on case study bases having an output of data file in text or XML format. So far the systems were targeting on addressing inspection, intelligent and autonomous process planning as a future extension.

The literature's covered exhibited STEP data model development implementation towards manufacturing resources functionality and specification which are also. This is mainly important for establishing a means to convert generative process planning in STEP-NC to a native STEP-NC which would be dedicated to a particular capacity. However; so far the implementation performed are towards displaying its effect on representing the machine kinematics and capacity, and also process variation investigation.

The reviews made on projects of STEP-NC and researches regarding STEP-NC exhibited to be limited to single domain implementation of ISO 14649 data model on either milling or turning operations. Therefore; the need in addressing turn-mill machining various configurations towards part programming difficulty and inefficient capacity utilization should be supported by STEP implementation. This research to develop combined deployment of enumerations, stating the feature set requirements of turning and milling operation designated as STEP AP224 and ISO 14649 data model for turn-mill operations. It sets process plan data model generation for turn-mill machining in a dual domain approach. The functional architecture can be deduced from previously proposed universal manufacturing platform on CNC machining [63]. This also gives an opportunity to utilize machine tool data models in shop floor resource representation and effective utilization by interlinking with Native STEP-NC process data generation which is also to be extended for turn-mill centers. Finally it provides a STEP-NC interface suitable for information representation and exchange through the different level of turn-mill manufacturing environment.

2.8 Summary

The chapter discussed literature reviews on STEP-NC compliant research such as intelligent manufacturing system (IMS), intelligent STEP-NC compliant machining and inspection. Industries and academia involved in the projects with their contribution are included. The overall technological progress, achievement and methodology development towards STEP implementation has been discussed. The second part of the chapter focused on evaluation and discussion of prototypes which have been developed so far. The prototypes covered are mainly related to milling and turning technology. At last, the review includes manufacturing resource modeling in STEP and STEP compliant machine tool data model and evaluated them towards Native STEP-NC process plan generation. Published information and documentations on prototypes are the background resources for preparing the above literature review rather than interactive experience with the proposed systems. The next chapter covered discussion on methodology and design points of STEP compliant system framework in reference to ISO documentation and turn-mill operations.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The problem statement and objectives of the research reported in this thesis have been outlined in Chapter 1. The states of the art and researches in the area of STEP-NC compliant systems and STEP implementation were reviewed in Chapter 2 together with some of the approaches adopted in this research. In this chapter, the methodology used to develop an appropriate STEP-NC interface with ISO 14649 based process plan data model for turn-mill manufacturing environment is presented.

After examining the various level of ISO 14649 specifications and implementation on turning and milling operations, a design on turn-mill STEP implementation and the programming system development have been seen as a requirement to be covered. In this chapter, the algorithm representing design and interlink of the programming system components has been presented. Serialization function and EXPRESS language representation of the system development has been shown. They are used to establish pseudo code representing process plan generation.

3.2 Design of STEP Implementation Model

The design and development of STEP implementation system has two broad categories. These are data model representation, EXPRESS language and dynamic data link (DDL) programming construction. The ISO 14649 data model representation has been reviewed in the literature survey and its adoption for turn-mill operation will be covered on chapter 5 and 6. The EXPRESS language schema construction with object oriented dynamic data link development algorithm is covered in the following sections.

3.2.1 Data Model Representation

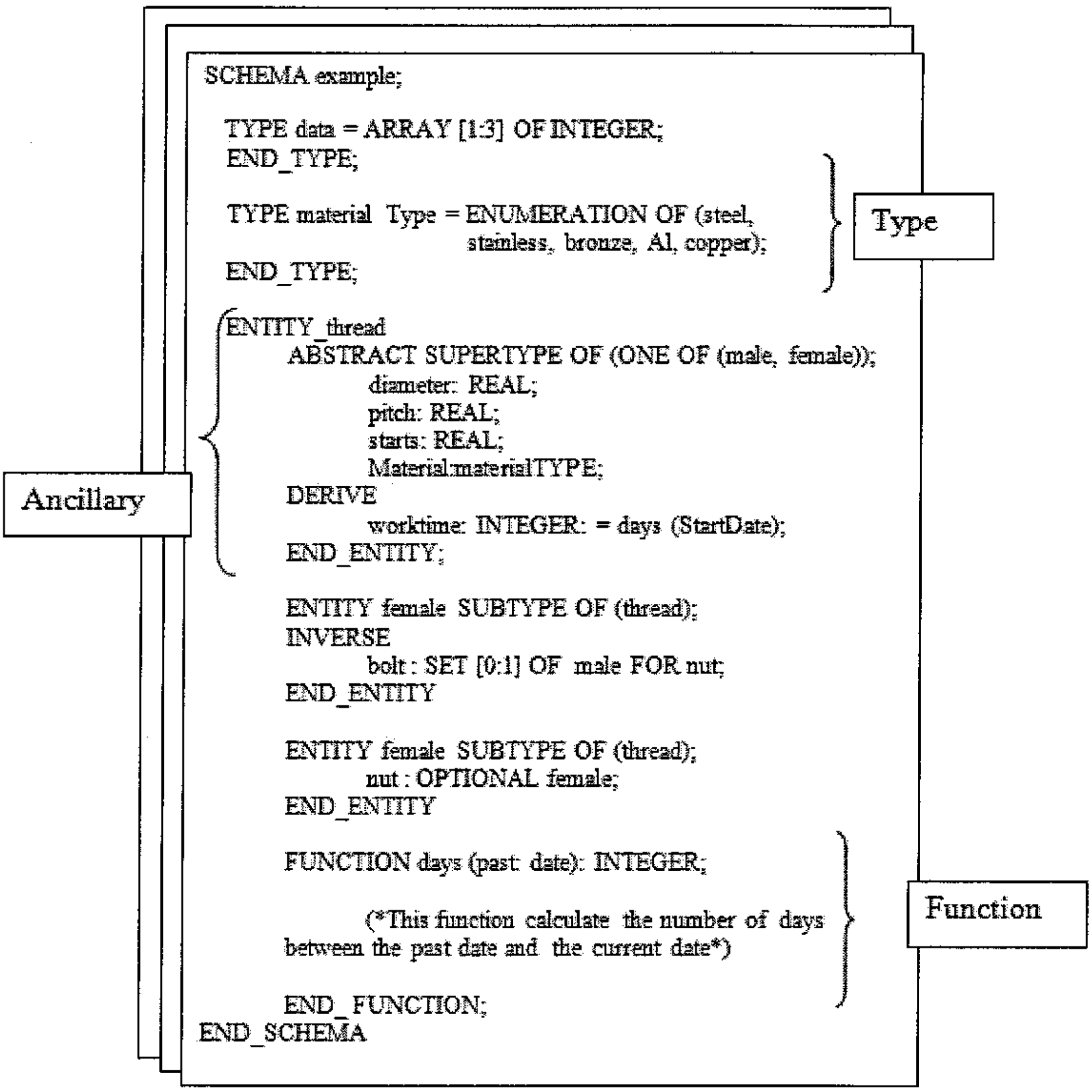


Figure 3.1 An Example of EXPRESS Schema

The system used EXPRESS which is generic modeling language. It is used in engineering data exchange standards; it combines modeling data object paradigms by declaration of entity attribute relationship. It defines information models as schemas and each schema contains the means of declarations and serves as scooping mechanisms to divide information models. They are entities, ancillary types, functions and rule of definitions shown in Figure3.1. This representation on information in the data model provides one definition of the manufacturing data common to many applications [19] as illustrated in Figure 3.1.

3.2.2 Product Modeling Using STEP

A product model is that describes the product of a process, e.g. its type, structure, properties and relationship among its components. It is devised to provide product information on wider level such as global and local supporting various manufacturing activities. At the local level feature-based modeling is commonly used on depicting geometric, tolerance and surface finish by predefined features sets. Every feature associated with local information concerning specific manufacturing activities. P .Gu and Kam Chan described detail development of a STEP-based generic product modeling system [72].

Products modeling on STEP and UML representation i.e. considered as major achievement of recent research direction on object-oriented product modeling. It combines various modeling methodologies; digitalize the product data as well and define structure that can easily be utilized and modified [73] .

STEP defines EXPRESS as Part-11, formal modeling language, to support product data representation with standard. Since it is a data description language (DDL), formulate product data structure with TYPE, ENTITY, and SCHEMA, CONSTANT, RULE, and also support utilization of FUNCTIONs, PROCEDURE and constraints. In addition it has graphical representation EXPRESS-G for complex modeling tasks, therefore: it is suitable for representation of Product information modeling as shown in Figure 3.2.

The mode of geometry and topology are represented with respective entities. They are used for interface specification, without supplying entity statement in topology mode repeatedly, therefore; logical layer of STEP define interface-specification. They can provide resource sharing and marked mechanism on mode variation. Outer frame that describes product data model in EXPRESS language (main function in C language) logical autonomous and complete perception form the product model in objective reality represented as SCHEMA like design of product information in Part-21 [74] .

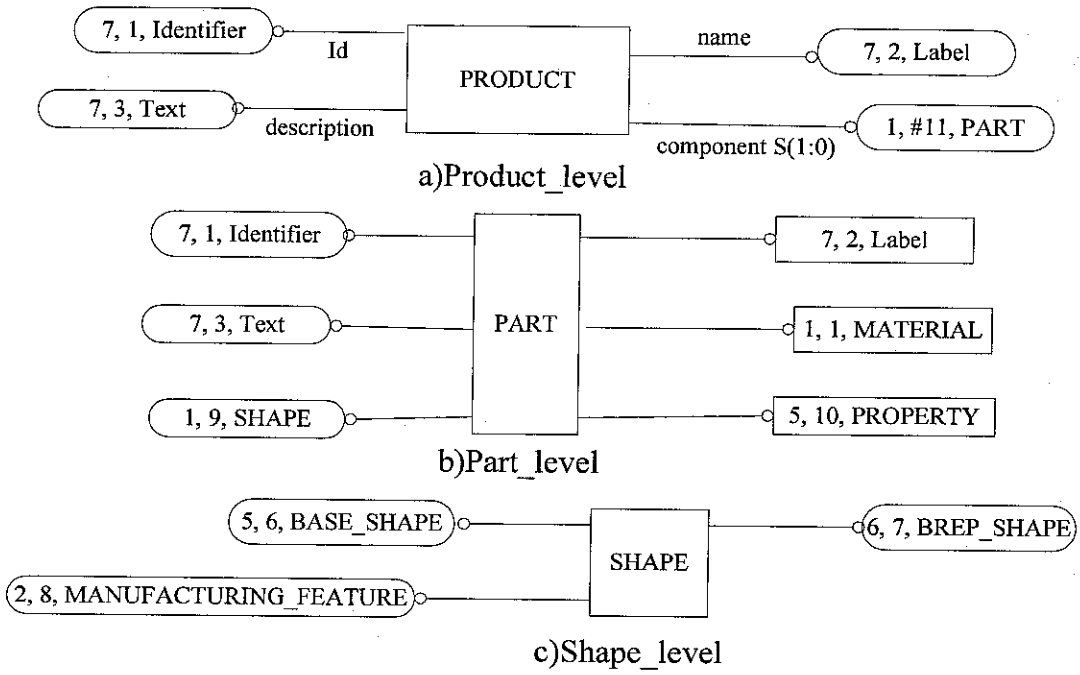


Figure 3.2 Product and Part level Description of EXPRESS-G Representation

Modeling based on APs and on integrated resources are the two approach of STEP based product modeling implementation. The former one is used by direct utilization of a well defined standardized model organized on a particular information domain such as AP 203 AP214 etc., whereas the latter is methodology on a functional combination of different modeling methods which includes geometric data, feature information and knowledge base such as information model of mechanical product description and assembly by Zha and Du [75] and proposed system DPIIM (Die and Product Integrated Information Model) by Tang et al. [76] such as given Figure 3.3.

STEP based product model is more informative since it able to model both geometric and manufacturing data. In addition to provision of neutral data exchange facility, it renders standard, inclusive, extensible and adaptable modeling environment for various engineering application supporting data exchange and sharing.

STEP information model has three layers architecture consisting of the logical layer, application layer and physical layer as shown in Figure3.3. The principal product representation of entities for all phase of product life cycle defined as logical layer. At the application layer, a number of topical models specific to individual application are developed. The physical layer provided methods including STEP format, file exchange and data base sharing etc. There are two commonly accepted product modeling approaches used in CAD/CAM: Geometric modeling the level of information is extremely low .It does not have enough information of tolerances, surface finish and material used. Feature modeling is used to depict information such as geometric shape, tolerance and surface finish through a set of predefined features. DPIIM is STEP methodology implementation for modeling of concurrent stamped part and die which was capable of capturing required product information. It provides complete, confirmable, neutral definition about the product object and used resource of STEP and six EXPRESS defined schemas at the logical layer [76].

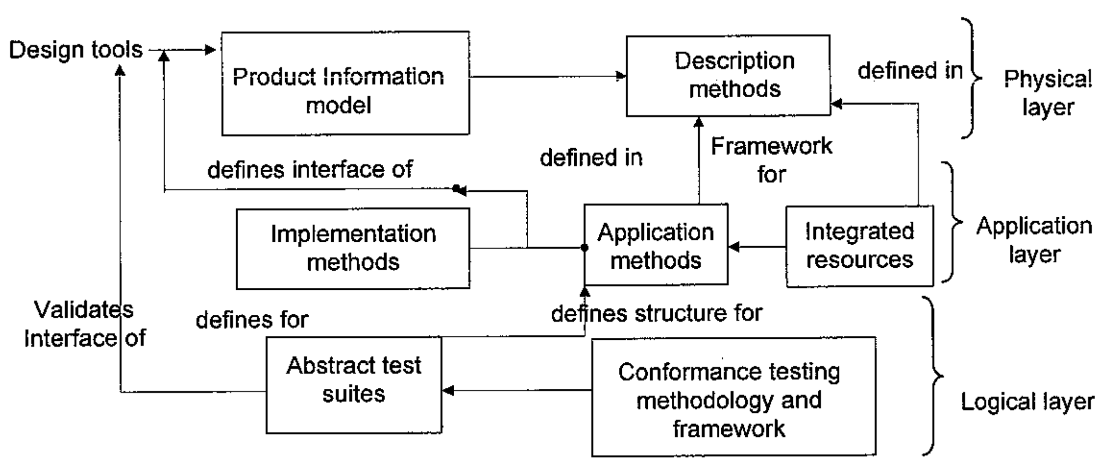


Figure 3.3 Three Conceptual Layer of STEP

STEP uses the EXPRESS language as a tool to represent product data in object-oriented and integrated environment. The syntax and related information of EXPRESS are described in ISO 10303-11. EXPRESS is an object-oriented data descriptive language which classifies and constructs product data in terms of entities. EXPRESS enables precision and consistency of product data representation and facilitates implementation. Each element of the product data has an EXPRESS representation format which describes the parameters associated in the definition of that element. For example, in the part shape representation model, base shape can be designed in EXPRESS format as it has been shown on Figure3.2c.

3.2.3 Product Data Exchange in STEP

Since the emergence of product data information modeling evolution from proprietary IGES/PDES to current standard product data STEP, served as the neutral format of data exchange system for modern computing environment. It is commonly understood as the exchange of neutral format data files between computer systems. It has a sending system that translates data from its internal format and encodes it into an established neutral format. This file is then transferred to the receiving system where the data is translated into the internal format of the receiving system [77].

Data exchange implementation requirements are neutral data file generator (pre-processor), transporting or linking mechanisms, neutral data files converter (Post processor). Data translation and data sharing are the two distinct approaches of data exchange performed by STEP specifically in STEP based product data exchange systems.

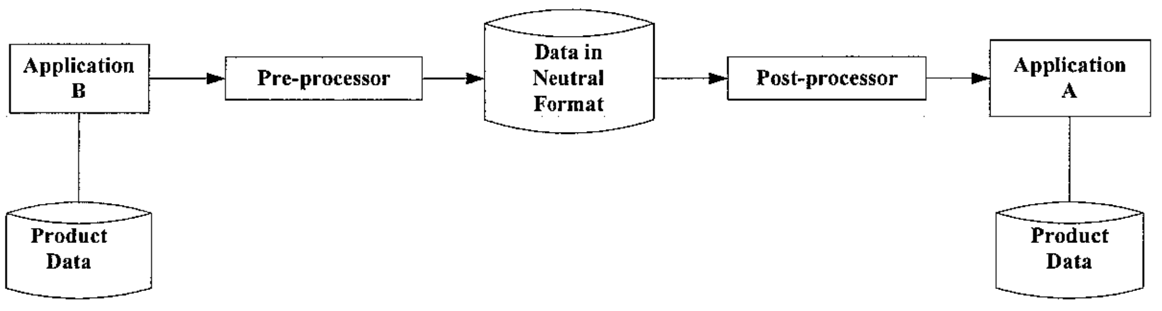


Figure 3.4 Data Translation

Data translation is the case where the data exchange is between two systems; local input/output data of an application is interpreted into a neutral format via a pre-processor and transformed for reuse by another application via a corresponding post-processor as shown in Figure 3.4. Data sharing is allowing various applications to access a unit neutral data file via a data access interface and to derive corresponding local data bases Figure 3.5 [35, 77-78].

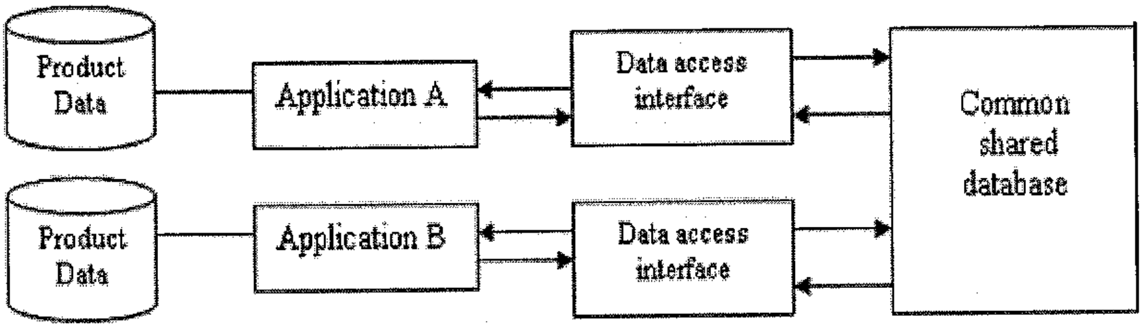


Figure 3.5 Data Sharing

ISO 10303 physical file format allows STEP to support data exchange. Each ISO 10303 application protocol provides explicit standardized data specification model for an application context. The scope and inheritance relationship of data exchange documents are delivered by a model which is provided by each ISO 10303 application protocol i.e. a model which serves as an explicit standardized data specification of application context. It is used, along with an encoding algorithm, to produce ISO 10303 physical files that contain both the data and its associated context, thus enabling effective and flexible communication between computing systems[78].

3.3 STEP-NC System Construction

Figure 1.1 flow chart includes requirement of the system which are given by EXPRESS data model of ISO 14649, STEP Product model and STEP manufacturing model. This has been transformed into an EXPRESS language representation which is bind by visual basic dot net. STEP-NC compliant process planning is organized by descriptions of successive tasks of features and corresponding operations. Product model supplement feature identification. This followed by operation requirement to produce the feature. It constitutes the manufacturing model of the system. The overall process is accomplished under a workngsteps. It encapsulates appropriate cutting tools and technologies linked to the feature.

The object-oriented STEP Data Access Interface (SDAI) implementation has supported to generate a native process plan and facilitate the access for editing too.

Serialization and De-Serialization functions are important in conversion of an object into and from a sequence of bytes for either storage or sharing to other systems (location) [93]. The X-path function also used in accessing the process plan data to configure or manage STEP-NC file as required. The approach used the object-oriented language, in this case Visual Basic dot Net, strength such as types, inheritance and polymorphism in manipulating STEP-NC data.

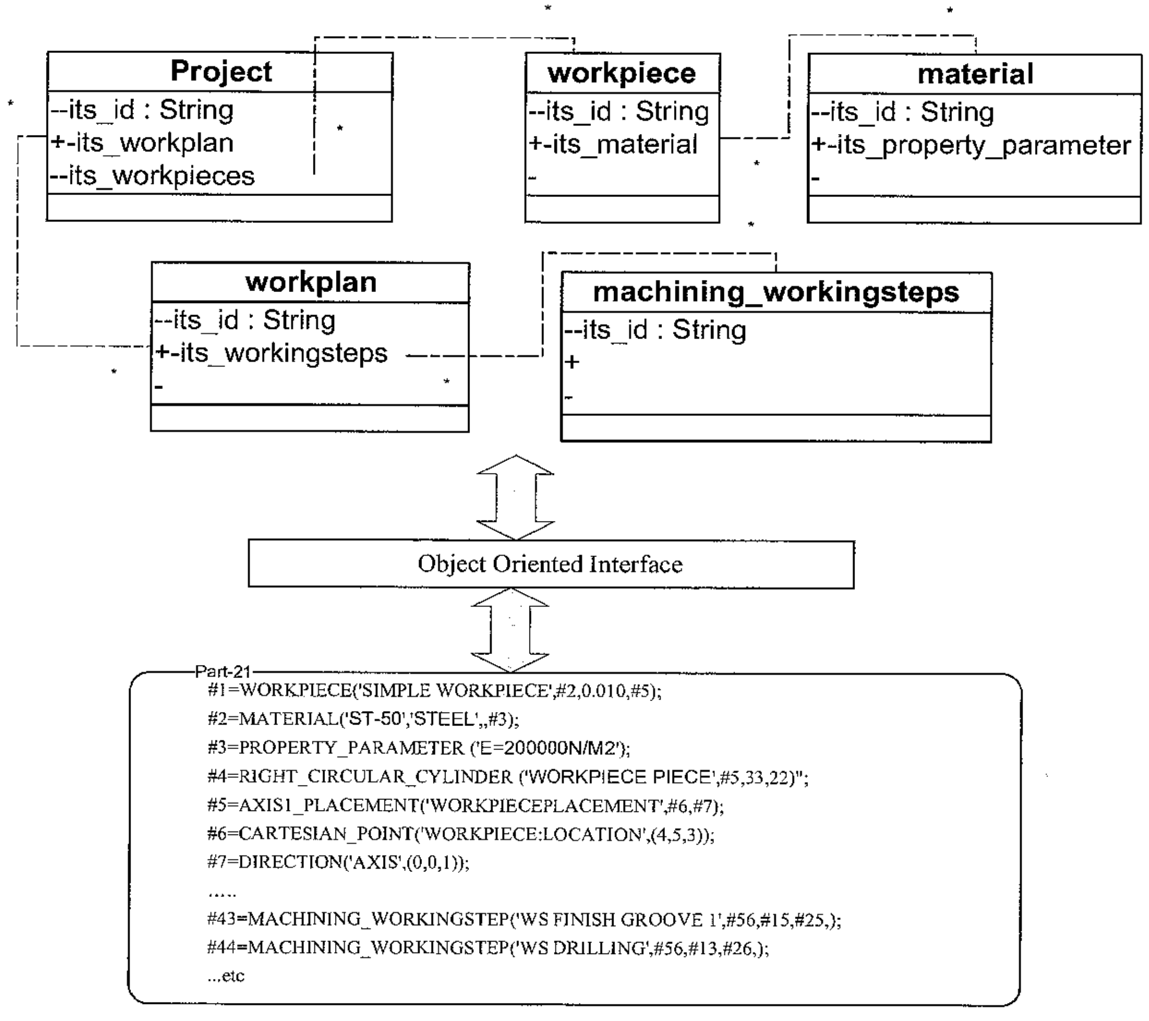


Figure 3.6 Object-Oriented Encapsulation of Manufacturing Information [25]

3.3.2 IMPLEMENTATIONS SYSTEM DEVELOPMENT

Implementation algorithm of the system is represented in the Figure 3.6 and Figure 3.7. Figure 3.6 shows how Super_class of the project is interlinked with its sub-class which allows the functions of the system to refer required information for generating the process plan file. In the Figure 3.7 shows EXPRESS representation of the Main_wokplan super calss and its base classes that allows generation of the process plan cycle.

```
Imports System.Xml.Serialization
Public Class processplan
  Inherits SerializableData
  'Members
  <XmlIgnore()> Public Items As New ArrayList

  'Add new Main_workplan
  Public Function AddMain_workplan() As Main_workplan

    'Declare its members
    Dim newMain_workplan As New Main_workplan

    Items.Add(newMain_workplan)

    'Return
    Return newMain_workplan

  End Function
```

Serialization function for workplan files generation

```
Public Class Main_workplan
  Inherits SerializableData
  Public id As String

  Public its_setup As setup
  Public machining_workingstep As New machining_workingsteps


End Class
```

Super class linking machining_workingstep as sub-class

```
Public Class machining_workingsteps

  Public its_tolerance As New length_measure
  Public its_id As String

  Public its_feature As New Abstractmachining_feature
  Public its_operation As New AbstractMachining_operation

  Public its_effect_name As New its_effect
End Class

Public Class Abstractmachining_feature
  Inherits SerializableData
  'to be checked
  Public milling_feature As New Abstractmilling_feature
  Public turning_feature As New Abstractturning_feature
  Public depth As New elementary_surface
  Public thread As New Abstractthread
End Class
Public Class AbstractOperation
  Public its_toolpath As New toolpath_list
  Public its_tool_direction As New tool_direction
  Public machining_operation As New AbstractMachining_operation
  Public rapid_movement As New Rapid_movement
End Class
```

Sub_classes of machining_workingsteps

Abstractmaching_feature
AbstractMachining_operation

Figure 3.7 Pesdo code in EXPRESS of Serialization

It also gives how functions such as Serialization, De-serialization and XPath (stands for XML document and related functions) are imported to the system development. Serialization function shown as defined on the Super-class which allows interlinking every component of manufacturing requirement information from the sub-classes. This has been accomplished by the hierarchy given in the algorithm.

3.4 Summary

In this chapter the methodology used to achieve the objectives of this research was presented. Specifically an object-oriented STEP Data Access Interface (SDAI) implementation has been proposed. Accordingly, the algorithm of the class hierarchy and the function from Visual Basic dot Net binder has been given. In the algorithm Serialization function is selected as a representative to show how the process plan file generated. Whereas De-Serialization and XPath function for editing and accessing the process plan document respectively follow a similar trend. The next chapter covered design of STEP compliant system framework in reference to ISO documentation and turn-mill operations.

CHAPTER 4

STEP-NC COMPLAINT SYSTEM FRAMEWORK

4.1 Introduction

It has been mentioned in the previous literature survey that the main concern of a STEP-NC requirements has been deployed in a data model based on STEP which can be used for a particular type of machine tool controller towards demonstration of data portability and interoperability. The design and framework development with regard to the context of turn-mill machining environment aimed to establish computer aided process plan (CAPP) integrating a design and manufacturing modules based on STEP. Mainly generic STEP-NC data model which respond to "What to do "requirement in place of method level "How to do" former representation of process planning methodology. This research objective is basically intended to suitable manufacturing information portability and standard data specification related to turn-mill machining operations and machine tool specifications.

In design and framework development of a STEP-complaint system, the primary step has been investigating the information requirement and specification of the manufacturing environment context. This chapter identifies and describes the design and framework of STEP-compliant CAPP/CAM system on the context of turn-mill operations, referring to ISO 14649 Part 1, Part 10, Part 11, Part 12, Part 111 and Part 121. It has been seen in the literature review that specification of process data requirements' of Numerical control (NC) programming with regard to machining technologies has been covered by these ISO documents. The outline framework on this chapter includes:

I. Base shape and size of original part selection i.e. Scope specification

II. What to machine i.e. feature addition or subtraction according to design, position, orientation and other attributes such as surface finish, tolerance on the bases of Part 224 description

III. How to represent required activities

IV. How to machine and

V. How to represent output of the system and construct implementation system

In response to the above requirements, the chapter begins with design and property of tools for STEP compliant system for turn-mill operations (SCSTMO). The chapter proceeds by selection and definitions of the basic shape for workpiece design. A detail form features describing the workpiece is accomplished by turning features, milling features. These are form features description used as an input to develop a machining workingsteps associated with machining operations of turn-mill environment. Finally, the chapter concludes with a detail discussion on the proposed system based on the framework model. The form features, machining operations and workingstep etc are all covered according to ISO 14649 data model.

4.2 Machining Process Planning Fundamentals

In view of turn-mill manufacturing environment, the main fundamentals for process planning include efficient capability utilization in addition to control and quality of operation and time. As the complexity and functionality of machine tools increases in computer integrated manufacturing (CIM), the need for digital machine tools used for decision making in process planning becomes more frequent. The lack of integration between these digital machine tools corresponds to machine tool configuration, functionality and related activities on the bases of concurrent engineering. They also determine the complexity of constraint factors on process planning. Hence, the focus has been planning by standard representation of tasks related to design and manufacturing process in object-oriented methodology. For instance, such planning structure can outline the required operation with regard to specific workpiece design information, manufacturing information and capacity of machine tool. These accomplishments mostly used standard requirement modeling and implementation established by ISO. This has been the basis for STEP and STEP-compliant system design and development methodology. The next section shows a proposed framework suitable to turn-mill operations based on ISO 14649 data model.

4.3 A STEP Compliant System Design for Turn-mill Operations (SCSTMO)

In this section, a framework of STEP compliant system comprised of functional and an information requirement for Turn-Mill operations is presented. A process planning system is used to generate manufacturing information by interactive definition of machining feature that can be associated with corresponding machining operations. The information requirements aimed at devising a feature-based process planning system with description of turn-mill operations. The methodology adopted towards STEP complaint system environment which comprised of feature modules of turning and milling. It has targeted at generating STEP file code compliant to ISO 10303 Part 21(ISO 2002). Its feature module provides machining features form feature-based design representation and describes workpice and accompanied by appropriate tool selection mechanisms. A part 21 physical file format has been used as an output describing the information components of the system and conformance of STEP compliance requirement.

The objective of this research is addressing process planning and machining operations environment requirements regarding a turn-mill machine in STEP. The system is also proposed a STEP Compliant NC structure for ISO 14649 code generation complaint to turn-mill components. In STEP-NC compliant system information represented various phases of the product life cycle through CAD, CAPP, CAM and CNC along with practical information structure for various configurations of turn-mill machine tool. The overall framework illustrated in Figure 4.1 which shows the different parts of the system bound by Visual Basic dot NET binding language. The prototype has been developed on Visual basic 2005 [79] for providing suite of integrated development to STEP standards. The platform has established a visual basic classes from EXPRESS schema and handled the STEP Part 21 physical file format and instantaneous generation. Brief details on the working procedures and interface of the system will be presented in Chapter 6.

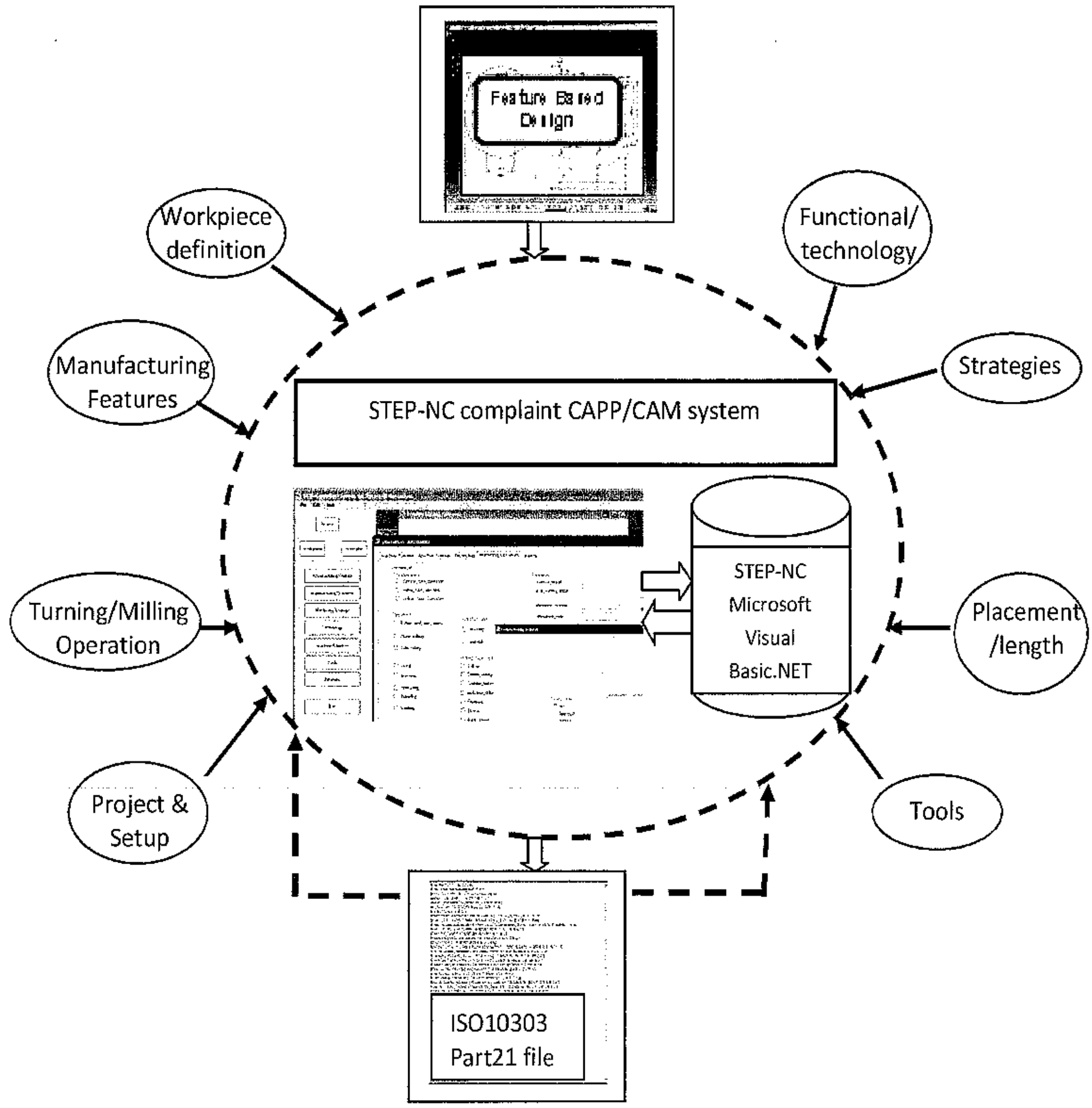


Figure 4.1 Proposed System frameworks

In developing a data model for STEP compliant system for turn-mill environment, ISO 14649 has been recommended as sufficient standard by Rosso [11]. In which ISO 14649-Part 10 standard provides the general data structure for the process plan. A workpiece is defined by the addition and subtraction attributes of ISO 14649 11 and 12 machining features. The part of data model regarding the task has been defined under a workplan with a sequence of machining_workingsteps. That is comprised of machining_*operation* to be executed on the workpiece to form the necessary *manufacturing_feature* in producing a part.

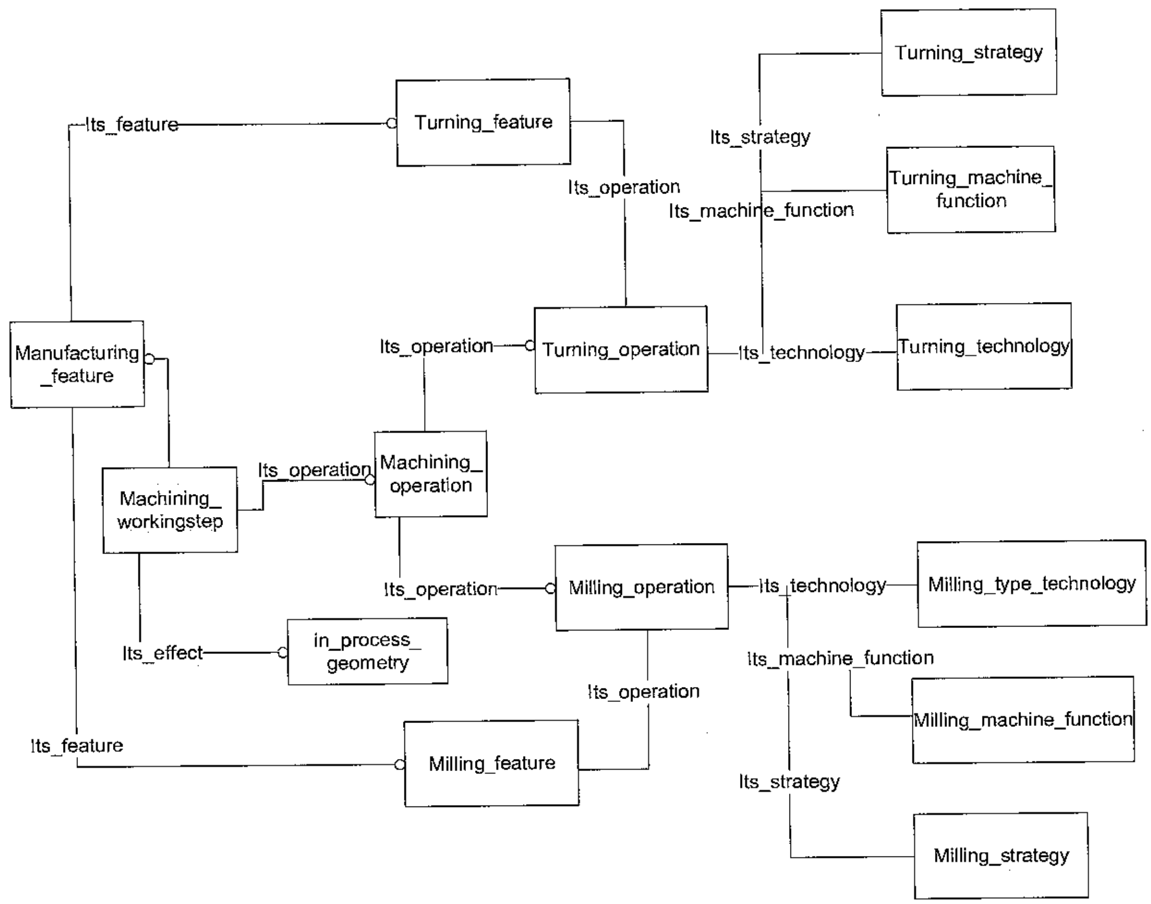


Figure 4.2 Overview of the turn-mill operation based on STEP-NC adopted from ISO, part 11 and 12

The collection of turn-mill operation form a workplan with a series of turning and milling type of operations on respective form features as defined in ISO14649. The turn-mill operations are supported by *turning_technology*, *milling_technology*, *turning_machining_function*, *milling_machining_function* and machining strategies able to address turn-mill machining. An overview of the ISO 14649 data model structure is shown Figure 4.2 for the proposed system. This diagram represented an excerpt of the system in EXPRESS_G diagram of Figure 4.3 from ISO 14649 Part 10, 11, and 12 [47, 3, and 2].

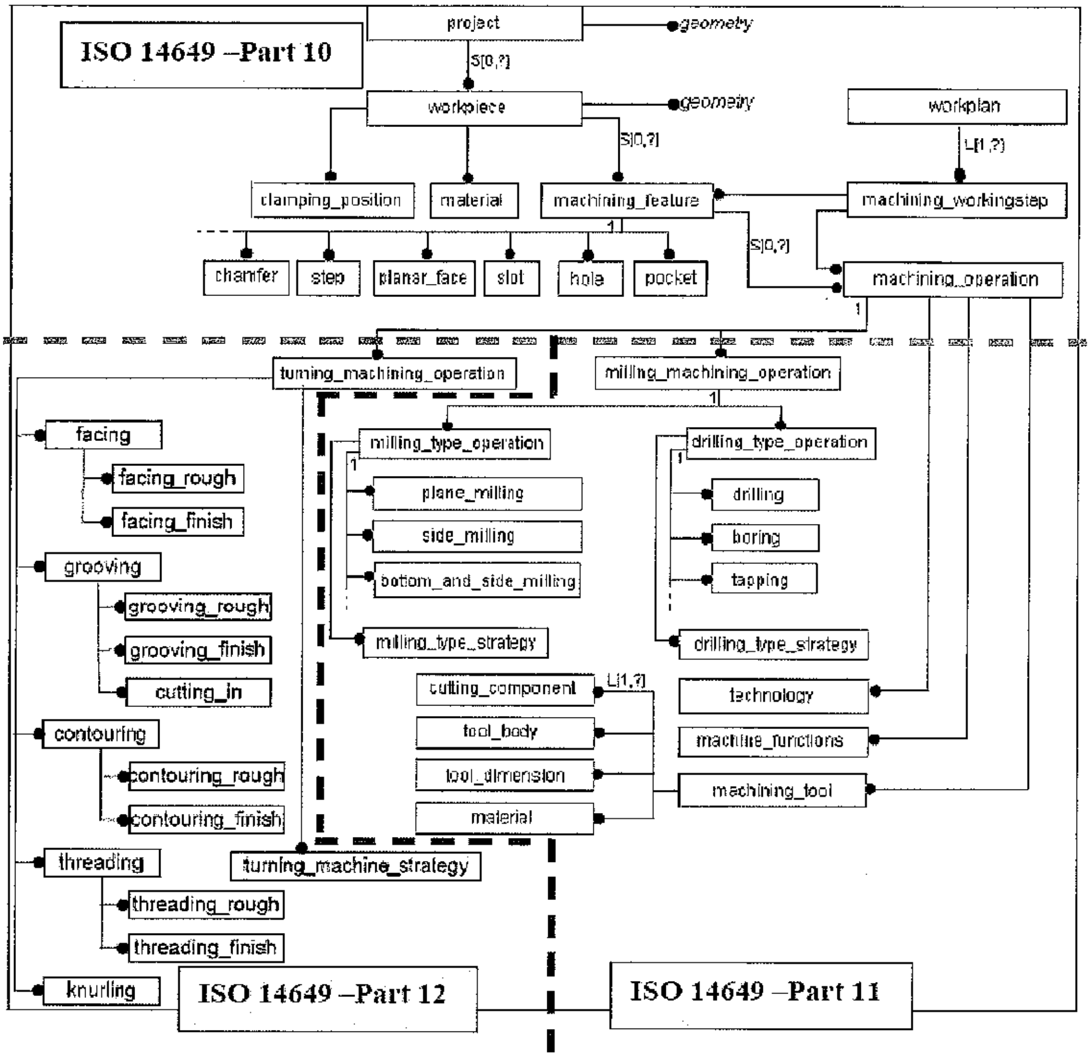


Figure 4.3 Overview of STEP-NC data structure (part-1, Part-10-12)

The data model development consideration related to product and manufacturing information models are described in Chapter 5. The main activities describing the tasks of manufacturing system with regard to the proposed system include geometric features translation, tools database, modules for planning machining operations, visual basic dot NET class of ISO 14649 EXPRESS data model and the generation of STEP-NC process plan (ISO Part-21 file). These are the main system components to establish manufacturing system environment towards information portability and interoperability implementation on specific machine capability such as turn-mill machine. The data structure shows the inheritance relationship of the entities of features and operations which are used in the STEP-NC file output. The output is a process plan of a turn-mill machine.

4.4 Manufacturing System Environment and Interoperability

The proposed system environment also considers the CNC machine capability and specification compliant to STEP-NC. That is composed of the data model structure prepared for turning and milling machine tools and capable of supporting a single spindle and dual spindle turn-mill manufacturing environment in addition to turning and milling machining environment independently. Figure 4.4 shows interoperable manufacturing environment for turn-mill operations. The output from the system is a process plan with corresponding CAx system or CNC machines implementation.

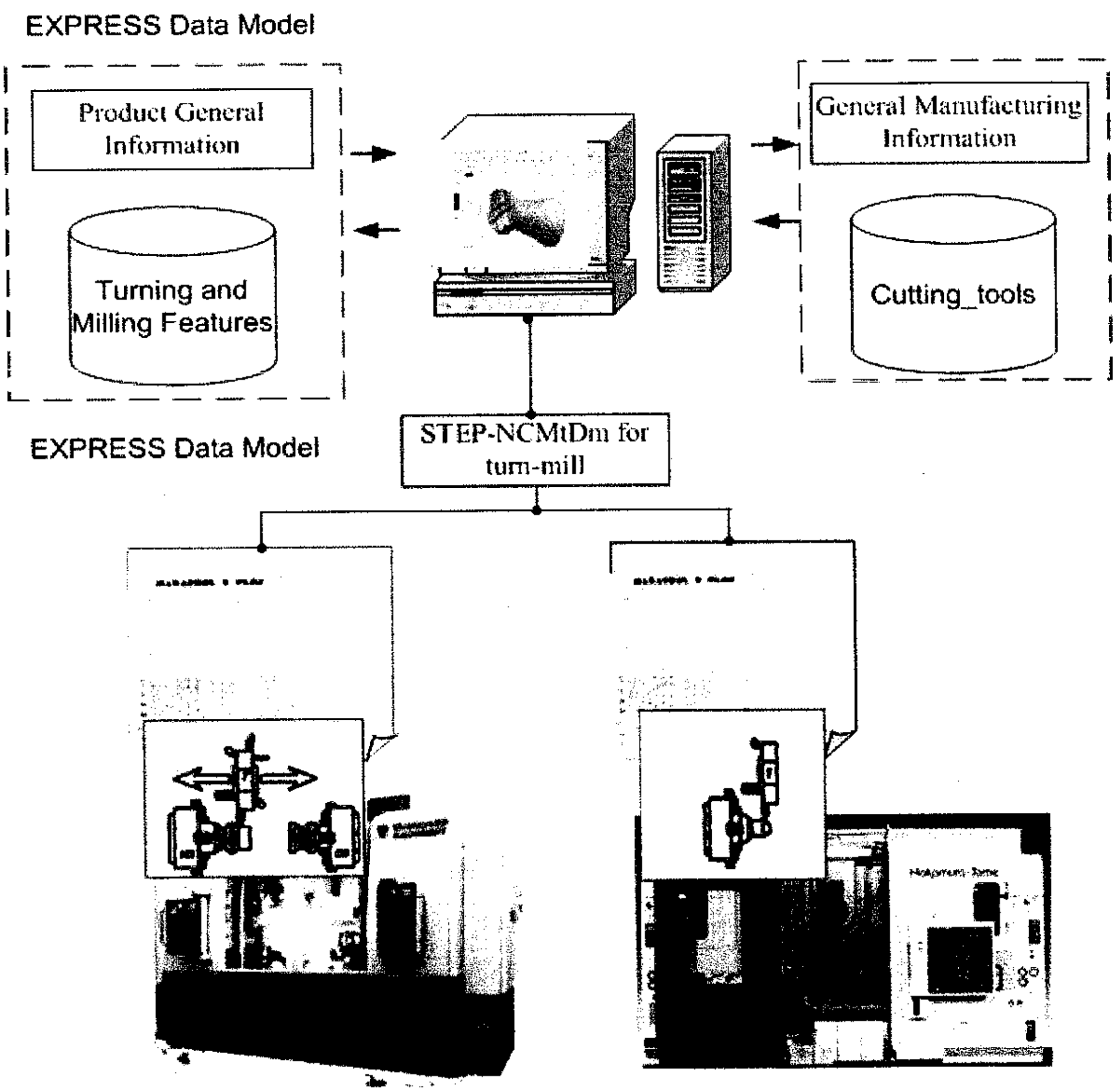


Figure 4.4 Inter operable manufacturing for single spindle B-axis and dual spindle turn- mill operations

4.5 Application Tools for SCSTMO

A SCSTMO is an implementation of STEP on a turn-mill environment displaying application of STEP-NC. The next chapter is about comprehensive descriptions of the system with the aid of information models supporting turn-mill operation. A UML class diagram has been used for representing the system design and these classes are converted to instances of Visual Basic dot NET programming language. A STEP methodology used to develop representation of product, process and machine tool resource models. It has been used to maintain integration and scalability of the system. In addition, the information model governs user interaction with the system and information requirements details with corresponding models will be covered in the next Chapter.

4.5.1 STEP

In this system, product data model and exchange methodology are performed by implementation of STEP standard i.e. ISO10303 - Industrial automation system-Product data representation and exchange. The detail of product data model development and methodologies of product data exchange has been described in Chapter 3, section 3.4 and 3.5.

4.5.2 UML

Representation of the various objects and their relationships comprising turn-mill manufacturing environment has been given by UML. It provides enhanced implementation method as XML[80]. UML primarily developed and standardized within object management group (OMG). It is a means to construct an information model from a collection of UML class diagrams. The design and structure of product and process knowledge explicit representation and illustration are given in UML which can easily show the domain of the implementation system to be transferred into an XML schema by visual basic dot NET programming for generating a data file in STEP. The Microsoft SQL server data base is employed in the system to store, modify and extract tools data from the database and allows data sharing among multiple applications. The functionality of the proposed system modules and their related representation with standard implementation has been discussed in the following sections.

4.6 Basic functionalities of SCSTMO

The basic functionalities of the system are modules of activities and requirements of process planning. These include the translation of geometrical features, planning of machining operations and generation of the STEP-NC process plan. In the domain of turn-mill process planning, the activities are outlined as follows:

I. ISO 14649 representation of manufacturing features

II. Turning and milling feature library

III. Specification of base part

IV. Machining operation planning

V. Process plan generation

4.7 ISO 14649 Representation of Manufacturing Features

ISO14649-11 and ISO14649-12 are milling and turning feature library respectively which mainly comprised of the Two5D feature domain requirements for turn-mill component. In the proposed system, an approach of feature extraction methodology has been adopted on the given feature domain. Machining operations and machining strategies requirements of turn-mill operations basically referred to operations attributes defined under ISO 14649 Part 11 and 12. The general machining operations description and the translation of linear and rotational function over the features coordinates provided under Part-10 utilized as explained in the adoption methodology proposed by Russo et al. [11].

4.7.1 Turning Features

In regard to turning features, ISO1649 Part-12 feature library used for extraction of machining features. Operation attributes given under ISO 14649 Part 10 and 12 are used for description of general machining operations and turning machining along with machining strategies respectively. Figure 4.5 shows both manufacturing features (Part 10) and turning features namely outer round, revolved features, knurl and cut in (Part 12) process data of turning [81]. In addition, entities of technology and strategy are also defined in Part-12. Whereas cutting tools and machine tool entities are referred from ISO 14649 Part 121 and used with machine tool model adopted for turn-mill machine information respectively.

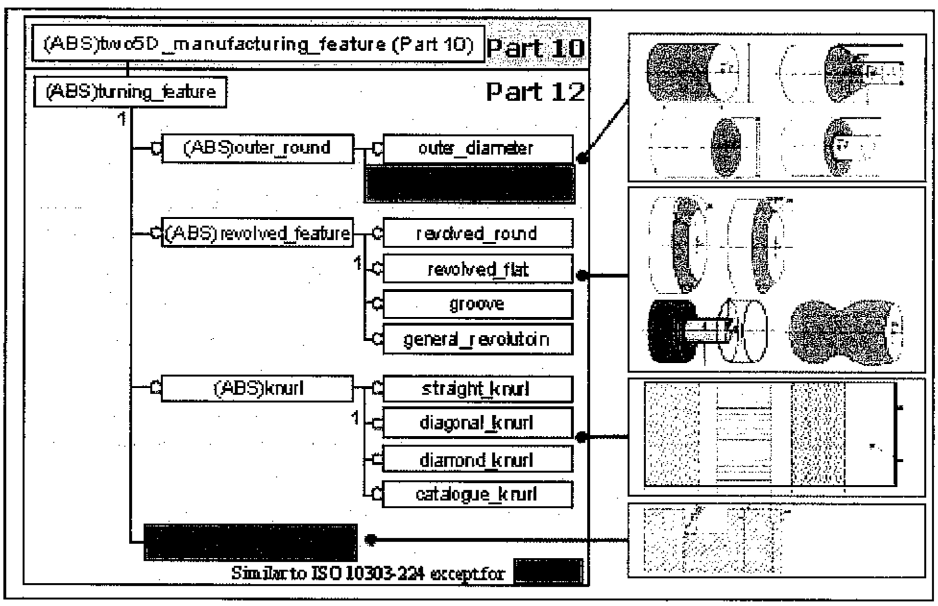


Figure 4.5 Manufacturing Features and Turning Features [2]

This system supports features under STEP-AP224 which was developed for mechanical product definition for computerized process planning based on features (ISO10303-AP224). It has been represented in EXPRESS schemas that are suitable to develop an implementation model on specific ARM bases.

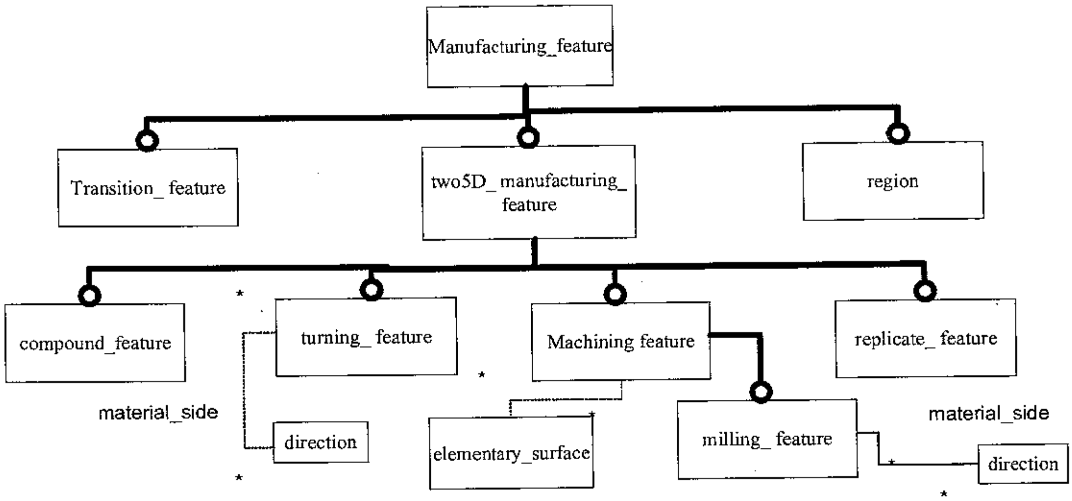


Figure 4.6 Location of machining feature for turning_feature and-milling_feature adopted from ISO 14649 Part-10 [22]

The manufacturing feature class structure shown in Figure 4.6, has included *turning_feature* and *machining_feature* entities which are subclass two5D_manufacturing_feature class [22]. A *manufacturing_feature* class comprised of feature type with requirement information necessary to define components of a product data and *machining_feature* entity. *Transition_feature, two5D_manufacturing_feature* or *region* are the main elements found in *manufacturing_feature* class defined in ISO14649-10. This general process plan data model coupled with specification of technologies to develop dedicated standard implementations. The *two5D_manufacturing_feature* class is the super class for *turning_feature, machining_feature* etc. where the *machining_feature* is super class for *milling_features.* The super class is the one which accommodate the common entities for the different sub classes found under it.

Figure 4.7 shows the UML format of ISO 14649-11 and 12: i.e. Process Data for Milling and Process Data for turning respectively. In the developed system (SCSTMO), manufacturing feature requirements for turning module of turn-mill manufacturing supported within the abstract subtype (ABS*)* *two5D_manufacturing_feature* specifically from *outer_round, revolved_round* and *knurl* subtypes. The detail description of the features and their related properties are given in ISO 14649 -12 [2].

4.7.2 Milling Features

The domain of ISO14649-11 feature was used to include *milling_features*. Whereas related general machining and milling machining information are also given in ISO14649-10 and 11 respectively. Figure 2-13 EXPRESS-G representation describes the inheritance relationship of *machining_feature* in *two5D_manufacturing_feature* class for milling machining. Figure 4.6 and 4.7 shows the UML representation supported by the developed system as excerpt of ISO 14649-10, ISO 14649-11 and ISO14649-12.

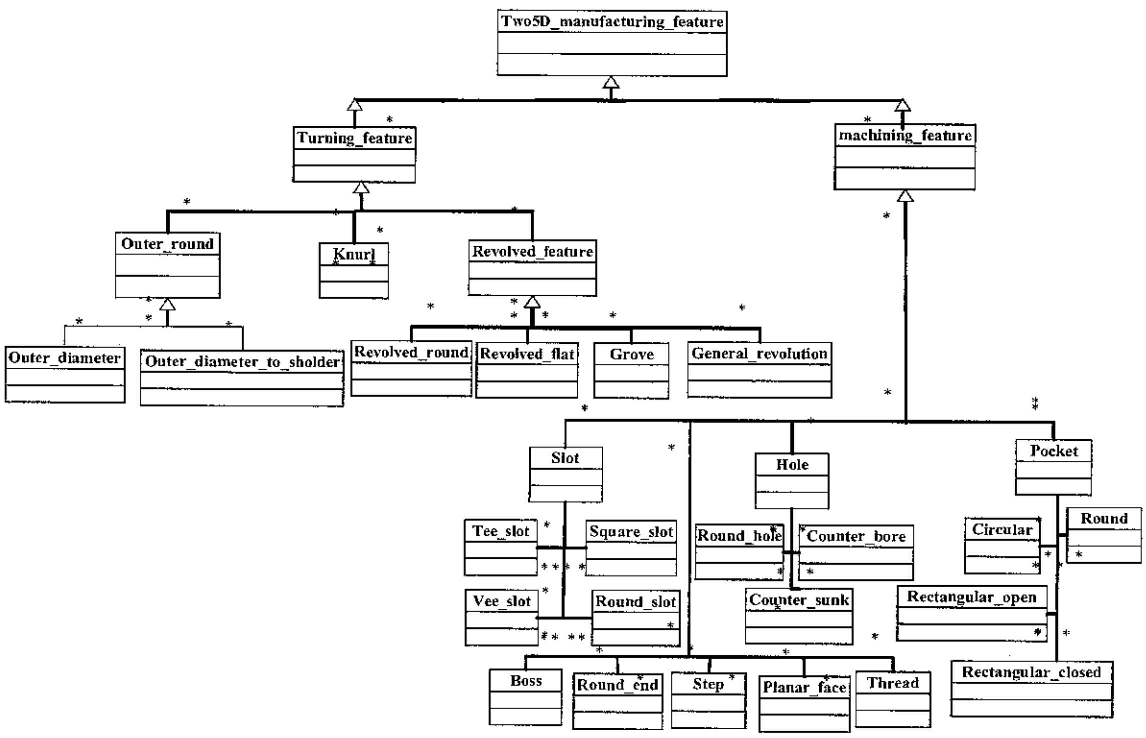


Figure 4.7 Two5D_manufacturing_feature in UML format

4.8 Specification of Manufacturing Base Parts

In developing a STEP-complaint system for turn-mill manufacturing, it is essential to specify properties for the base shape under consideration. In this case a cylindrical base shape is considered for illustration and its dimensions, location and orientation has been taken as show in Figure 4.8.

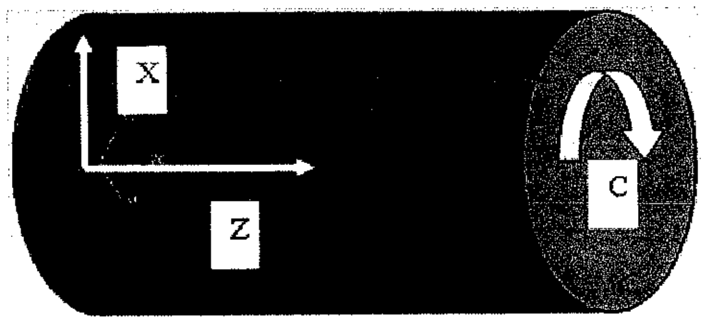


Figure 4.8 The Cylindrical Base part

4.9 Machining Operation Data

The base class of all operations includes the necessary attributes to describe technology and cutting strategy. Figure 4.9 shows EXPRESS-G representation of workingstep as a subtype of Workplan. It comprised of the machining feature model and Machining process model able to represent turn-mill manufacturing environment information on a feature based process plan presentation using content and structure of ISO14649.

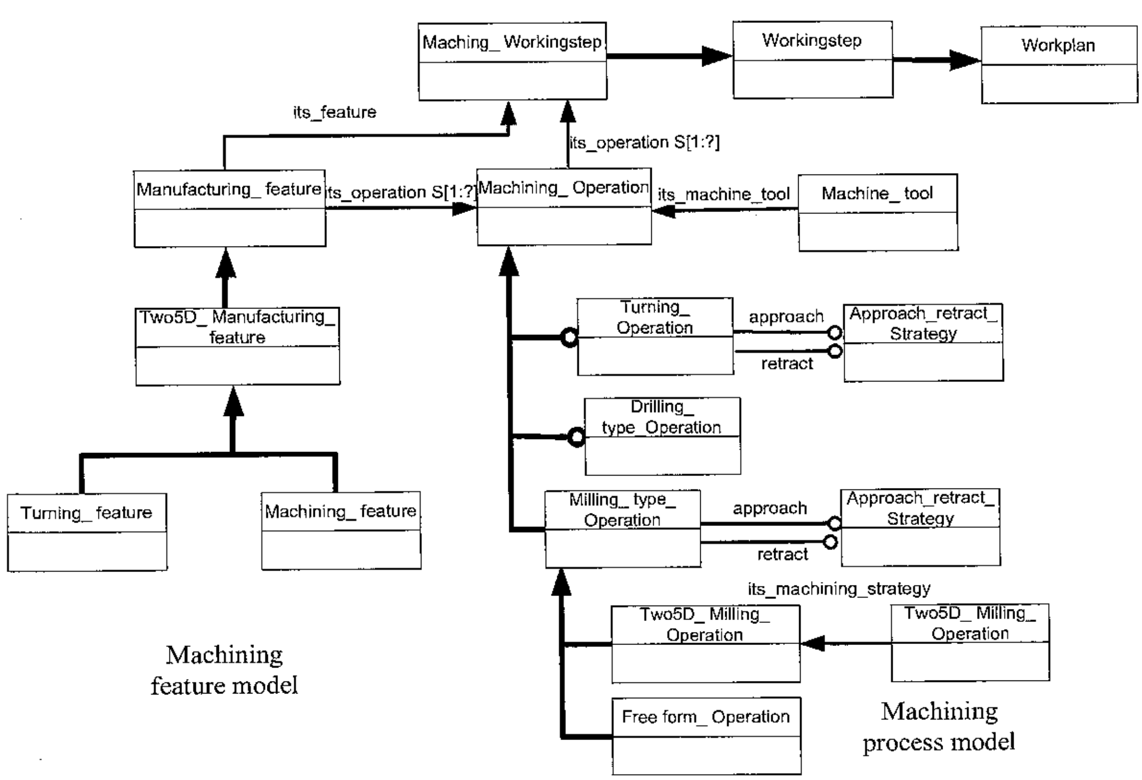


Figure 4.9 Workplan structure for turn-mill operation

In general turn-mill machining capacity is intended to be addressed by the CNC data model formalized using ISO 14649 that is established on STEP product model (ISO 10303). The process plan information is represented by Workplan structure given in Figure 4.9 which is composed of descriptions that relates to tasks, technologies, tools and geometry. The general machining information requirements for turn-mill machining environment can be represented by EXPRES-G diagram of Figure 4.10.That is mainly focusing on ISO 14649 contents for technology, machining operation and machining strategy, machine function and technology. These contents are utilized to develop an implementation on turn-mill machining environment addressing description of specifications throughout the product life cycle. In the next sections the UML representation, contents and information requirements for the product and process model of the system has been described.

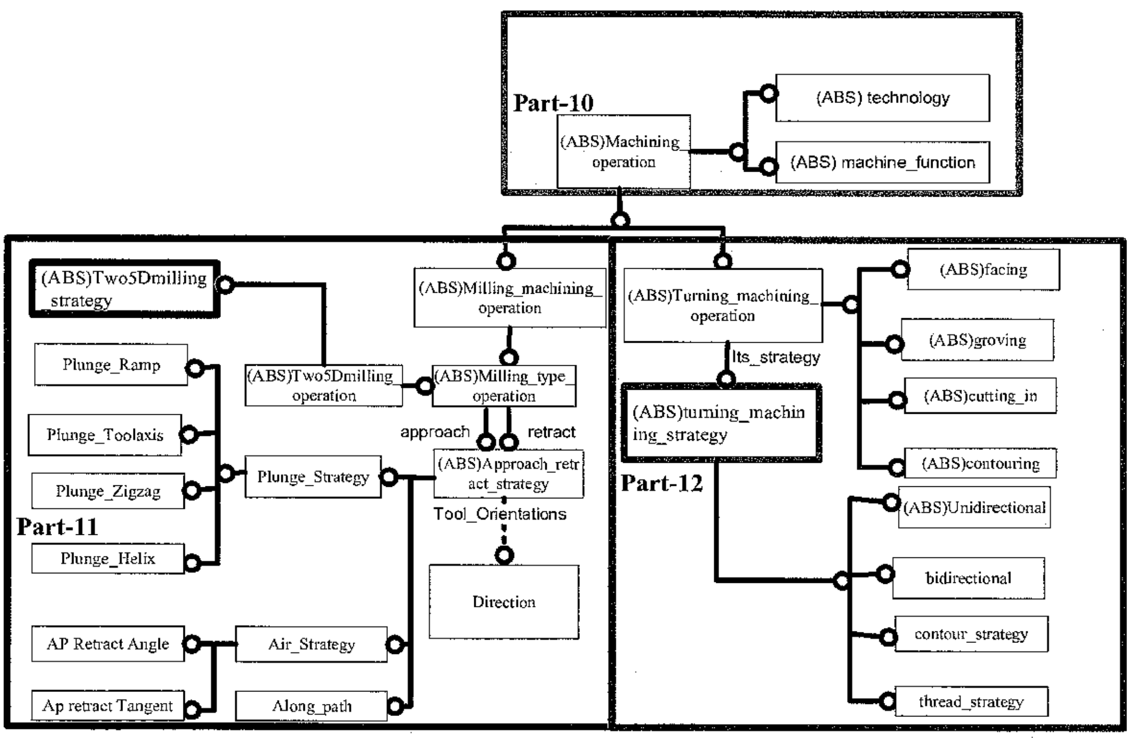


Figure 4.10 The EXPRESS-G representations for *machining_operation*

4.9.1 Workpiece and Manufacturing Feature for Turn-mill Operation

In the proposed system, all features are from base class of *turning_feature* and *machining_feature*.These base classes are sub-classes of *two5D_manufacturing_feature* described in ISO14649-10. The feature classes are fully harmonized with ISO 10303 AP224. In other perspective, the system is limited to the entity of *turning_feature* and *machining_feature* that are the abstract base classes for most features used for turn-mill components as shown in Figure 7, 9 and 10.

Additional adoption in accordance to ISO14649-10 is required for the two types of coordinate systems in locating the features on designed part. The geometric shapes that can be obtained by turn-mill operation on cylindrical workpiece with 2 axes (X and Z) operation or 3-axes and 5-axis operation as shown in Figure 2.10. The liner movement designated by X, Y and Z axes while the rotary movement of the workpiece referred by B and C- axes as shown in the Figure 4.11.

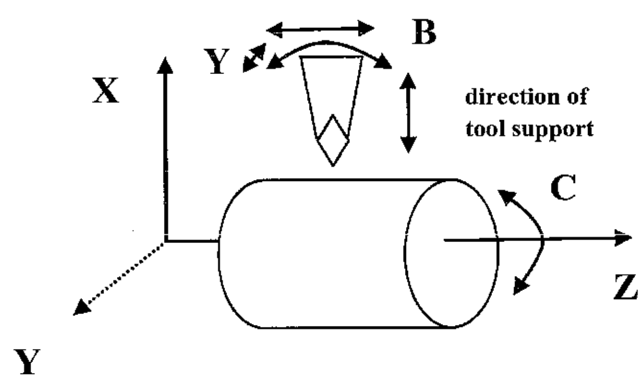


Figure 4.11 Axis motion nomenclature of turn-mill operation

4.9.2 Turn-mill Machining Strategy

As shown in Figure 4.9, a *Workplan* has a list of workingsteps and can be processed. The *workingstep* includes *manufacturing_feature* for *two*5D turning and milling operations. Furthermore, each *Workingstep* determines the sequence of execution for operations, based on a geometrical item /entities from *turning_feature* and *machining_feature* sub-classes shown in Figure 4.7. The *machining_operation* as shown in Figure 4.10 composed of sub-types of (ABS) *two5D milling_strategy* and *(ABS) turning_machining_strategy* which in turn contains information for process strategy requirements of turn-mill machining operation.

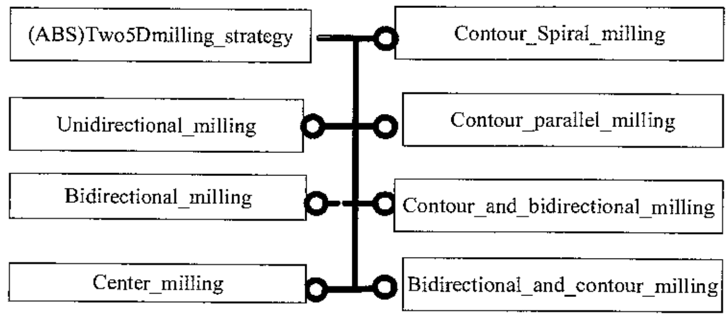


Figure 4.12 Structure of Two5D_milling_strategy in EXPRESS-G

These entities are used as an abstract super type (ABS) for the description of strategy that can be used for creating toolpath. They are a subtype of *machining_strategy* as defined in ISO14649-10. All directions defined in these subtypes are related to the workpiece co-ordinate system. UML representations of strategies shown in Figure 4.10 and 4.12 are adopted from ISO 14649-12 and ISO14649-11 for turning and milling module respectively used for turn-mill operations.

4.9.3 Turn-mill Technology

The abstract base class (ABS) *machining_operation* includes (ABS) technology class as its super type class. The (ABS) technology super type class includes technological parameters suitable for turning and milling modules of a turn-mill machining operations that can be defined in ISO1464-10 and represented as shown in Figure 4.13 using EXPESS-G diagram. Appendix D.2 shows the pseudo code representing Serialization function and inheritance relationships between (ABS) *machining_operation* and (ABS) technology. This class encapsulation enables to generate STEP-NC process plan file since the entities required to express the information regarding technology can be accessed from the super class of (ABS) technology.

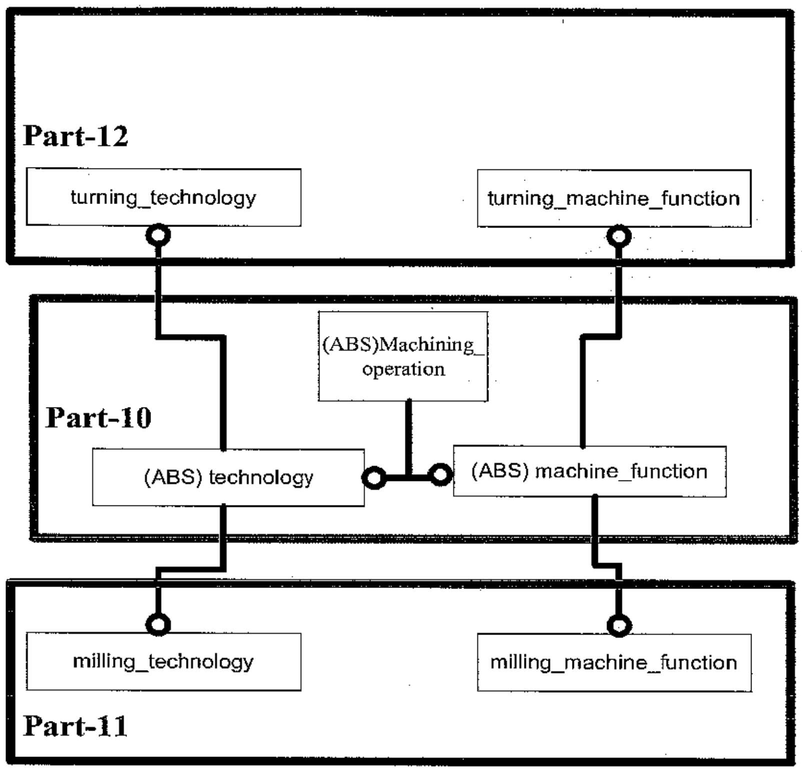


Figure 4.13 EXPRESS-G diagram representing structure of technology and machine function

4.9.4 Turn-mill machining function

The state of various functions of machine can be described by entities of sub-class for machine function included in ISO 14649 data model shown in Figure 4-13. In case modules of turning and milling machine functions sharing common attributes have been included under the base (ABS) class of technology or machine_function. Appendix D.2 shows the pseudo code representation for process data generations.

4.9.5 Turn-mill machining operation

This is the base class of all operations suite for turn-mill. It includes all attributes to describe technology and cutting strategy. It has been given under subtypes of *machining_operation* super type class defined at ISO14649-10. Figure 4-10 shows its structure in UML diagram. The structure developed on an object-oriented methodology where a specification of attributes for *machining_operation* and features are instantiated in accordance to the requirements. Appendix D.2 shows the pseudo code representation for process data generations

4.10 Machine Tool Database

The super type class (ABS) *machining_tool* is used to include resource information requirements suitable for describing specification of manufacturing operation modules. In this case, the technologies which can be executed by using turn-mill machine and cutting tools that have been given in (ABS) subtype class of *turning_tool* or *milling_tool* under (ABS) super type class *of machining_tool.* The entities of these (ABS) subtype class have been used to define overall tool assemblies' referenced from ISO14649-111 and ISO14649-121 for milling and turning cutting tools respectively as shown Figure 4.14. Appendix D.2 shows the pseudo code representation in the process data generations

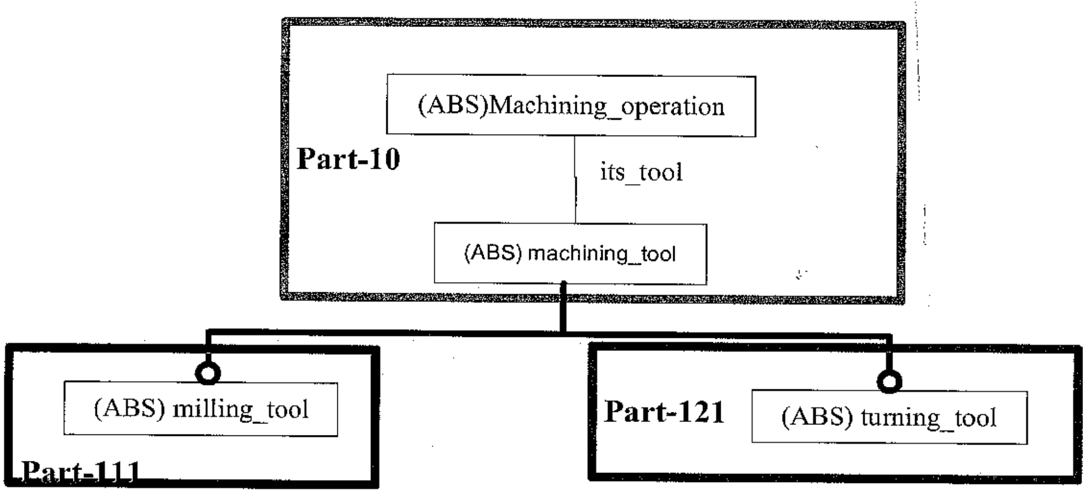


Figure 4.14 Machine tool [23-24]

4.11 ISO 14649 Process Plan Generation

As it has been shown in the previous sections, ISO 14649 data model and its contents are utilized to represent requirements of turn-mill machining process plan. The *Workplan* structure of turn-mill operation information requirements has been represented in Figure 4.9. The structure supports to generate a physical STEP-NC process plan file. It is mainly intended to process information supplied by using a STEP-NC interface on functionality of the machines. Two major categories of functional information are to be supplied. The primary one related to feature base design of a workpiece (features, tolerances, material, etc.) and the secondary information is regarding the specific process to be accomplished (machining operation, cutting tools, machining parameters, etc). This fulfils generation of STEP-NC process plan, since the information has comprised of an ISO 14649 data model defined for turning and milling operations. The proposed system used both turning and milling data model and generated a STEP-NC process file. ISO10303-AP224 domain of mechanical feature description has been used for representing the information requirements of machining operations and machining features. EXPRESS representation of Pseudo codes for the different sections of the process plan given in Appendix D

4.12 ISO 14649 Implementation Data Structure and Contents

A Physical File Format developed according to ISO10303 Part 21 describes a part program consists of two sections namely "Header" and "Data" as shown in section 2.2.7 of Figure 2.5. It has been described that the proposed system SCSTMO used ISO14649 data model, which allows the importance of ISO10303 fundamentals that is computer interpretable product manufacturing information representation and exchange. ISO 14649 implementation is development of an exchange structure format with ISO10303 Part 21 format consists of product data description by STEP AP224 schema as specified in EXPRESS language (STEP Part-11) [70]. The implementation has met conformance with STEP-NC interface specified to the content of particular technology. In this case, turn-mill machining process planning used to construct an output on ISO10303 Part 21 file format suitable to transfer a user editable product data among computer systems. The description of generated process file has been given in the section follows.

4.12.1 Header Element

The elements of a physical file format which contains information applicable to the entire exchange structure and found in every part of the exchange structure is identified as Header Element. It specifies every requirement by a single occurrence in the structure. Some of its elements are:

I. Verification of this part of ISO10303 used to create the exchange structure and its contents.

II. Human readable information about the exchange structure as a file name.

III. An EXPRESS schema specifying the entity instance in data element indicating a file schema.

4.12.2 Data Element

Data elements contain the product data to be transferred by the exchange structure. They consist of entities instance that correspond to the EXPRESS schemas governing the exchange structure:

I. The part properties contain the description of characteristics of the part that is being defined. These characteristics specify requirements for manufacturing that is applicable to either the state of the part at a particular time prior to or after the manufacture of the part. Some of these properties include part material, alternative material, material hardness, surface property, etc.

II. The base shape specifies the size and shape of the initial stock from which the part is to be produced. Placement element specifies the location and orientation of the part as a set of axes information is also included.

III. Administrative data contains information that identifies product data order information. These elements include order information that allows for tracking of the work on a part's manufacture.

IV. The document element provides the ability to specify documents that are directly related to part data as they support the definition of the part and it may be related to specification of an operation or manufacturing process.

V. The machining feature element contains the information necessary to identify shapes which represent volumes of material that shall be removed from the part by machining or shall result from machining.

VI. The feature definition element contains the information necessary to create a machining feature

The data section program identified by three main categorized information such as workplan and executables, geometry, and technology descriptions.

4.13 Summary

In this chapter the contents of STEP compliant framework has been explained on the bases of ISO14649 Part 1, Part 10, Part 11, Part 12, Part 111 and Part 121. It has covered the requirement tools that are essential to the STEP-Compliant CAPP/CAM system for turn-mill operations. The developed STEP compliant system manufacturing for turn-mill operation. It has been established to address process plan for turn-mill discrete components manufacturing and generation of ISO 14649 codes or STEP-NC file. These have been targeted to the next generation intelligent CNC turn-mill machine tools. The overall aspects of part programming, machining process planning and a design framework on ISO 14649 data model suits has been provided. The system is limited manufacturing features which are defined in ISO14649 whereas the capacity of turn-mill machine can be used beyond that. The developed framework functionality will be discussed on the aspects of STEP NC compliant information model in the subsequent chapter.

CHAPTER 5

STEP-NC COMPLIANT INFORMATION MODEL

5.1 Introduction

This section outlines the content of framework developed in the previous chapter with regard to STEP-NC compliant information model. It comprised the description of information models design supporting process planning activity and a structured systematic methodology for developing process planning model using STEP compliant approach. It is also to address entity elements of the system. They are mostly higher level data representation. STEP-NC uses feature based approach of STEP information modeling serving for the various stages of product life cycle in a concurrent engineering approach.

Product and manufacturing elements model integration and implementation based on STEP-NC towards Generative process plan generation in STEP. Modeling intelligent CNC machine tools data and modeling of an extension of developed generic process plan on turn-mill environment towards Native process planning or machine tool level STEP-NC implementation are significantly covered.

EXPRESS, EXPRESS-G, IDEF0 and the Unified Modeling Language (UML) are information representation and analysis methodologies which has been recommended for STEP manufacturing system data management and development. This has been discussed with the nature and involvement of the product, process and resource modeling languages by Larson [82].

The framework development for the proposed system in the previous chapter mostly used EXPRESS, EXPRESS-G and UML in combination with IDEF0 information model represents implementation model of both Product Model and Manufacturing Model related to the manufacturing capabilities of turning and milling operations on turn-mill manufacturing environment. The product model addressing the design and process planning function models in concurrent engineering approach have been constructed on Object-oriented system. The object oriented programming language, Visual Basic dot NET (Micro soft) and UML in Microsoft Visio are used to implement the proposed data model and process planning functions.

UML represents the entities and their inheritance relationship. IDEFO gives the activity model of the system. It constitutes information model representing implementation of Product Model and Manufacturing Model on the aspects of design and manufacturing modules. The information model functionalities are towards capabilities of intelligent turn-mill manufacturing environment on a two5D manufacturing features.

5.2 Categories of Information Model

An information model presents a usable, structured and classified entities or elements for describing the approach, scope and methodology of a system [83]. ISO established standards for context representation of a data sets provided elements for an explicit interpretation with rules. The modules of such manufacturing systems comprised of manufacturing information classification such as product, manufacturing process and resources in view of concurrent engineering methodology. A general product information model schema illustrating the constituent elements represented hierarchically in the Figure 5.1. The description of its components and their coverage on the system functionality aimed at information sharing and integration. These realize the requirement of manufacturing models focusing on representation of manufacturing resource model interlinked with manufacturing processes which are used to represent components of resource model and manufacturing activities in object oriented methodology CAPP on product manufacturing [84-85].

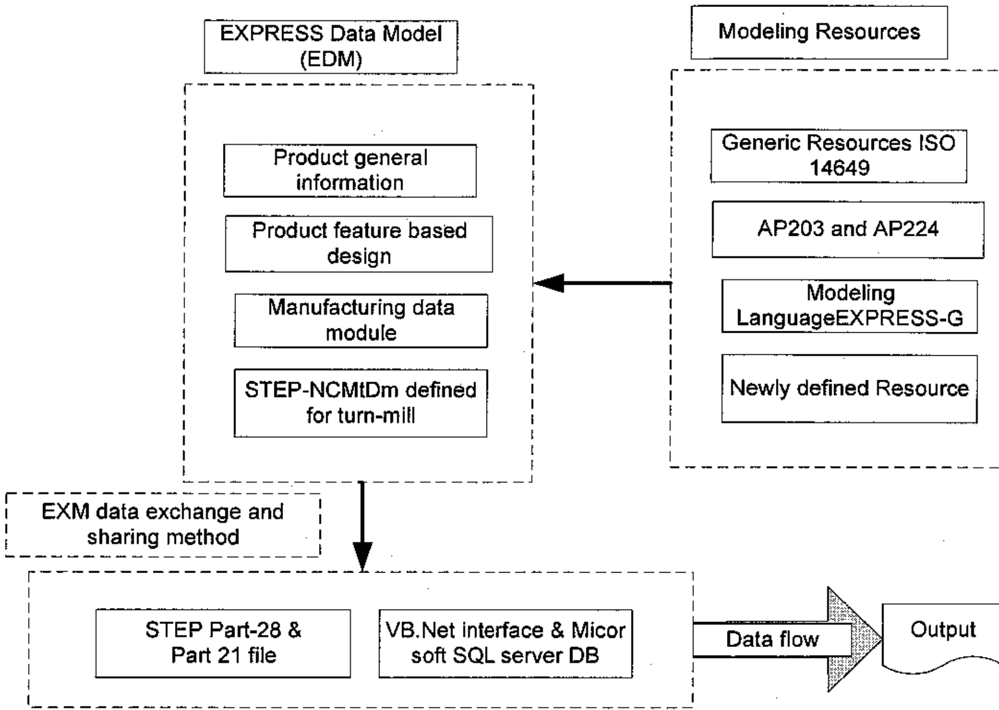


Figure 5.1 STEP-based general product model schema

The model represented four fundamental EXPRESS data model; STEP based modeling environment, functional methodology and EXPRESS data model data exchange and sharing. The implementation of SCSTMO was comprised of three main stages, namely information model representation, tool database and application of the system. Figure 5.2 shows the ISO 14649 information model of the proposed system machining operation. SCSTMO information model primarily derived from STEP-NC standards. It describes requirements of information and functional perspectives related to CAD to CNC process chain. Molina information model used to construct two modules of the system namely product and manufacturing models [10].

The information model of the proposed system includes original workpiece material, design and corresponding manufacturing perspective of product. In maintaining, the requirements to establish an implementation on the next generation CNC controller a manufacturing model has been used which includes information regarding resources, operations and strategies. These system models have been developed on the bases of ISO 14649 Parts 10, 11, 12,111, and 121 entities [2-3, 22-24]. UML model representation has been given for the operations, features and machine tool model of the proposed system.

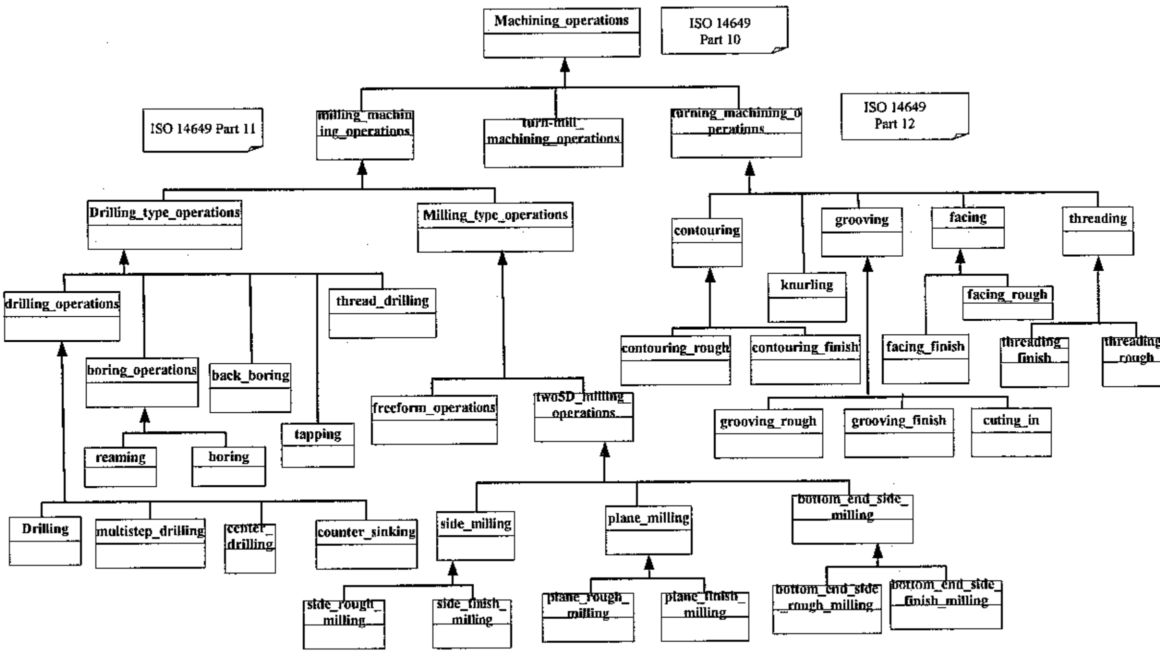


Figure 5.2 Machining_operations information model

The machining operation entities shown in Figure 5.2 with corresponding manufacturing object model are main inputs under manufacturing module along with others shown in Figure 5.1. It has included attributes required on process plan data generation. It is part of the ISO 14649 covered under the *machining_operation* in Figure 4.3. This information model used to show the operation coverage of the system and the inheritance relationship of sub-classes. The data deliver information on the bases of "What to do" stands for design representation to construct "How to do" stands for manufacturing process representation of a process plan. That is the design representation of a part is designated under "What to do "and manufacturing process representation of a part is designated under "How to do". These process plans are two types namely; Generative machine independent STEP-NC file and a Native specific STEP-NC file.

In addition to entities of design and manufacturing process information, the system has got cutting tools database by Microsoft SQL server 2005. SCSTMO database included milling and turning cutting tools. A graphical user interface (GUI) has been used to submit requirement data and cutting tool selection. The system developed based on Visual Basic NET 2005 programming which is used to bind ISO 14649 entity set classes and cutting tools. The design and manufacturing modules of SCSTMO process planning GUI and corresponding data generation described in Chapter 6. UML representation and description for the product model and manufacturing model of the proposed system are given in the following sections.

5.2.1 Product Model

The product model is considered as an abstraction representing the part design module of the system. It elucidates the entities requirement for design consideration with their associations and inheritance relation in object oriented programming perspective. It comprises of tolerance, base shape, geometric information etc. as shown in Figure 5.3. The model served as the basis for generating process planning file supporting feature based design information since it has been established using ISO14649-10, 11, 12 and PA224 entity sets. This entity based model used Visual Basic dot NET program as binder which render emphasis on fulfilling compatibility, maintainability, and extendibility and robustness requirement. The product model supports integration of design and manufacturing process information modules of the proposed system since it includes both turning and milling features. It is identical to the entities described under ISO 14649-Part 10 of figure 4.3 elaborated with requirements of Resources, Process and Strategy. Therefore; an equivalent manufacturing model has been developed and described in the following section. The main part of product data can be given in Pseudo code representation of Appendix D.1. It shows the inheritance relation of Workpice, (ABS) manufacturing_feature class and Serialization function. An example of process plan file displaying workpiece data is indicated in Chapter 6 of Figure 6.27.

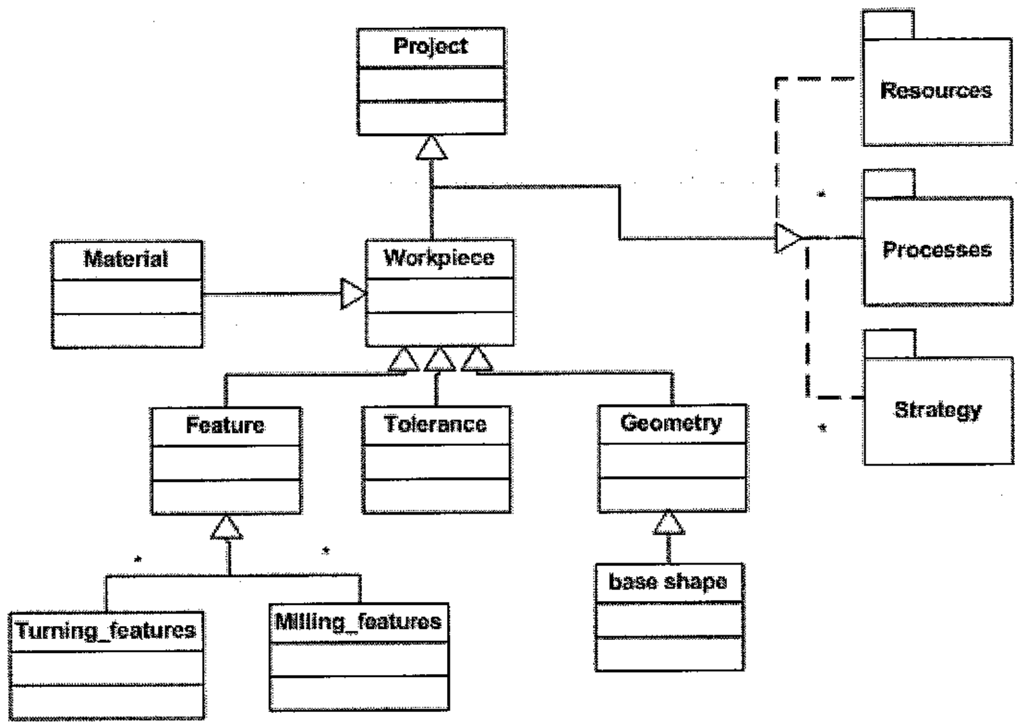


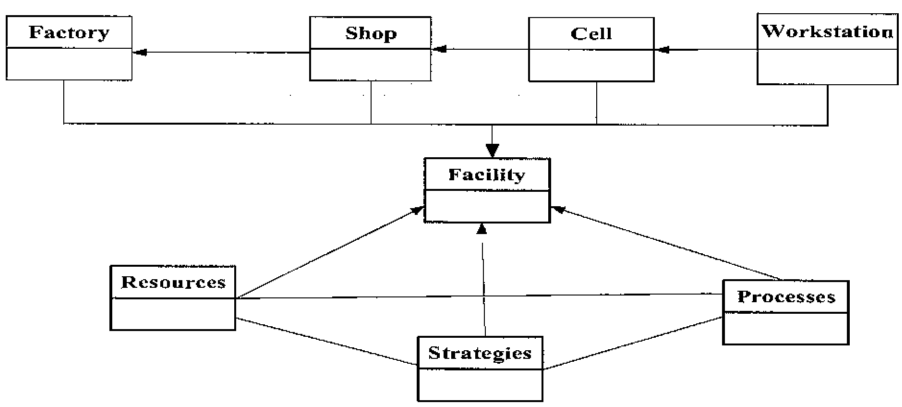
Figure 5.3 Representation of STEP-NC Compliant Model for Turn-mill– Product Data Model

5.2.1 Manufacturing Model

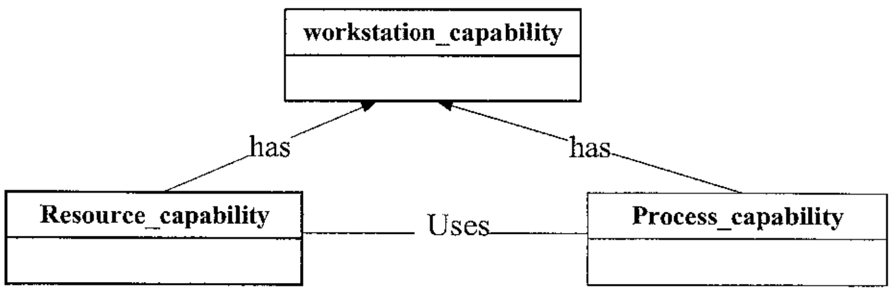
Manufacturing model primarily consists of a specific process capability and constraint description in a generic format. It supports appropriate resource allocation suitable for product manufacturing on evaluating requirements of manufacturing process describing specific manufacturing resource of a manufacturing facility. A comprehensive framework of workstation level manufacturing modeling was outlined and discussed. That has been established comprising processes, resources and strategies with reference to factories, shops, cells and workstation primarily designed by Molina[10]. But Rosso suggested that manufacturing entities has to comply with ISO 10303 and ISO 14649 standards. This mainly maintains neutral and STEP compliance of the model. This has been taken as a consideration for integration tool and accomplished by Zha and Du [75]Xu and He[17]. Figure 5.4a and5.4b.shows Molina and Rosso manufacturing models [19].

In this research, the proposed system manufacturing model attributes comprised of:-

- Physical constraints with reference to turn-mill process based on machining requirements of a part such as *turning_tools, milling_tools* and machine.
- Representation of machining capabilities for turn-mill process with regard to machining operations such as *workpiece_setup, turning_machining_operations, milling_machining_operations* etc.
- Turn-mill strategies in this model represented by schemas of turning and milling process modules specific to the given turn-mill process with regard to a allocated resources and processes such as *approach/retract_strategy, turning_technology and milling_technology.*



(a)



(b)

Figure 5.4 The Manufacturing Model Representations of Molina [10] and [19]

These attributes have lead to the author to adopt a manufacturing data model compliant with STEP-NC which has been partial considered in previous researches as shown in Figure 5.5 [12]. The system developed utilized both the milling and turning attributes sequentially in accordance to satisfy requirements of turn-mill manufacturing. D.2 pseudo code shows the inheritance relationship and functional instruction for including machining operation information in STEP-NC process file.

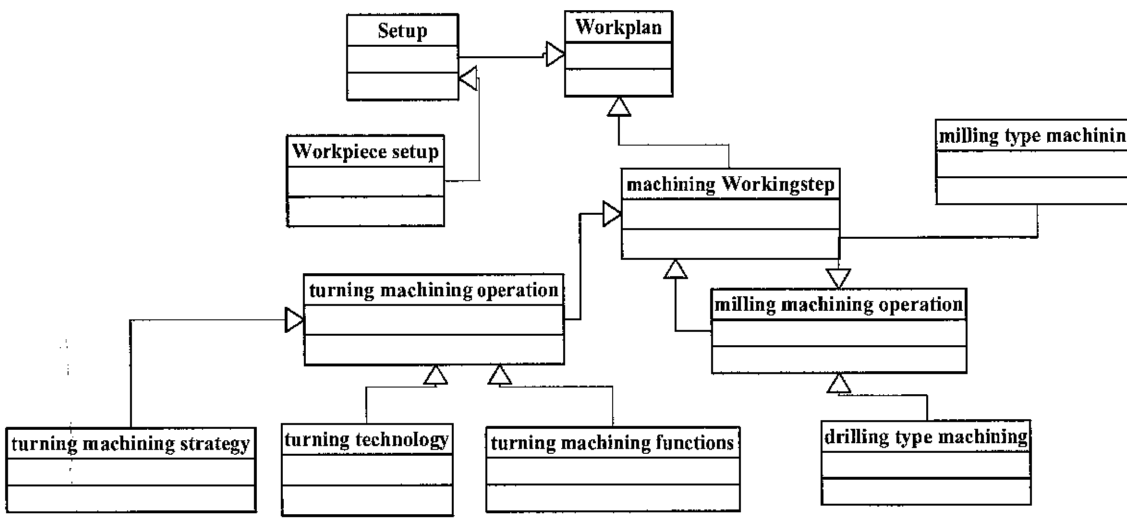


Figure 5.5 Representation of STEP-NC Compliant for Turn-mill – Manufacturing Data Model [12]

5.3 Binding Language and ISO14649

ISO 14649 included process data for milling and turning indentified as Part-11 and Part-12 respectively. ISO 14649 Part 10 represents general process data for interfacing computer numerical controller (CNC) and CAPP system between CAM or shop floor programming system for milling and turning. The author utilized ISO 14649 data model considering the adoption recommended on Part -10 by Russo, a STEP-NC interface for turn-mill operations which is suitable in addition to the conventional milling and turning. The proposed system intended to support B-axis, Y-axis and C-axis machining without composite features representation. Figure 5.5 with EXPRESS representation in Figure 5.6 shows turning and milling classes defined on ISO 14649 by using Visual Basic dot NET programming tool as a binder. It is an object oriented platform which can accommodate integrated manufacturing information requirements in accordance to the product, manufacturing and resource model developed in previous section. It provides description of the attributes for product and manufacturing tasks in an interactive design and manufacturing modules of the system developed that have been used to generate editable ISO10303 Part 21 file format process data.

The programming system started by establishing a feature-based design CAD/CAM system modeling with concurrent engineering perspective in line to STEP-NC structural modeling approach. ISO 10303 Part 21 physical file generated from a two stage STEP-NC interface of the design and manufacturing modules. STEP-NC compliant CAPP/CAM system on a JAVA information class from STEP-NC ARM model definition, developed by Loughbourgh University [86] Where as a Visual Basic dot NET information model class has been used in this research. In which a user provided to define STEP-NC features and prompted for corresponding inputs of manufacturing designated as workingsteps, operations, cutting tools, feeds and speeds consistent with STEP-NC ISO 14649 Parts 11, 12, 111 and 121 standards [3, 23]. ISO 10303 Part 21 physical file [85] automatically generated. In previous researches, STEP-NC translator developed by ISW, Stuttgart and Siemens used to convert into Siemens proprietary format for a system developed from ISO 14649 Parts 12, and 121 standard MPF file. This file has been directly supported on any CNC workstation equipped with Siemens controller and Shop Turn CAM software [87].

5.4 Turn-mill Operations

Turn-mill schema suggested on this research has been designed to accommodate technology specific data types regarding machining features and processes for turn-mill operations using ISO standard. Its content abides common practices of machining i.e. the two categories of machining operations namely roughing and finishing. As it has been represented in the information model given at Figure 5.2. The operations provided on the proposed system are under machining operation which is a sub class of operation. Figure 5.6 shows EXPRESS schema of ISO 14649 object entities definition instantiated in representing turn-mill machining operation from *machining_operation* class. In a turn-mill, workingsteps include manufacturing features and machining operations as referenced in *milling_feature, turning_feature, milling_operation, turning_operation* respectively which has inheritance relationship to *machining_operation* (ABS) super class.

```
Public Class AbstractMachining_operation

    Public operation_id, retract_plane As String
    Public milling_machining_operation As New Abstructmilling_machining_operation
    Public turning_machining_operation As New Abstructturning_machining_operation
   Public turn_mill_maching_operation  As New  Abstractturn_mill_machining_operation
    Public its_machining_strategy As New two5D_machining_strategy

    Public start_point As cartesian_point

    Public its_machining_tool As New Abstractmachining_tool

    Public its_technology As New Abstracttechnology
                Public its_machine_functions As New Abstractmachine_functions
    Public its_machine_tool As New Abstractmachine_tool

End Class
```

Figure 5.6 EXPRESS Schema for Machining_operation (ABS)

*5.4.1 **Turning Operations***

ISO 14649-12 constitutes operation class of turning machining since the information model independent to machine tool and based on feature related to tool motion. These operation classes can be used for representing part of turn-mill components. UML representation of turning_operation is shown under machining operation in Figure 5.2. Its EXPRESS representation of the proposed system is given in Figure 5.7.

```
Public Class Abstructturning_machining_operation
    Public approach_retract_strategy As New approach_retract_strategy
    Public facing As New Abstructfacing
    Public grooving As New Abstructgrooving
    Public contouring As New Abstructcontouring
    Public threading As New Abstructthreading
    Public knurling As New knurling
...............
  End Class
```

Figure 5.7 EXPRESS Schema for turning_machining_operation(ABS)

5.4.2 Milling Operations

ISO 14649-11 covers the base class for milling and drilling type operations. The class structure representation has been given under (ABS) super class of *machining_operations* in Figure 5.2. This operation class used for developing parts of turn-mill components in turn-mill manufacturing environment. The given UML representation displays the general structure of *milling_maching_operations*.

5.4.3 Integrations of Manufacturing Operations

Integration of manufacturing has been considered on a machining operation level in a STEP-NC. This has been preferred to accommodate process planning data of one or more feature performed with identical cutting tool, roughing and finishing cuts in single workingstep by incorporating step by step machining feature consideration. Therefore; the process capability and constraint of turn-mill machine workstation has been integrated with a CAPP/CAM system using ISO 14649 data model.

As it has been seen in the Figure 5.2, the manufacturing model presumed from ISO 14649 part 11, 12 and turn-mill operation class as proposed by ISW-Stuttgart

[19]. It is also a means to interlink product data model with the process capability of the turn-mill machine enabling the corresponding operation data mapping with specific machine tool resource. This operational level machining information needs a corresponding manufacturing feature. The general manufacturing information has been given in ISO 14649 whereas related machining features definition has been given on ISO 10303 AP224.

In the proposed system, two information layers in EXPRESS are formed. The primary layer used to represent each machining feature and machining operation designated as a logical layer with descriptions of required parameters. Serialization of the logical layers based on the process planning requirement generates a corresponding STEP data file. The secondary layer has a physical layer and used STEP data file structure which can be desterilized in to EXPRESS schema defined in logical layer. These schemas constitute the methodology used to pass process planning tasks through different platforms that confirms data integration.

5.5 Machining Feature Library

Machining feature library provided a collection of geometric data representation which has been used to identify shapes. These shapes designated volumes of materials that are resulted from various tasks of a machine tool. In this research, two5D_manufacturing features defined in ISO 10303 AP224 document are used to establish a manufacturing feature library suitable for turn-mill machining components. Figure 5.4 displays product data information model constitute most of the useful features suggested in the proposed system in accordance to the adoption made considering turn-mill machining requirement. The Visual Basic dot NET has been utilized to define every feature class in EXPRESS model. The system also maintains the inheritance relationships among the classes of machining features, operation and attributes required for representing turn-mill machining environment.

Object oriented methodology and machining feature library extended form features information for adaptability of variability (and communality) application in terms of capability, operating environment, domain technology and implementation[88]. Machining features developed for turning and milling operation provided objects reused for turn-mill capability, technology and implementation. The implementation of object oriented-feature based design in concurrent engineering with in STEP-based machining realized process planning architect provided unit interface and management [89].

SCSTMO developed mechanical product definition for computer process planning of form features given under STEP AP 224. These entity sets defined under the class of (ABS) *manufacturing_feature* represented in the Figure.5.8. It is excerpt of ISO 14649. It includes entities of *turning_feature, milling_feature.*

Based on the requirements of turn-mill machining, a machining feature library have been organized with reference to ISO 14649 on the EXPRESS schema as shown in Figure 5.9 and bind with Visual basic dot Net object oriented programming. The platform provided the attributes of the features in execution of the system implementation.

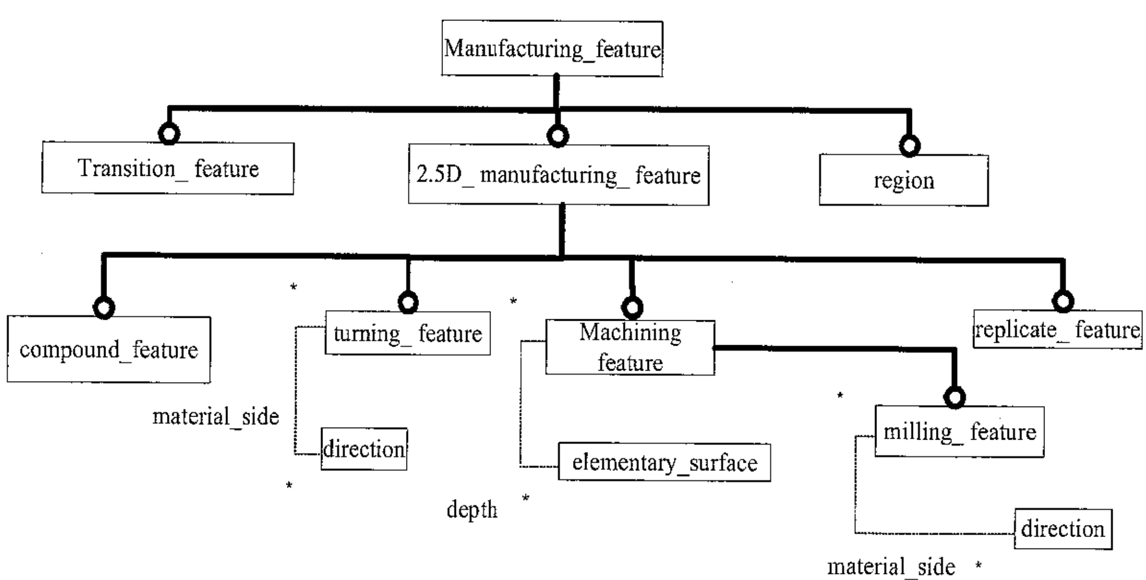


Figure 5.8 Inheritance Relationships and Location Information of Turning and Milling Features in ISO 14649 Part 10.

```
Public Class Abstractmanufacturing_feature

   Public its_id As String
   Public Two5D_manufacturing_feature As New AbstractTwo5D_manufacturing_feature
   Public region As New Abstractregion
   Public transition_feature As New Abstracttransition_feature
   Public its_workpiece As New workpiece

End Class
```

Figure 5.9 Class of *manufacturing_features* of the Programming System

5.6 UML REPRESENTATION OF THE SYSTEM

The UML representation used to depict the class diagram of SCSTMO. It is mainly to address the requirements of turn-mill manufacturing environment. The computing tools are required to bind the developed classes according to their inheritance relationship. The Visual Basic dot Net programming language served for this purpose in this research. It allows an object oriented methodology and representation by using UML modeling language. The information models enables an XML schema from the classes of the system and serialized for generating a process plan document representing modules of production tasks such as operations and strategies. These data model representation of UML abides data model structure of ISO 14649 part 10 [22], ISO 14649 part 11 [3] and ISO 14649 part 12 [2]. Correspondingly graphical user interface (GUI) has been developed on the bases of STEP-NC manufacturing systems given in the literature review and turn-mill machine capability. The system started with interface for submitting general information related to SCSTMO. The rest of the system progresses on the perspective of product and manufacturing models to support additional requirement for constructing conceptual information of manufacturing environment. The task description and the system architect of the proposed system presented in Chapter 6.

5.6.1 Machining Features

Figure 5.10 and 5.11 show the contents of turning features classes and milling feature classes respectively that are included in the proposed system. Most of the classes have other sub-classes as given in the Figure5.10 and 5.11. This representation can accommodate new definition or existing features in reference to the respective features classes such that definition would be recognized. Appendix D.1 shows the super class of the features in the pseudo code for product data to be included in STEP-NC process plan file generation.

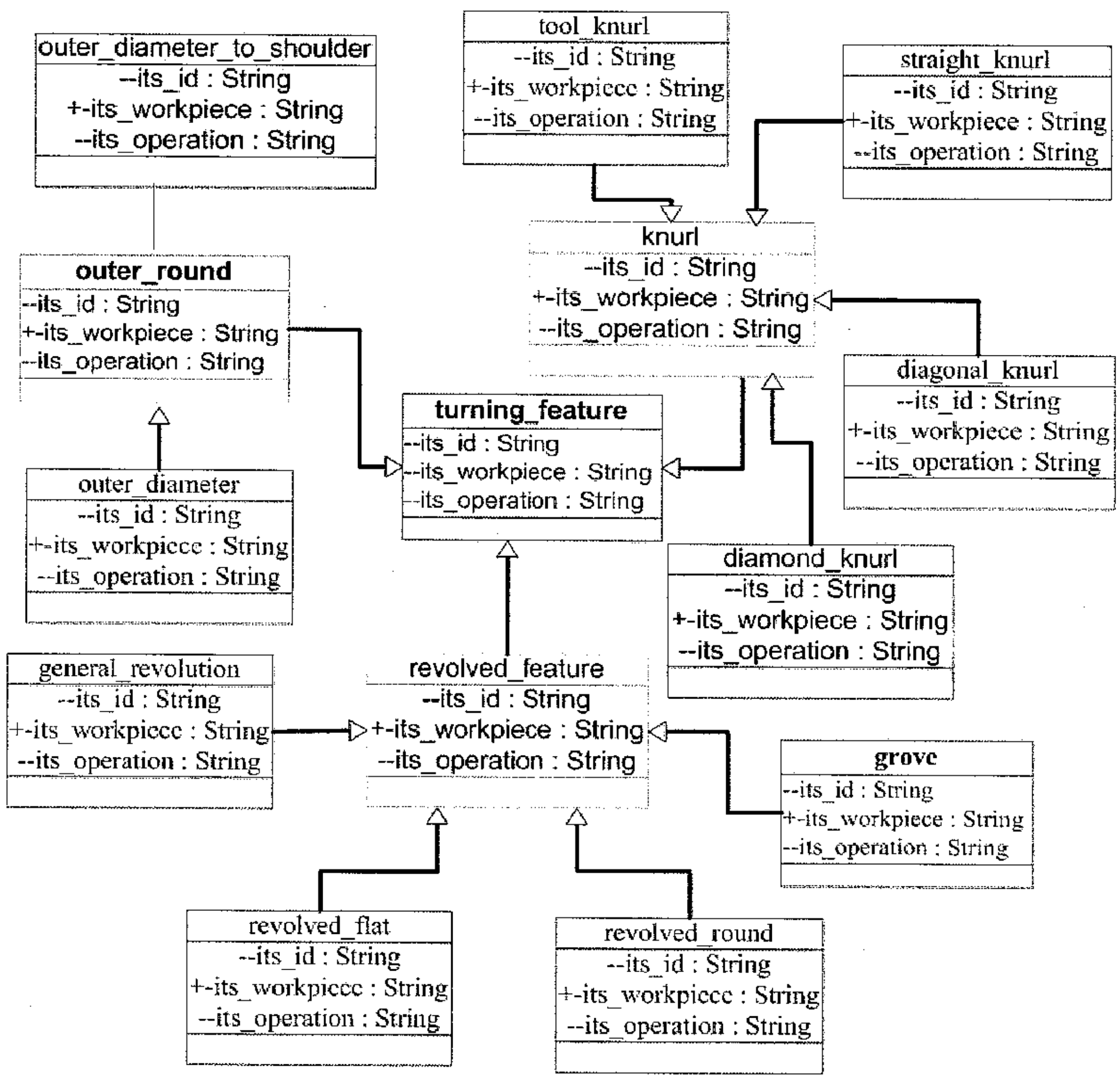


Figure 5.10 UML Diagram for the Turning Feature

The UML representation for turning_feature and milling_feature in Figure 5.10 and Figure 5.11 are exploded detail inheritance relationship of their sub-classes.

Figure 4.2 indicates the basic structure of Super-classes of turning_feature, milling_feature, turning_operation and milling_operations summarized for the workingsteps of turn-mill. Figure 4.3 shows the overview of these super-classes stressing on the main data model structure of ISO 14649.

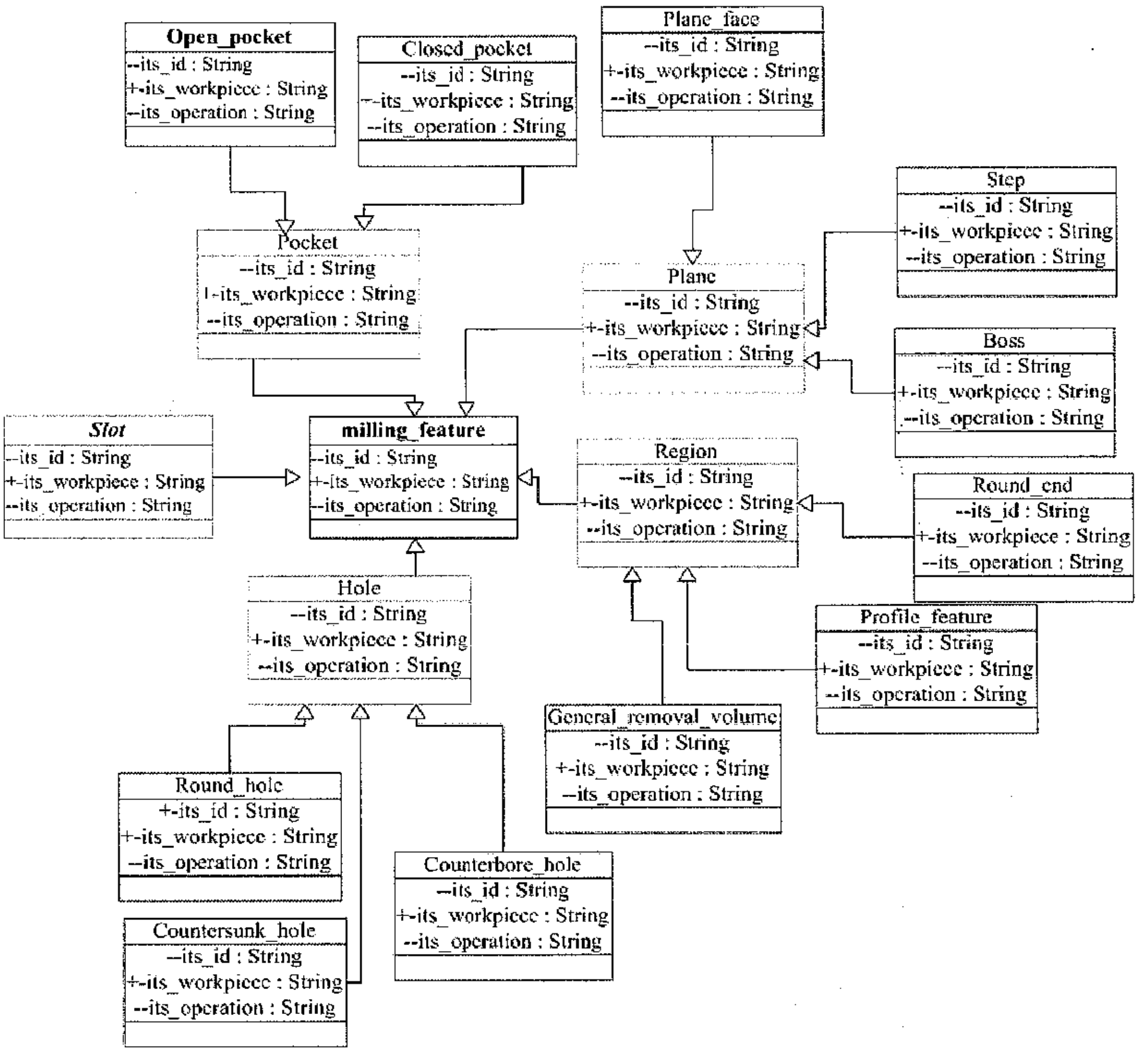


Figure 5.11 UML Diagram for the Milling Feature

5.6.2 Turn-mill Classifications and Representation

There are two levels of turn-mill machine classifications, namely high-level and low level turn-mill feature classifications. The former classification considers number of turrets and spindle types as given in the Figure 5.12 where as the later is based on the generic machine tool capabilities such as Y-axis capabilities, tool indexing time and machine accuracy [90]. The proposed system uses the high level turn-mill classification for selection of the machine type and considers the low level classification in its static data type information of native process plan document.

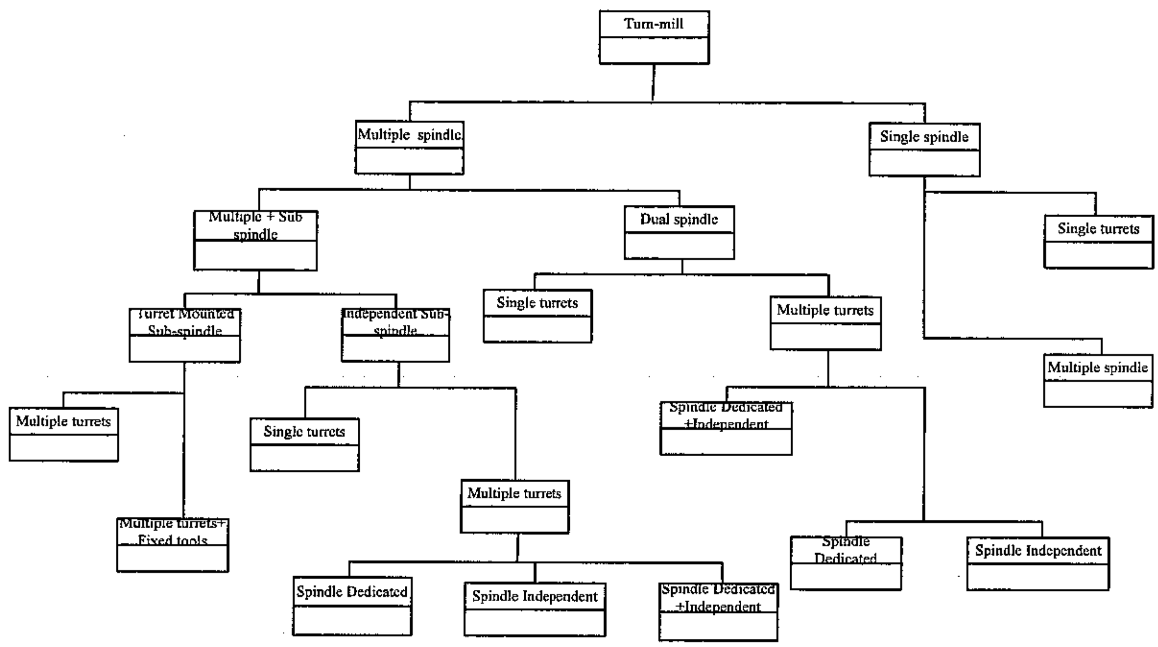


Figure 5.12 turn-mill classification [90]

5.6.3 Machining Strategy

Manufacturing strategy for milling and turning operations are identified as two5D milling strategy and turning machine strategy .They are defined under the manufacturing operation super class. Figure 4.10 included two5D milling strategy as sub class of two5D milling operation and turning machine strategy as sub class of turning machining operation in the previous chapter.

5.6.4 Manufacturing Resources

Manufacturing resource model for the proposed system is constructed to fulfill manufacturing information requirement. The main perspectives are process planning, STEP-NC and route of process planning. It has focused on the representation of machine tools and auxiliary device in STEP-NC. Manufacturing resource for turn-mill manufacturing intended to accomplish turning, milling and turn-mill operations routes. It has also included entities of auxiliary devices that are peculiar to turn-mill machine which are also basic constituent elements to form a unit machine entity.

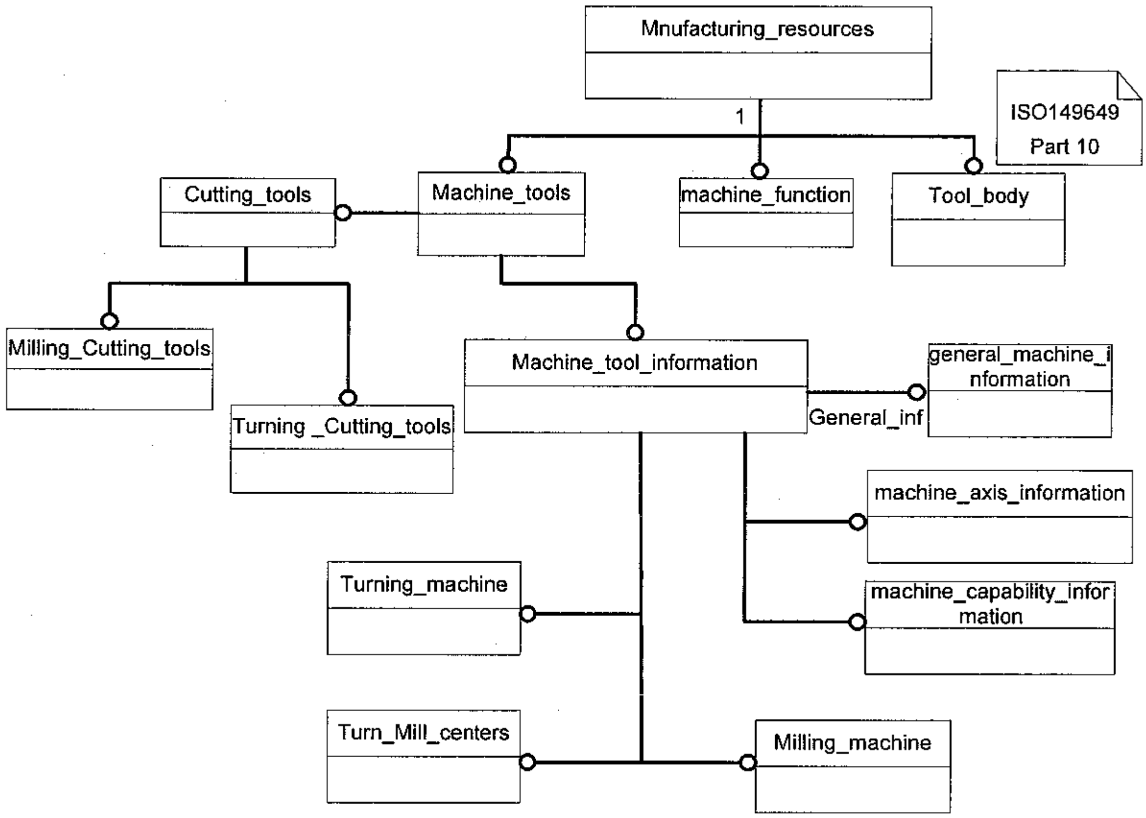


Figure 5.13 Manufacturing resource class diagram

Figure 5.13 represented manufacturing resource class of the proposed system in relation to ISO 14649 Part 10. It shows that *machine_tool* class is the super class for machine tool general data, machine tool capability and it is also includes machine tool specific components under the respective machine tools such as *turning_machine, milling_machine* and *turn-mill_centers.*

SCSTMO (ABS) *machine_tool* class has been given as a sub class of (ABS) machining_*tool* class in Figure 5.14.It is a sub class comprised of axes, spindle, auxiliary_devices, chuck etc... In this class *machine_tool*_capability has been given under turn-mill class. It supports to make an adoption of STEP-NCMtDm for a turn-mill information data set representation. The programing system has also included kinematic links of turn-mill machine configuration as shown in Figure 5.15 that can be considered in Native STEP-NC process plan document generation.

5.6.5 UML Diagram Representation of SCSTMO

Figure 5.16 shows UML diagram representing elements of workplan for turn-mill and Figure 5.17 a UML diagram representing the general model of the programming system. In the former Figure the product model and manufacturing model constructed with regard to turn-mill manufacturing has been considered to develop a model for SCSTMO based on STEP-NC schemas defined under (ABS) *machining_tool*. The model represented product and process flow modules of the system under workplan. In the latter Figure 5.17 all object classes and inheritance relationship among them in the programming system has been indicated.

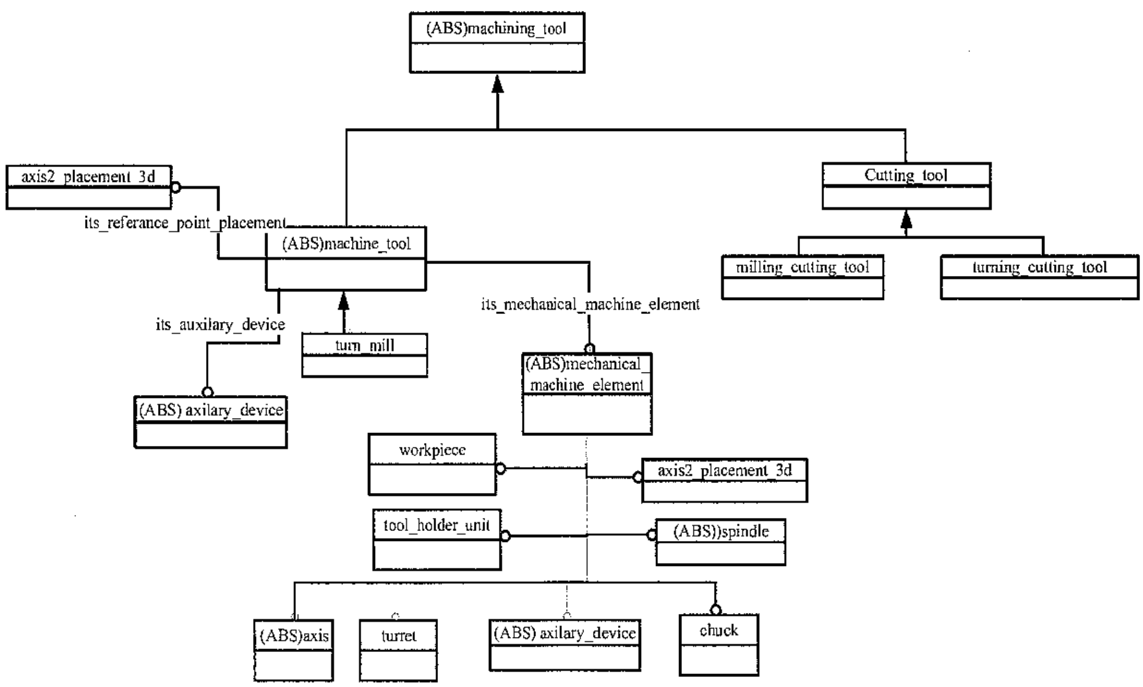


Figure 5.14 *machine_tool* class diagrams representing turn-mill center

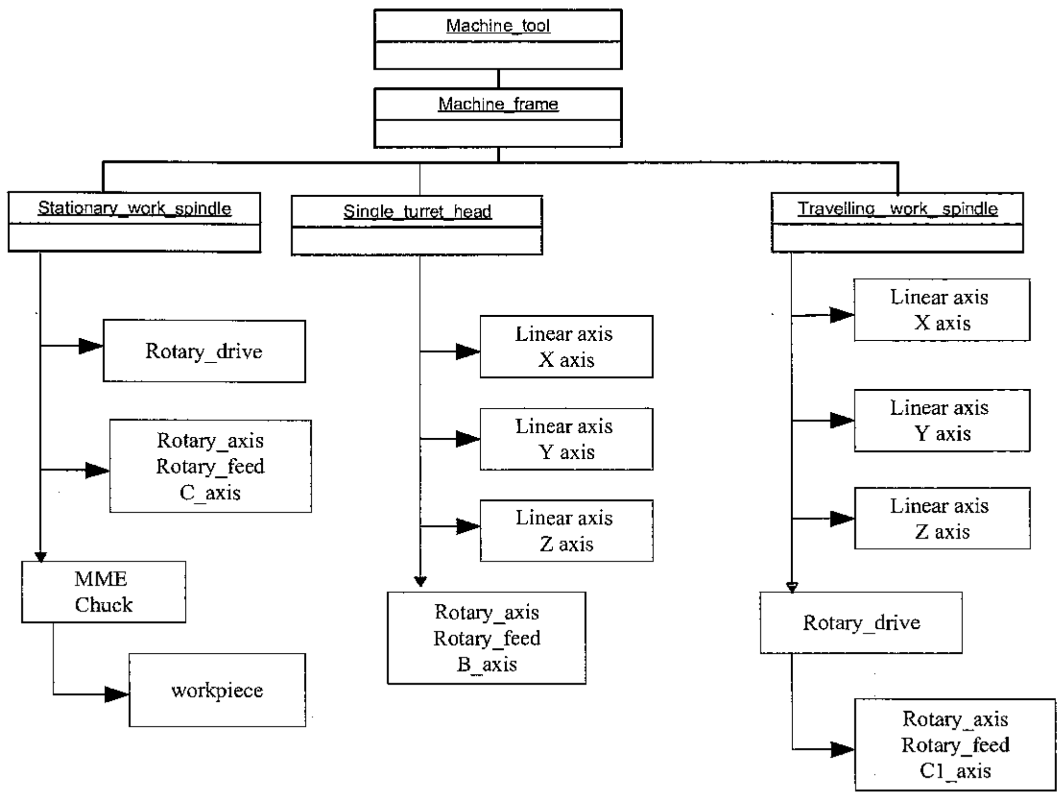


Figure 5.15 UML diagram representing kinematic links of turn-mill configuration

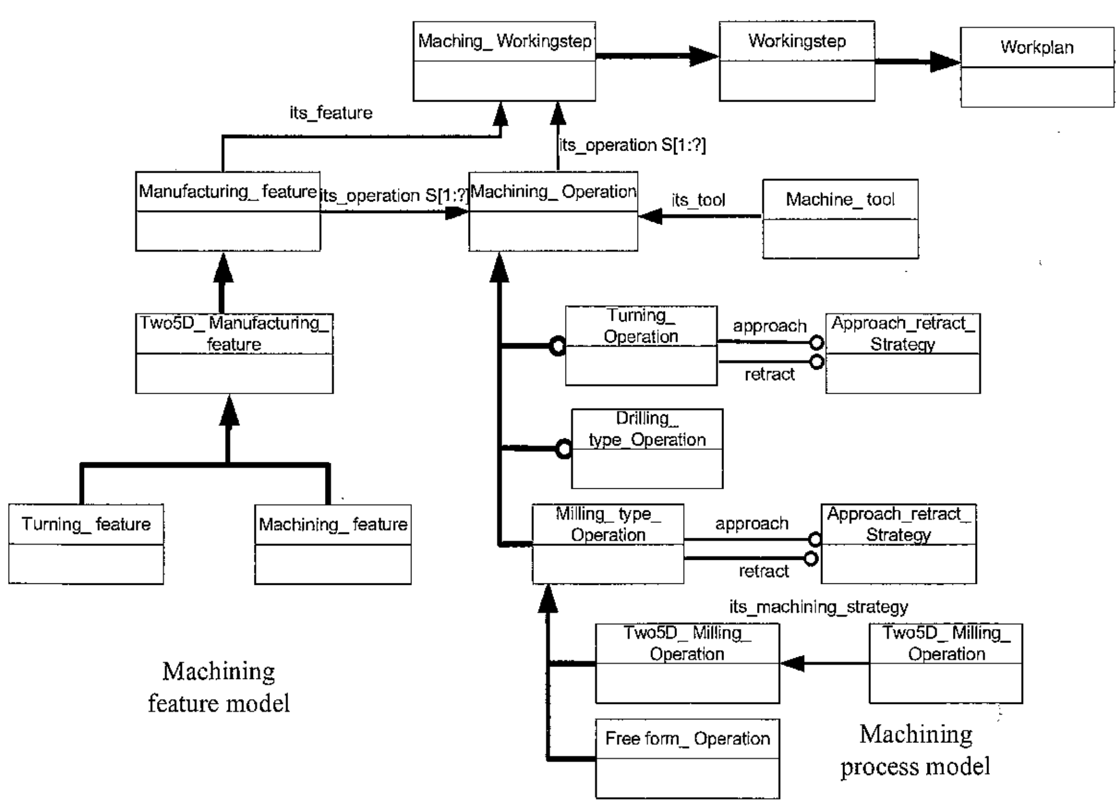


Figure 5.16 UML diagram representing elements of workplan for turn-mill operations

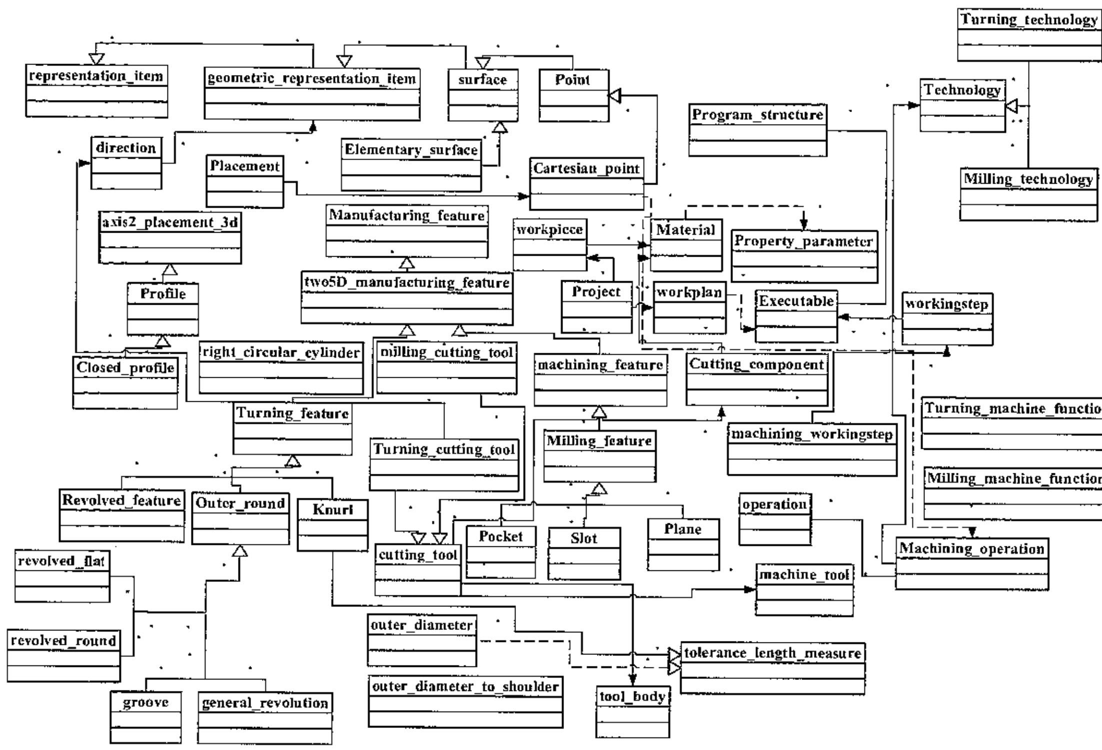


Figure 5.17 UML diagram for SCSTMO

5.7 Summary

This chapter used a STEP-based product model in EXPRESS model comprising requirement information for turn-mill manufacturing. It presented a STEP-compliant information model (UML diagram) that supports turn-mill operations. The models include turn-mill machine classification based on higher level machine feature information. ISO 14649 contents have been used to develop requirements of machining feature, machining operation and strategy of the system.

An object oriented modeling and EXPRESS class in visual basic dot Net has been used to develop a platform binding product, manufacturing and machining resource information to address turn-mill manufacturing environment. The system used methodologies of an Integrated Definition for Function Modeling (IDEFO) and UML to develop STEP implementation of product and manufacturing model on turn-mill capabilities. The following chapter will discuss an illustration of the developed system on a turn-mill components manufacturing regarding Generic and Native STEP-NC file.

CHAPTER 6

PROGRAMMING SYSTEM AND TESTING

6.1 Introduction

The implementation of programming STEP-NC model given in chapter 5 has been used to discuss the proposed system in this chapter. It emphasis the accomplishment of STEP-NC compliant system framework developed in chapter 4. Here, the focus is on the adoption of ISO 14649 contents to establish an implementation regarding turn-mill operations. It discusses requirements of the system representation such as information model, cutting tool data bases, user interface and process plan file output in STEP. The functionalities of the system described on a prototype bases. As the previous Chapter 4 and 5 covered information model and the design model of the system respectively. The foundation and outline of functional module, domain of the system specifications, design and structural methodology on the requirements of turn-mill manufacturing environment have been laid out.

This chapter includes brief explanation and illustration of STEP Compliant System for Turn-mill Operations (SCSTMO). It also includes adoption of STEP compliant system working with machine tool data model. This prevail the importance of an integrated CAD/CAPP system established on an object-oriented approach. That generates process plans supporting concurrent design based on machining feature approach. It comprises logical knowledge representations of the real objects [91-92]. It provides representation and selection of design components and manufacturing resources that offers advantages of increased flexibility, incremental system development and reusability.

The presentation begins with the overall architecture of the system development, flowchart and implementation details with regard to manufacturing information categories. These are design representation of the product, manufacturing information of the product and machine resources information. They are represented in the UML models given in the previous chapters. Finally, the implementation provides a generic STEP-NC Part 21 file and its native counterpart related to specific turn-mill machine.

6.2 Development Tools and Implementation Architect

The system is Microsoft Windows-based, and was built using the object-oriented modeling techniques. The principal programming language is Visual basic® in a Visual Basic dot NET platform. Visual Basic dot Net® is used for developing and processing classes of STEP and STEP-NC data, and OpenGL® (Open Graphics Library) is used for visualizations of case study product representation.

6.2.1 Microsoft Visual basic Dot NET 2005®

It is used as an integrated development environment and facilitate adoptable STEP-NC interface. The basic classes are developed on the basis of the assumptions made on using ISO 14649 CNC data models with regard to STEP compliant manufacturing environment reviews. These are drawn from previous works on promoting a unit suit amalgamate of ISO 14649 Parts 10, 11, 12, 111 and 121 representing STEP-compliant manufacturing for turn-mill operations as a subject of ongoing research. [2-3, 22-24] This has been dealt by the developed STEP compliant model assigned as SCSTMO. The Architect used to accommodate the information model and requirements of the programming system has been given in the section 6.2.3 of Figure 6.1.

The EXPRESS class of ISO 14649 data model, defined on visual basic dot NET, offers libraries for reading, writing, processing, checking and developing of STEP data Part 21 or Part 28 formats. It allows editing of the process plan through design and manufacturing stages of the product development. This has been possible with Serialization and De-serialization [93] class which enables functionalities of the class libraries listed in the system architect of Figure 6.1. The classes provide support database connections organized for cutting tools.

6.2.2 OpenGL®

OpenGL® is introduced in the proposed system to develop an interactive 2-D and 3-D graphics representation of a product. It creates most complex lighted and texture-mapped NURBS curved surface by rendering simple geometric point, line, or filled polygon. Therefore; industry application software such as CAD, CAM and CAE widely utilized to adopt OpenGL. In this research, OpenGL is used to display 2-D model defined by a STEP-NC physical file for visualization of case study product or feature and ease the implementation procedure with regard to specific machine tool data.

6.2.3 Architecture of the System Implementation

The architecture shown in Figure 6.1 describes the system components for deploying Generic and Native STEP-NC files. The implementation system enabled to extract machining features designations from CAD system which has ISO 14649 machining feature representation. This has been established by commercial graphic software such as Unigraphics for the case at hand and also other digital machine tool. In the former case Deserilization class read Part-21 file, where a user defined graphical object model constructed for the latter case. This data model is stored in XML schemas which enable to integrate the feature model data constructed with manufacturing and cutting tool data to generate a Generic STEP-NC file. This file also transformed to a Native STEP-NC file with the additional consideration of machine tool specification with regard to machine tool data model included in the XML schema from EXPRESS representation.

Figure 6.1 displays the interaction of the system model with Part-21 digital output, XML schema as file storage of the data models and EXPRESS representation for the various level information requirements of a process plan and finally the system output in accordance to specific consideration with the help of STEP-NC interface established.

These system components of SCSTMO enable STEP-NC document generation represented by the flow chart given in Figure 6.2.

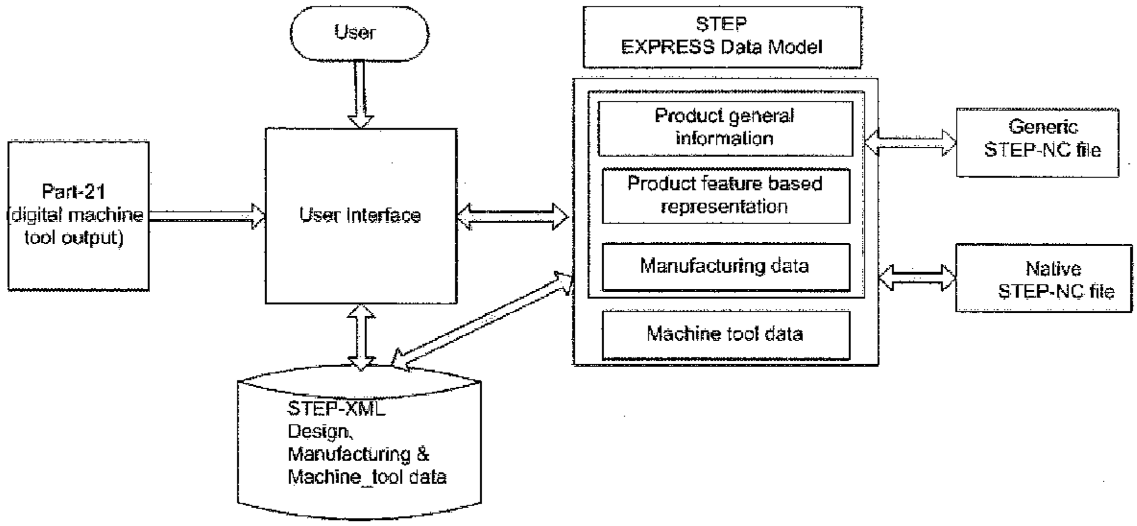


Figure 6.1 Implementation System Architure

6.2.4 Flow Chart of the SCSTMO

The system functionality consists of three main subsystems serving as selection and edition of information related to; base shape and manufacturing features, manufacturing operations and its attributes and STEP-NC program generator as shown in Figure 6.2. In SCSTMO, the user has two options Figure 6.2 (1) and Figure 6.2 (2) in the first subsystems that are either use to read or search a machining feature from process plan data in AP-21 format then define feature attributes by interacting with an EXPRESS representation of machining features class. Then the prepared interface used to complete the design information by summiting description of location and orientation in accordance to the developed interfaces. ISO 14649 11 and 12 machining feature domain geometric descriptions are utilized. As the available features are extracted from a corresponding Part-21 file in the first option, a user required to provide the placement and location information accordingly. In the latter option, the machining feature library given in Figure 6.2 used to define machining feature on a user selected base shape. The proposed system is limited to right circular cylindrical as an original part geometry or base shape. The execution given in the options above finalized with addition of cylinder length and diameter supporting the requirement given in section 4.8 of Figure 4.8.

The second subsystem has been used for execution related to function of manufacturing operations. In which manufacturing information selection and edition with regard to attributes of manufacturing operations such as machining strategies, machining technology, machine function and machine tool data bases performed based on the sequence shown Figure 6.2.

Finally, the third subsystem represented Generation of Process Plans document consists of workplan elements given in section 4.9 of Figure 4.9. As it described in section 4.11, an ISO 14649 data model sets and structure used to generate a STEP-NC process plan document which is editable at the machining feature and machining operation attributes set up phase with regard to specific needs. The following section describes the deployment of the proposed system on different stages of process planning on the basses of a system architect methodology aimed at illustrative process plan document development.

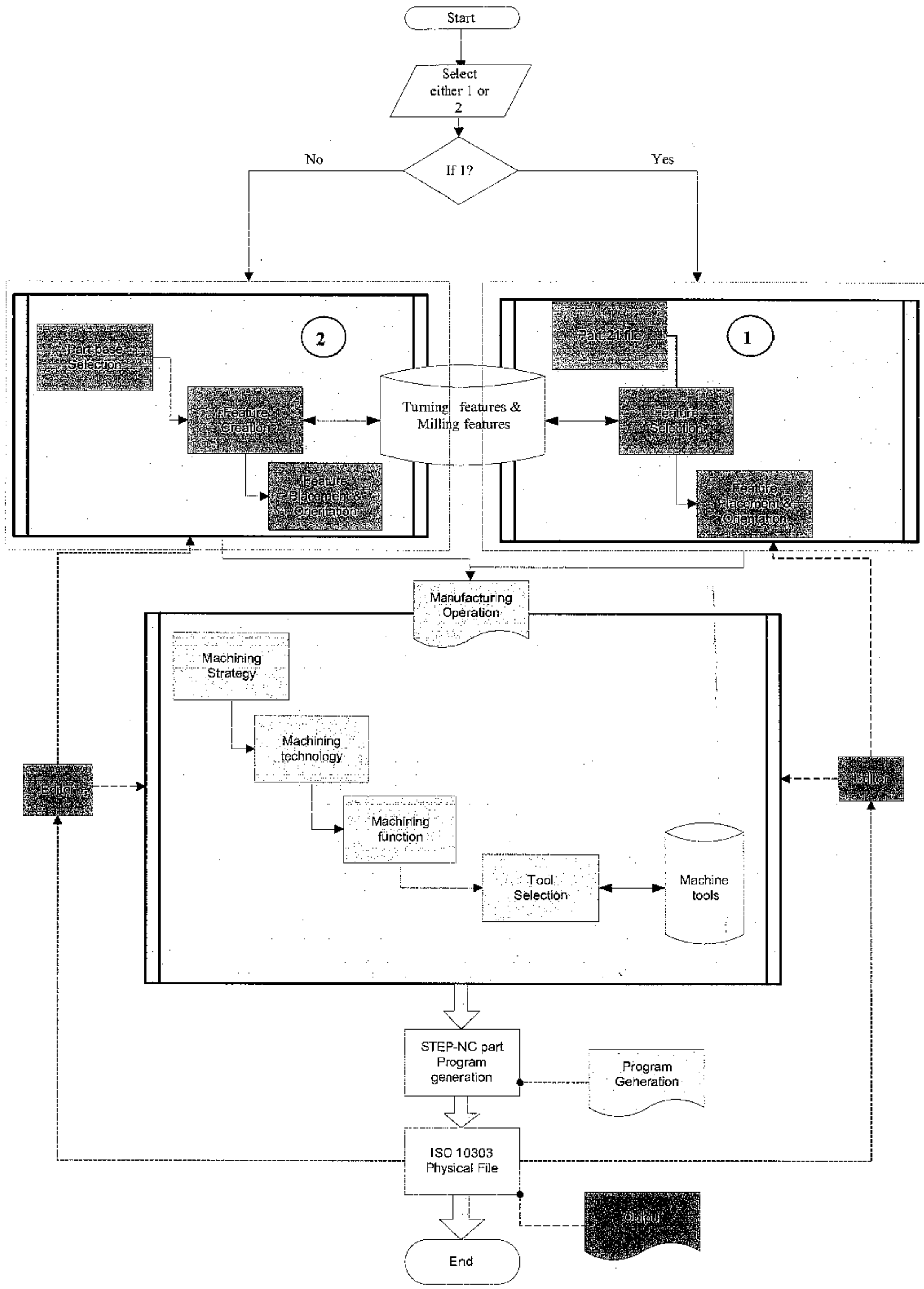


Figure 6.2 Flow chart of the proposed system

6.3 System Architecture

The system architect delivers tools and methodology of requirement representation, design feature and product on programming system functional modules. This has been used to establish prototype component. The development of the prototype provided four main functional modules. These are composed of: information model, Tool database, graphical user interface and a STEP file format representing output of the system as shown in the Figure 6.3.

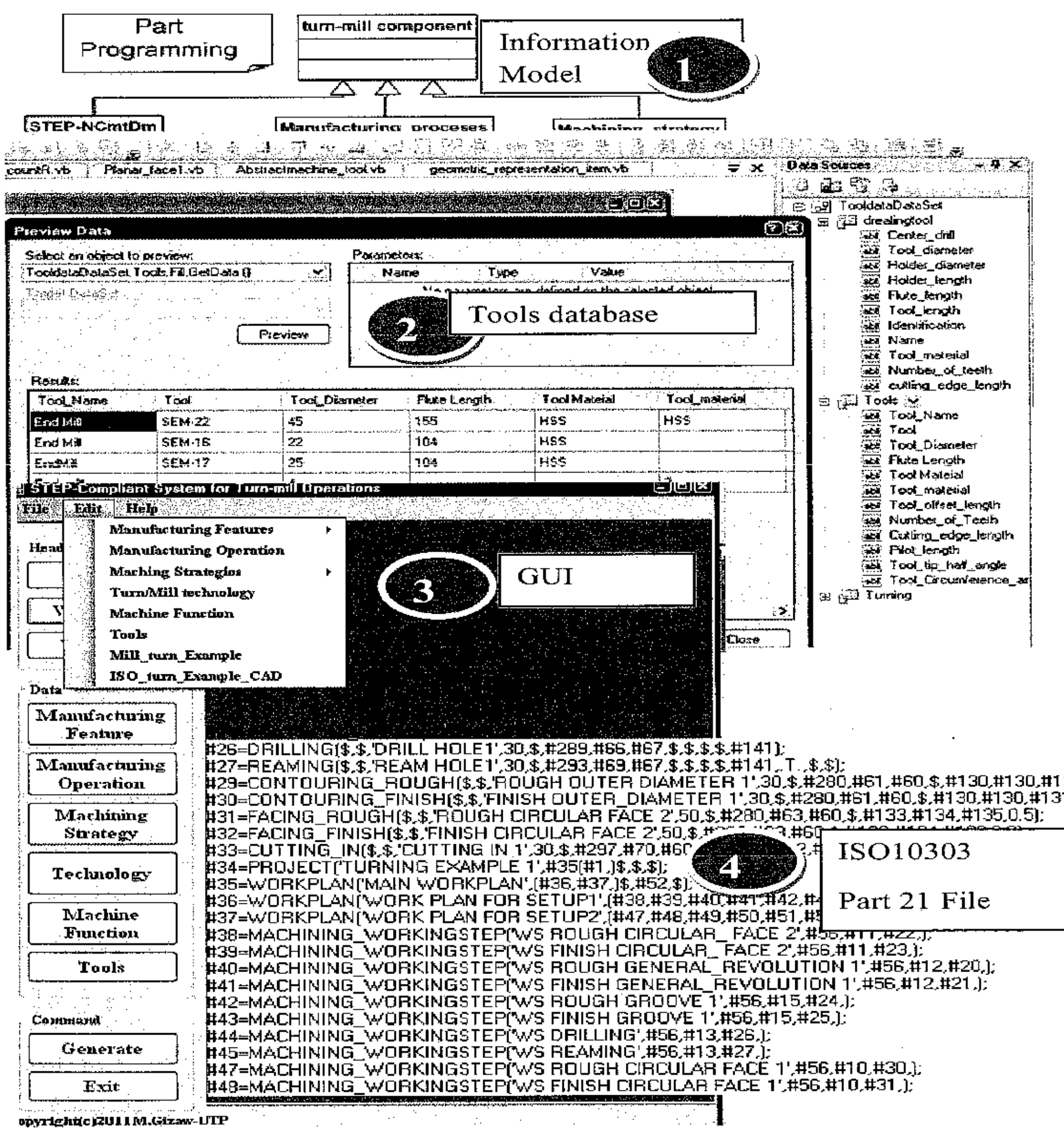


Figure 6.3 SCSTMO System Architect

The programming system information model and inheritance relationship has been given in Chapter 5. The functionality and importance of graphical user interface GUI along with integrated cutting tool database will be presented in the following prototype development. In the programming system development, manufacturing processes, resource and product geometry object representation and description sets have been managed by using IP3AC development methodology [25].

ISO 14649 data model classes are defined and implemented with IP3AC methodology on Visual Basic dot Net programming binding language. The organized ISO 14649 classes are represented in EXPRESS entities and governed the process plan file generation program that instantiates required entity attributes from Visual Basic.net classes.

6.3.1 System Deployment

SCSTMO established as a windows-based program which starts with login interface and enables the user to get into the main functional interfaces of the application through start up buttons or status bar commands. The interface allows a user to create a new model, Opening and editing an existing model. It also allow user to view SCSTMO instructions under help.

Figure 6.4 shows the main start up window of the programming system which allows us to access functional interfaces of applications via the buttons, pull-down menus and status bar commands provided. The interfaces allows user to construct new model, access and existing model either for editing or converting from Generative to Native file. The interface developed organized the buttons in accordance to ISO Part 21 file structure. Figure 6.5 shows an example activity diagram for a new feature addition. Detailed activity diagrams for SCSTMO are presented in Appendix B.

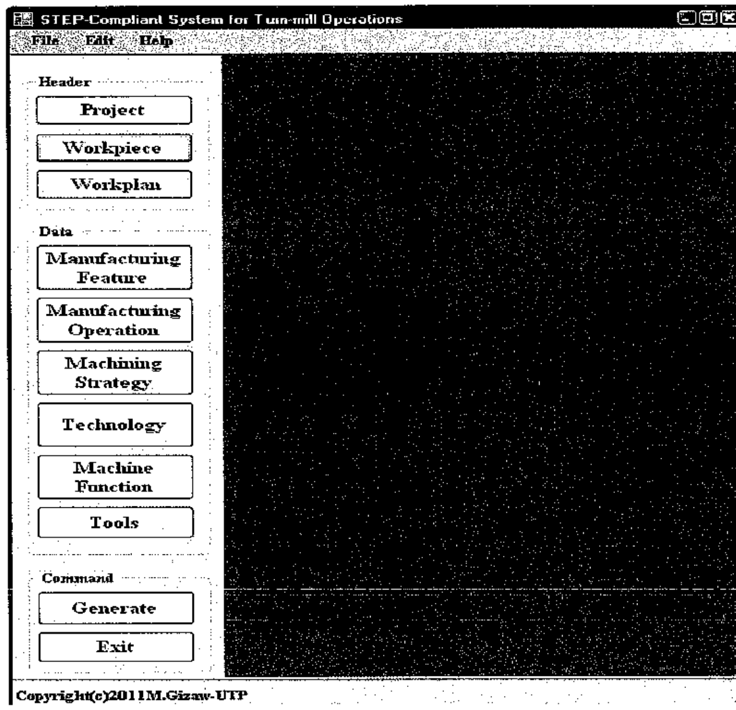


Figure 6.4 SCSTMO Start up Window

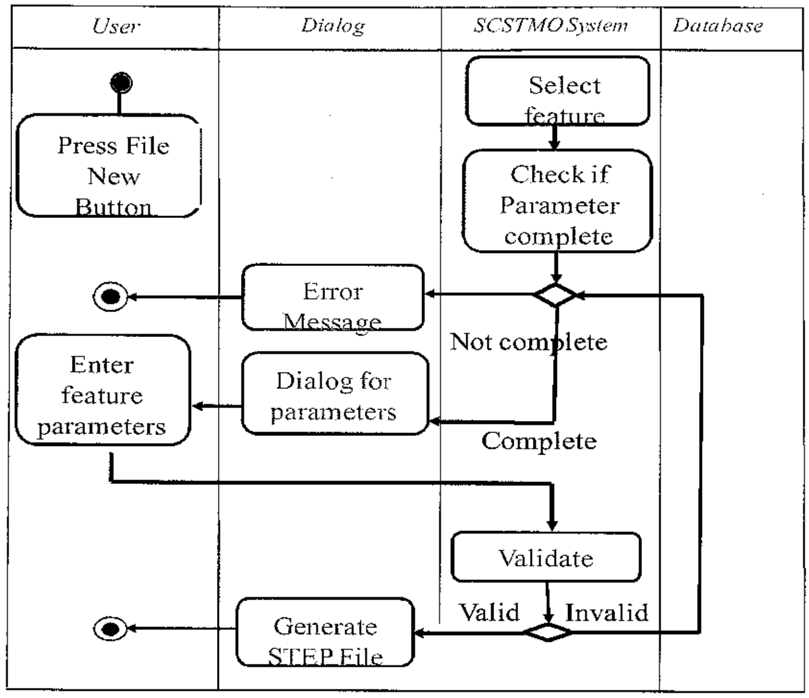


Figure 6.5 Example Activity diagram New feature addition in SCSTMO

6.3.2 Project User Interface

Every process plan document started with header information which can be governed by the project interface assigned for workpiece, workplan and project as shown in the Figure 6.6. These are used to establish a part program consists of top level entity of project class provided under ISO 14649 data model[22]. In this particular system, the project setup information and the sequence of workingsteps and the security plane location has been set up.

A process plan document in STEP-NC file format consists of Header and Data elements. The content and related interface of Header has been discussed above. The Data elements are composed of information about workpiece geometric information using feature based representation. It has corresponding machining workingstep information with manufacturing and cutting tool information requirements related to machining features. In addition, machine tool static and dynamic specifications with appropriate selection mechanisms are supported to convert a generative process plan document to native process plan. The detail of information description are included in a unit workplan that consists of workingsteps composed of geometric, machining and machine tool information specific to machining feature and machining operation.

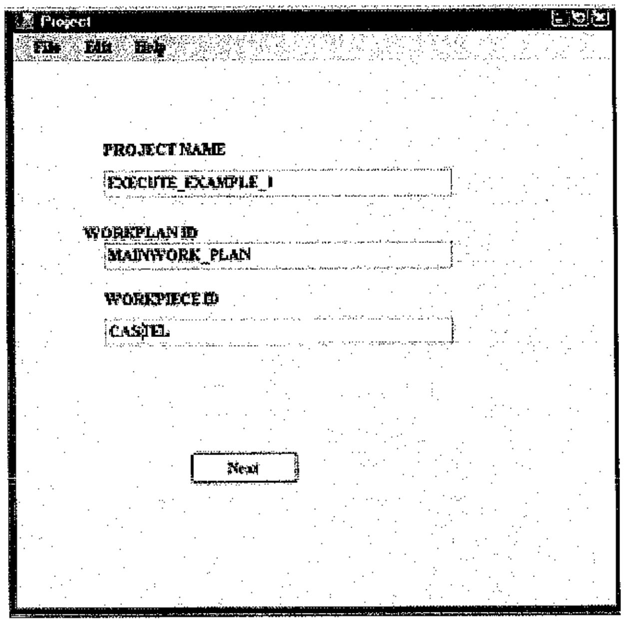


Figure 6.6 SCSTMO Project Information

The programming system has provided three modular options which are used for selection of machining feature type, machining operation attribute and machine tool capacity with specification. These are in accordance to the manufacturing information related to product, process manufacturing resource for process plan documentation. The following section illustrates functionality of the system with regard to a prototype developed.

6.3.3 Machining Feature Addition

ISO14649-10, 11 and 12 general machining data, EXPRESS information model and mechanical product feature description given on STEP-AP224 with additional modification identified Russo [11], constitute feature base design representation of turn-mill components. SCSTMO used the above representation to establish EXPRESS manufacturing classes which provide a feature addition after a specified base shape part selected the interface proposed has been given in Figure 6.7. This feature selection interface followed by corresponding interface that enable a user to define attribute of a specified machining feature.

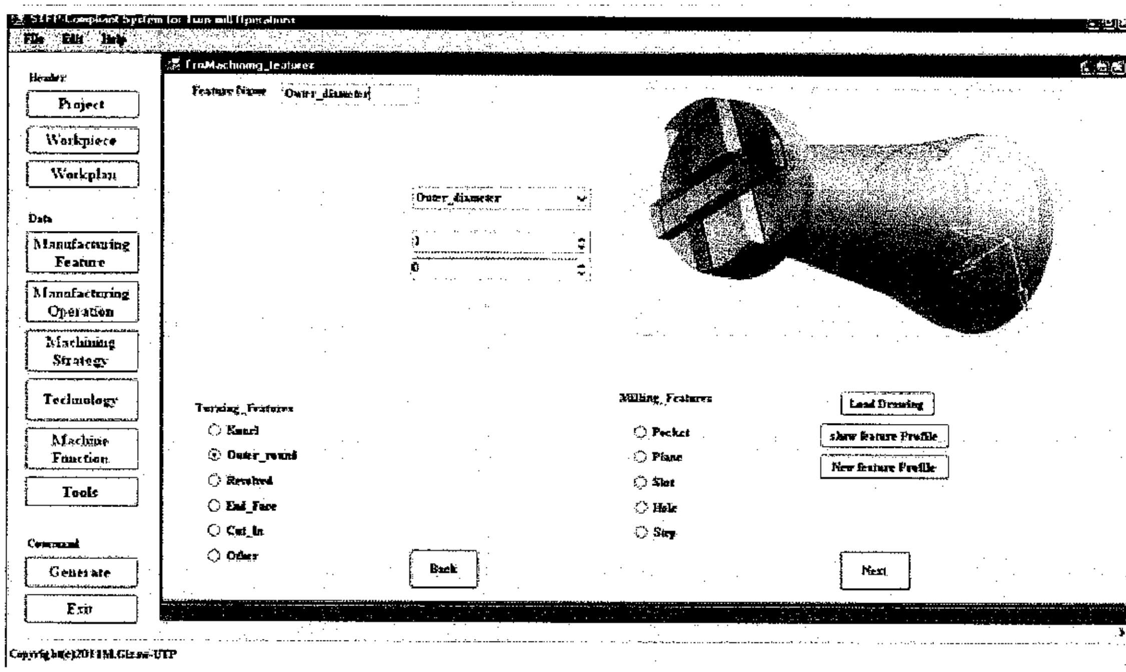


Figure 6.7 SCSTMO Turn-Mill Feature Selection Dialogs

6.3.4 Turn-mill Machining Operations

The main purpose of the preprogramming system is to represent the manufacturing capacity of a turn-mill machine tools. Basically, turn-mill components are composed of form features which are mostly expressed by a feature based design representation of STEP. Therefore; a corresponding class of manufacturing operations given in ISO14649-11 and 12 have been used to establish an implementation system for a turn-mill environment as suggested by Russo [94].The UML representation for these class of manufacturing operations has been given in section 5.2 of Figure 5.2. The system included an interface given in Figure 6.8 allows the user to edit or submit required information regarding manufacturing operation attributes.

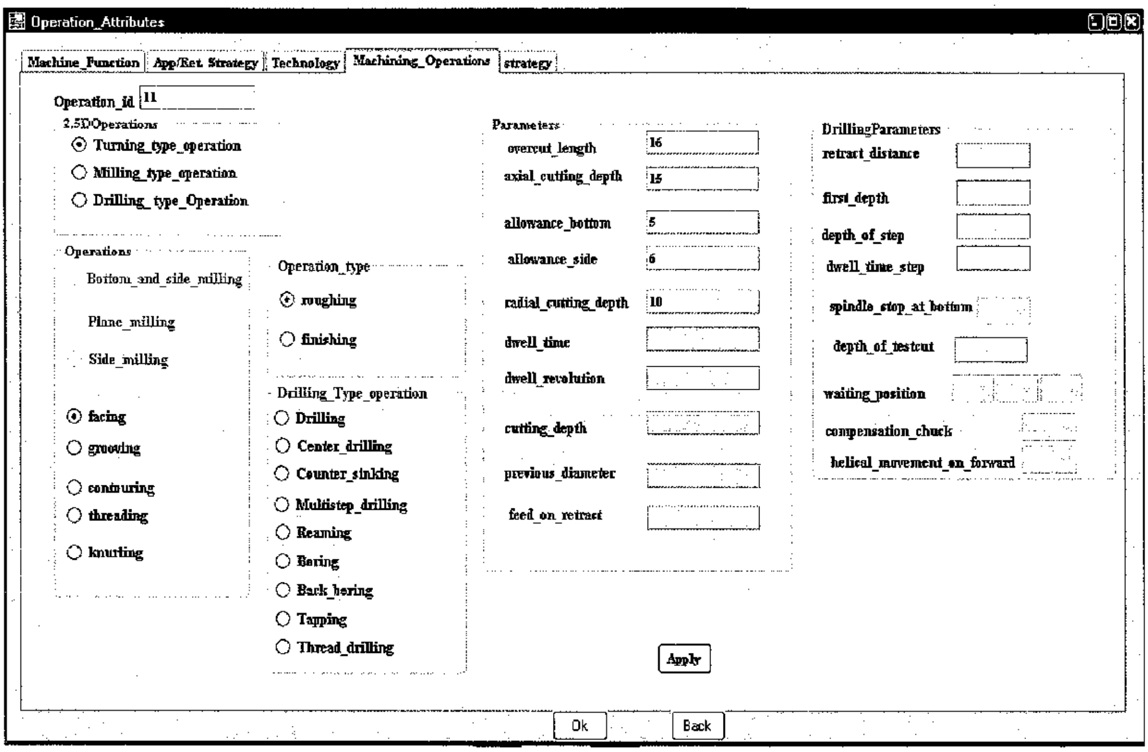


Figure 6.8 SCSTMO Turn-Mill feature operations dialogs

6.3.5 Machining Strategies

As it is represented in Chapter 5 information model design, the proposed system accommodates ISO 14649 Part 11 and Part 12 [2-3] milling and turning machining strategies which has been defined as a subtype of *machining_strategy* in ISO14649-10 [22]. They are used to create a turning and milling tool path respectively for a turn-mill machining environment with the respective operational module of the machine tool. The EXPRESS class of *machining-strategy* defined in Visual Basic Dot Net is shown in Figure 6.9 and a corresponding dialog developed based on the schema is given in the Figure 6.10. The interface served as a medium for selection and planning among available machining strategies.

```
Public Class two5D_machining_strategy
    Public Drilling_type_strategy As New Drilling_type_strategy
    Public two5D_milling_strategy As New  Abstracttwo5D_milling_strategy
    Public turning_machining_strategy As New Abstructturning_machining_strategy
End Class


Public Class Abstracttwo5D_milling_strategy
    Public overlap As String
    Public unidirectional As New unidirectional
    Public bidirectional As New bidirectional
    'Public feed_direction As New direction
    'OPTIONAL positive_ratio_measure
    Public multiple_passes As Boolean
End Class
```

Figure 6.9 Machining Strategies

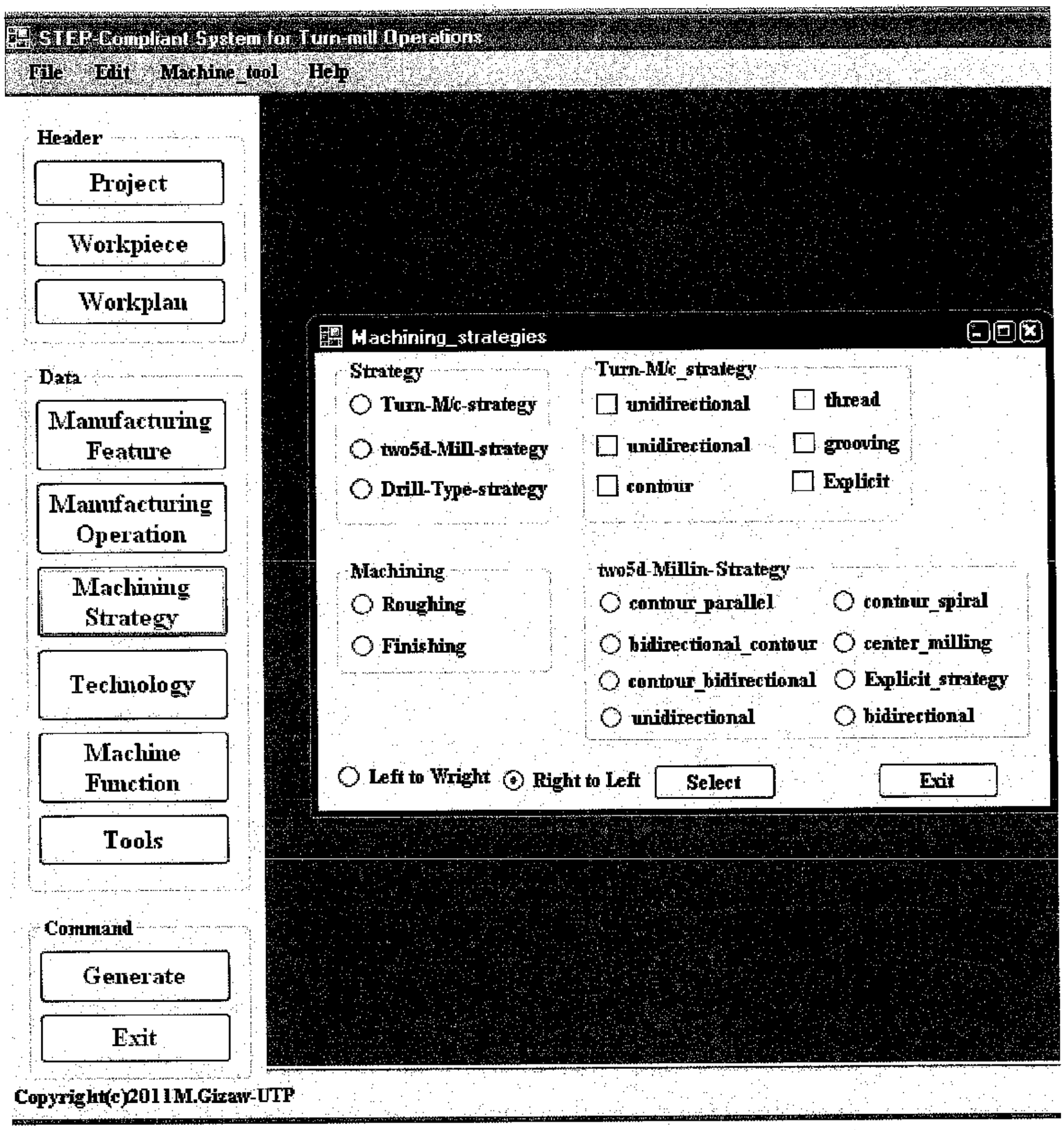


Figure 6.10 Turn-mill Machining Strategies Dialog

6.4 SCSTMO Editor System

In the system, the process plan document can be edited in two ways i.e. either using an integrated interface which allows selection or accessing two5D manufacturing features or using an alternative interfaces that can allow selection of turning and milling machining feature independently. Here, the system allows performing edition of the information sequentially as preferred by the user. Figure 6.10 shows the dialogues representing the latter option. Here the class of feature library organized in section 5.6.1 of Figure 5.10 and 5.11 shows the inheritance and attributes of machining features requirements which can represent a turn-mill component description based on ISO 14649 Part 11 and 12.

The programming system dialogs shown in Figure 6.11 allows the user to make a modification and interaction to a process planning document at any preferred stage. The functional modifications that can be performed by the system are related to *machining_feature, operation_attribute* and machine tool selection.

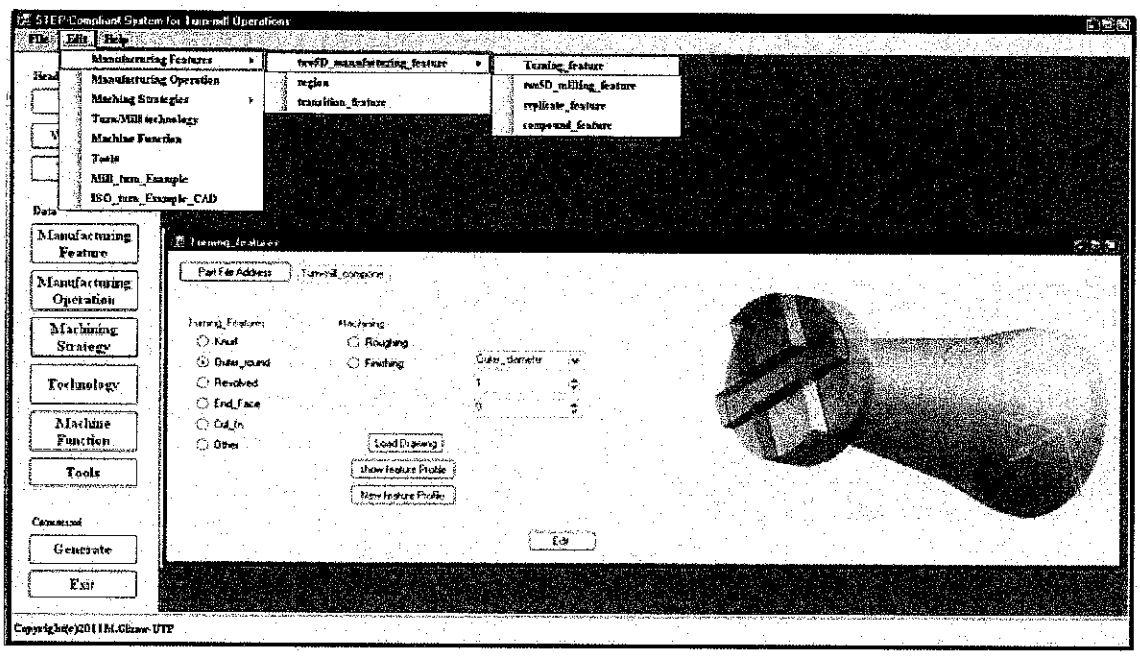


Figure 6.11 SCSTMO Turning Feature Editor Dialog

6.5 Process Planning Dialogs

The above procedures allows the user to prepare a process plan document by using either of the above method for preparing a user defined document in AP 21 or AP 28 file format. As it is indicated the system information organized from an individual feature until it represents the work piece component taken as illustration. In this case the system has started from base shape selection followed by feature addition, machining operation attribute selection and cutting tools selection. The flow of process planning file development has been given in the Figure 6.12 interface outline of the programming system.

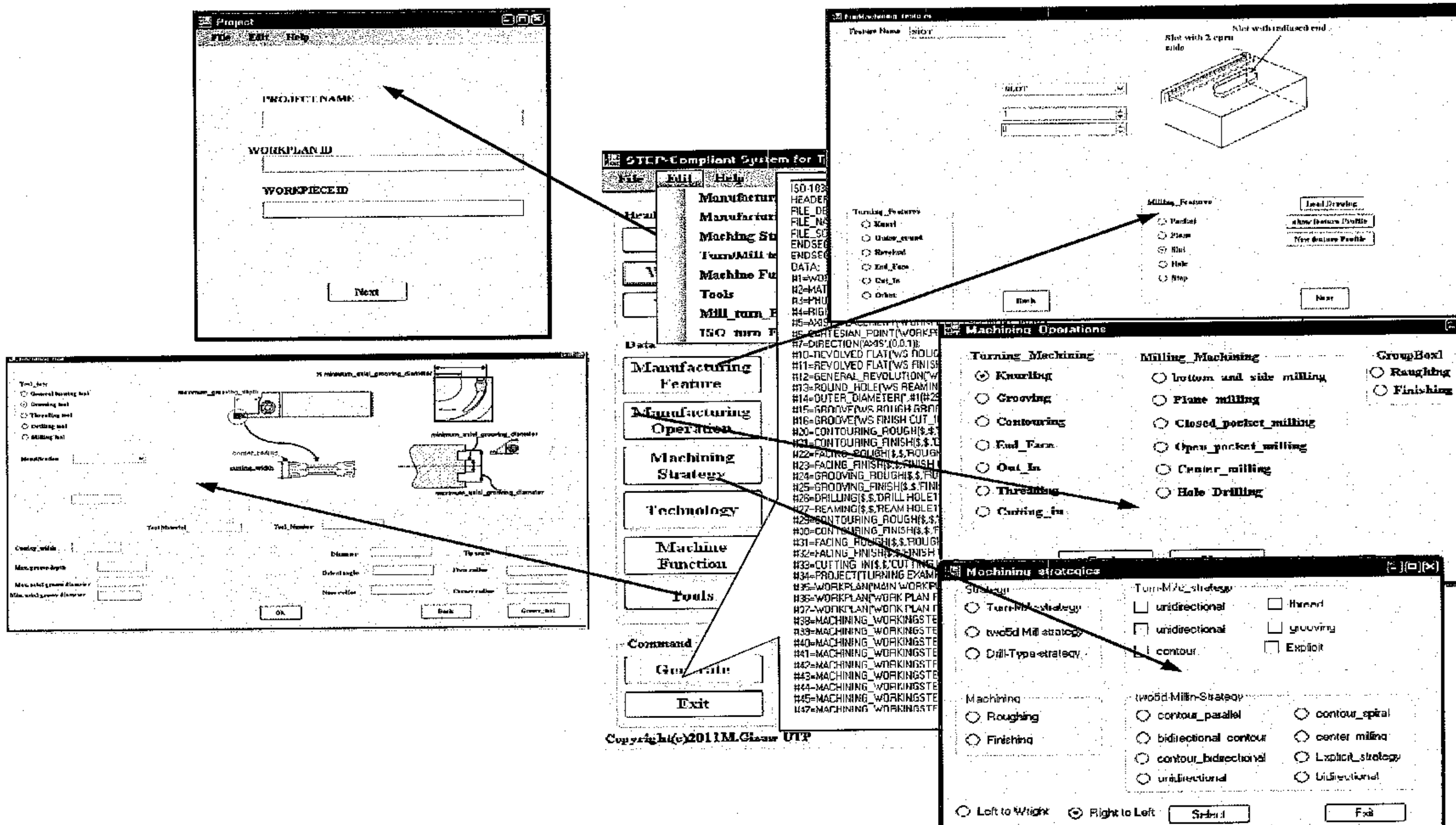


Figure 6.12 Dialogs Representing Procedures of Process Plan Development

6.6 Case Study Component

The case study components used to illustrate the function of the programming system have been given in feature based graphical representation shown in Figure 6.13. The first case study is an example component used in ISO 14649-12[2]. Its process planning and feature based design representation constructed by the programming system. The second is a popular component from a chess board "Castle" as selected specimen by the author to represent turn-mill component characteristics since the same component is also among demonstration parts selected by CNC machine suppliers such as Mazak which has been using Mazatrol controller.

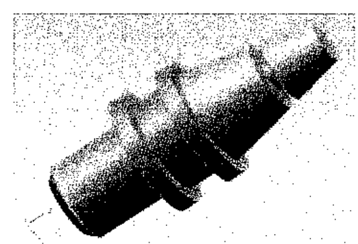
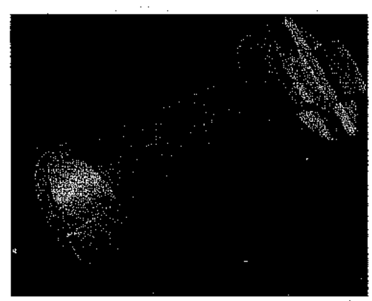
No.	Description	Graphic representation
1	Example Part from ISO14649-12 (Component-1)	
2	Turn-Mill component (component-2)	

Figure 6.13 Case Study Components

The first case study component used to demonstrate the programming system compliant to STEP-NC by generating Part-21 process plan file format output given in ISO 14649-12 manual. The programming system generated an equivalent process plan file in a procedure as shown in the Figure 6.15. The second component process plan will be evaluated in the perspective of B-axis turn-mill and two turret turn-mill machine setup.

The components are manufactured on Mazak integrex-200 with a mazatrol controller. The process planning used to the components are complied in a way to represent the manufacturing capability of turn-mill machine and a corresponding component manufacturing activities.

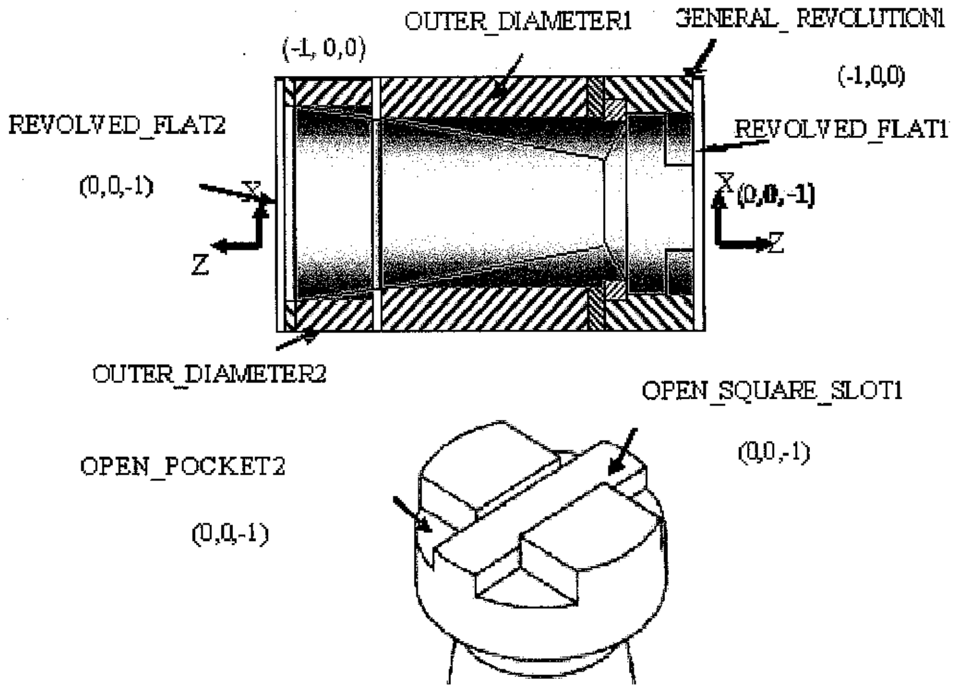


Figure 6.14 Machining Features in Case Study Component- 2

Figure 6.14 shows component-2 and corresponding placement and orientation of turning and milling features that represents a turn-mill component. The overall size for the component is 120mm x52mm. Feature geometric attributes and their absolute placement are given with regard to machining and tool aspect. The required machining operations are turning, grooving, facing and end-milling.

6.7 Prototype Process Planning

The process planning considered on two types of turn-mill machines. The first consideration is for a single turret turn-mill machine having three-linear axis X, Y, Z and two rotary axes namely B and C. The second case is considered on double turret turn-mill machine having three pair linear axis's and two pair rotary axes labeled B and C. Among different possible set up configuration the author described representative single set-up for the first machine type and a unit pair setup for the later machine.

In the first single setup machining, the machine can perform the roughing and finishing operation of turning module machining of the part in a single run followed by the end-milling roughing and finishing operation which is finally accompanied by parting operation.

In case of the double turret machine, the setup started by mounting on one of the turrets, then facing, two taper turning and a straight turning will be performed on the free end of the work piece. This followed by transferring the work piece to the secondary turret on which facing and end-milling for producing the five slots. Figure 6.15,6.20 and 6.21 show schematic and the graphical representation of the sample part and list of machining features and operation required to manufacture the illustrative component respectively.

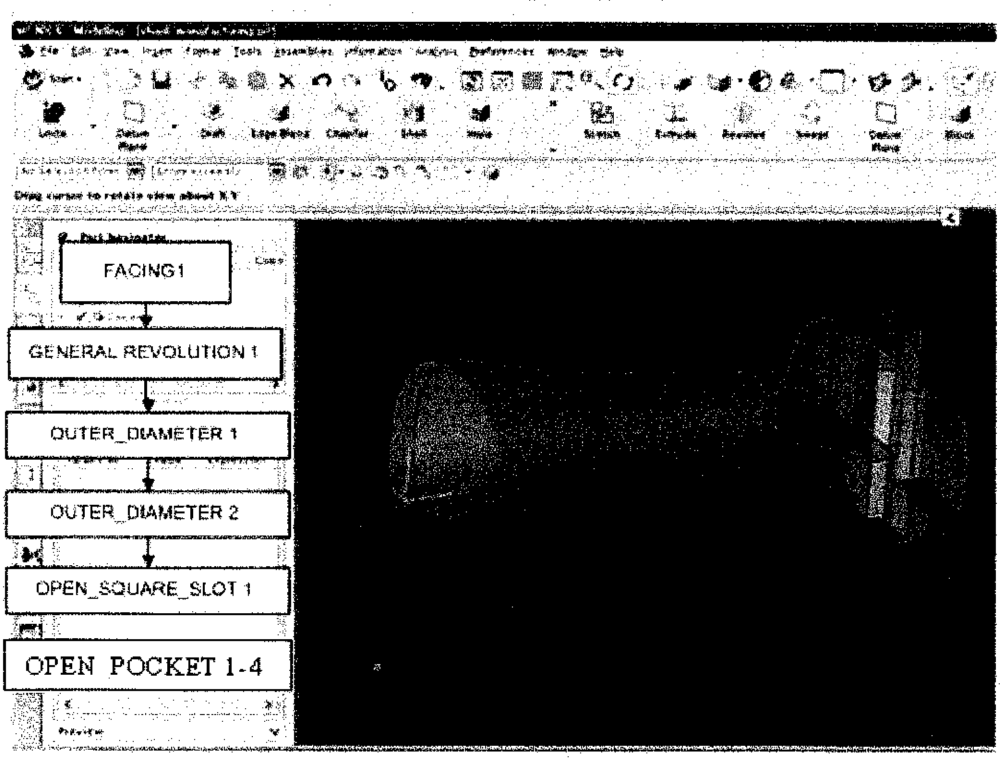


Figure 6.15 Unigraphic View of the Example

6.7.1 Working procedures of SCSTMO for the Example Component

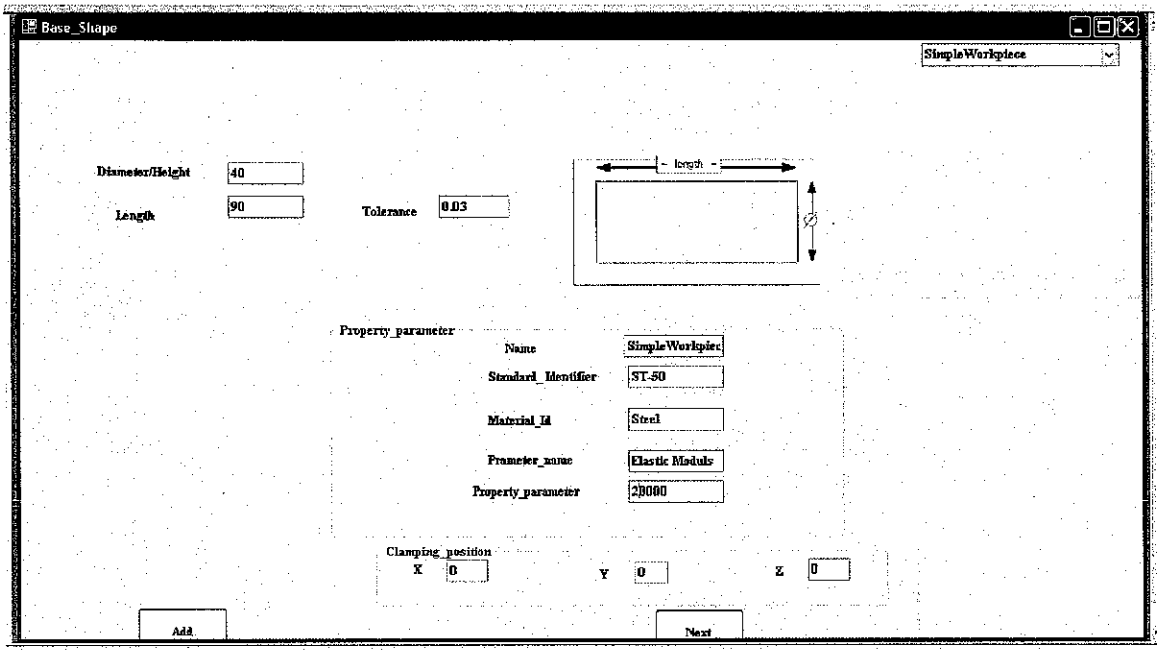


Figure 6.16 Workpiece Base Shape Information

The use of SCSTMO begins with the main interface as shown in Figure 6.3. The available dialogs allow starting up for every corresponding function. Initially the project interface is used to submit or read (De_serialize) information which belongs to the header element belongs to ISO 14649-21 file. As it can be seen under section 5.2.1 of Figure 5.4 UML class, the Project class consists of subtype class related to Resource, Processes, Strategy and WORKPIECE. This inheritance relationship enables to provide an interface given in Figure 6.22. Finally, the interface assists the user to summit information regarding Project ID, workplan and workpiece. It includes selection of setup and clamping point.

The case study component can be developed in two ways i.e. by starting a new project under menu file given in the main interface which provides feature selection that allows user defined feature creation. A bases shape definition interface supports to submit material property, location and geometric parameters as shown in Figure 6.16. In this case a right_circular cylinder option is chosen. Feature attachment process followed the base shape selection. Figure 6.17 supports turning and milling features selection with radio button controls. This proceeds to a specific feature definition followed by manufacturing considerations. In manufacturing case, the type of machining, cutting tool selection and machining strategies with regard to the specific feature have been defined by the user.

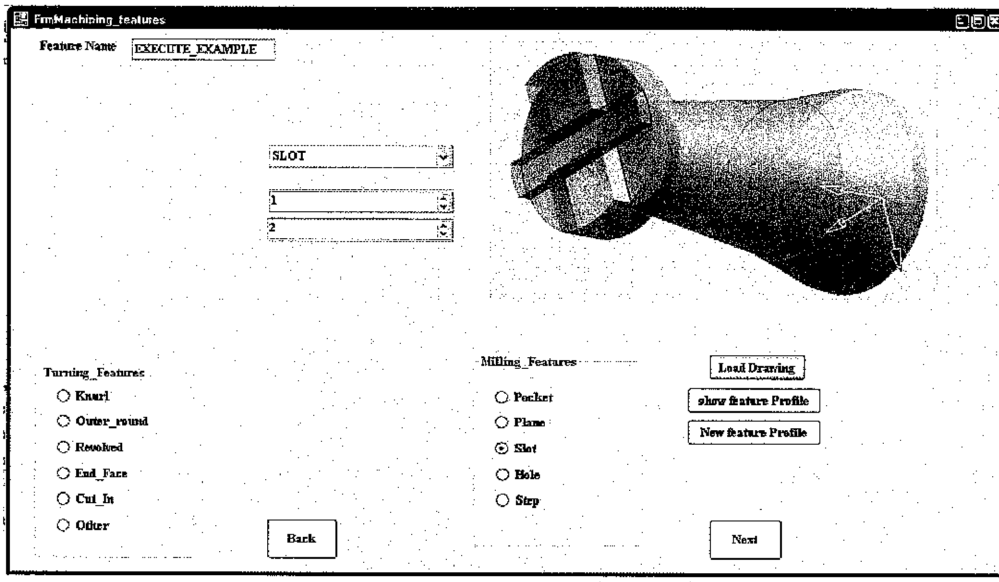


Figure 6.17 Turning and Milling Features Dialog

6.7.2 Machining Strategies

The machining strategies can be selected using the dialogs given in Figure 6.18a and 6.18b. They assist to incorporate machining strategies information along with other *machining_operaton* attributes.

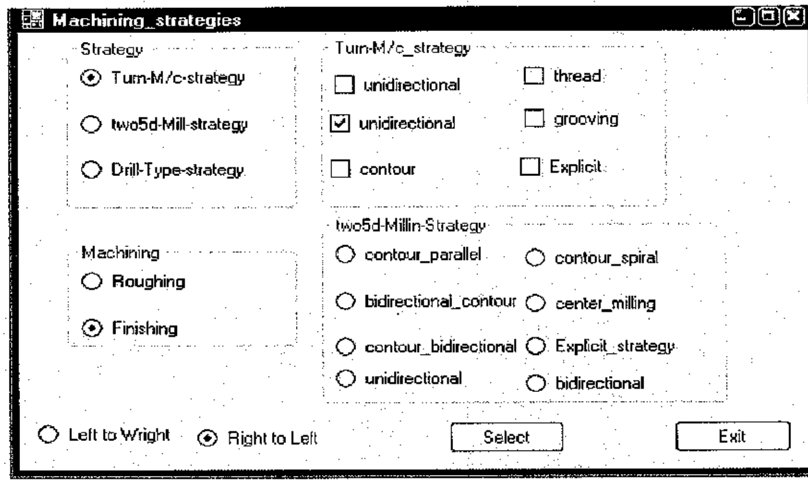


Figure 6.18(a) Machining Strategies Selection Dialog

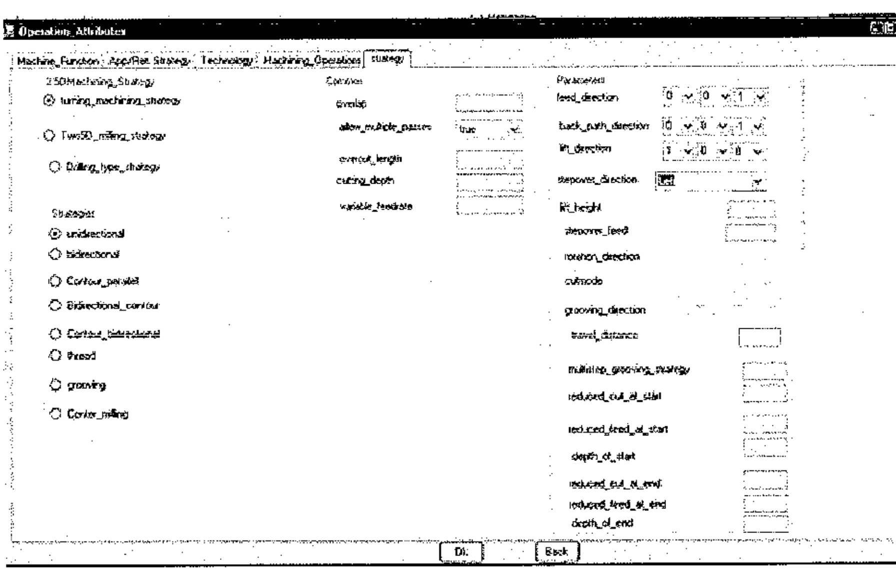


Figure 6.18(b) Machining Strategies Selection Dialog

6.7.3 Machining Technology

Here the programming system supports selection of the technology module to be performed for specific feature. It has accompanied by corresponding cutting tool and machining operation attribute selection. Figure 6.19 shows the requirement and attributes related to machining technology based on module selected. The method supports to edit these attributes according to the machining capacity.

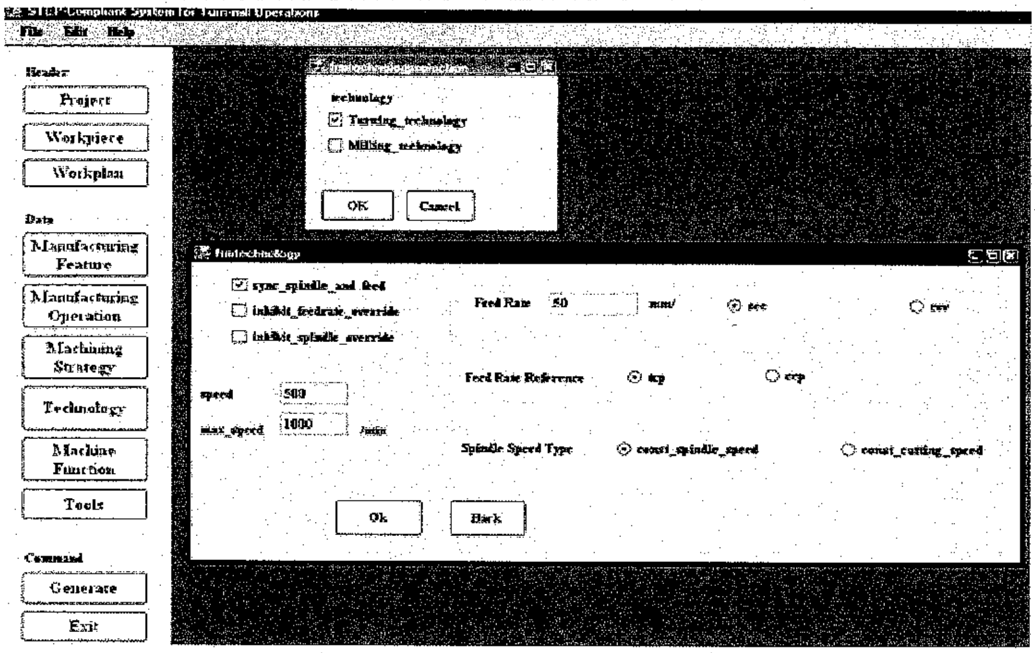


Figure 6.19 Machining Technology Selection Dialogs

Machining features defined with machining operation attributes under a workingstep .It has been included in workplan node tree structure and also constitute specific machine dynamic and static information to represent Native STEP-NC file. Figure 6.20 and 6.21 show list of workingstep under the workplan generated by the programing system for the turning and milling features found on Part-12 sample and the case study component respectively. It supports to investigate the entities of workplan elements under the STEP-NC file constructed.

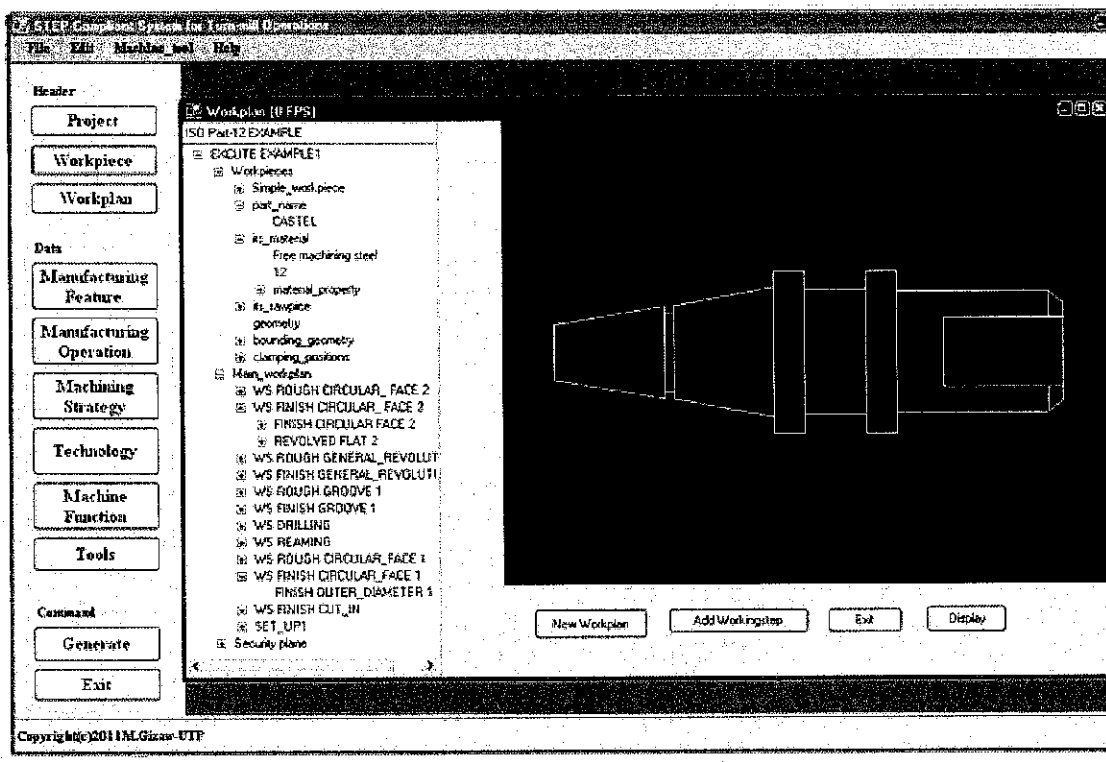


Figure 6.20 Workplan Dialog

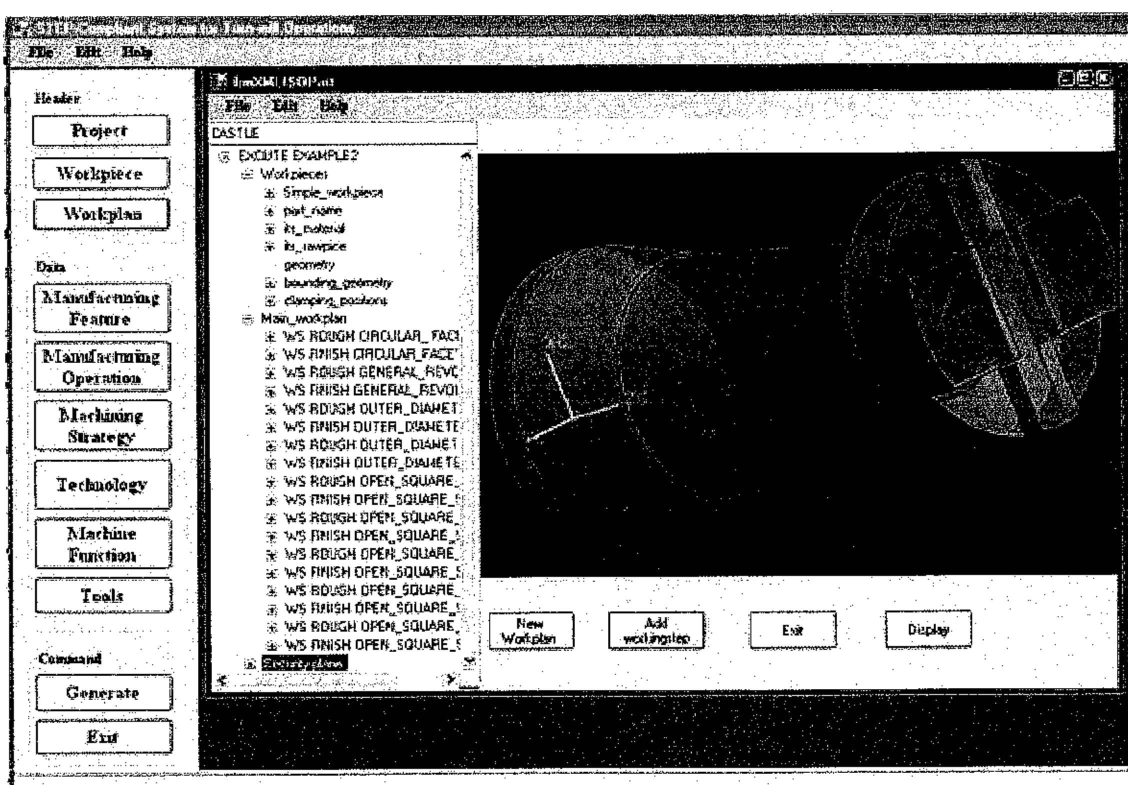


Figure 6.21 Workplan Dialog

Finally, an ISO 14649 part program is generated as shown in the Figure 6.22.The program uses elements of information submitted in defining requirements of machining features and machining operations. The text format physical file generated constitutes a header section and data section. It has provided the required information about workpiece and *machining_workingsteps*. In addition to the physical file generated, the system supports saving the part program to facilitate forwarding the file to a presupposed controller of next generation machine tool.

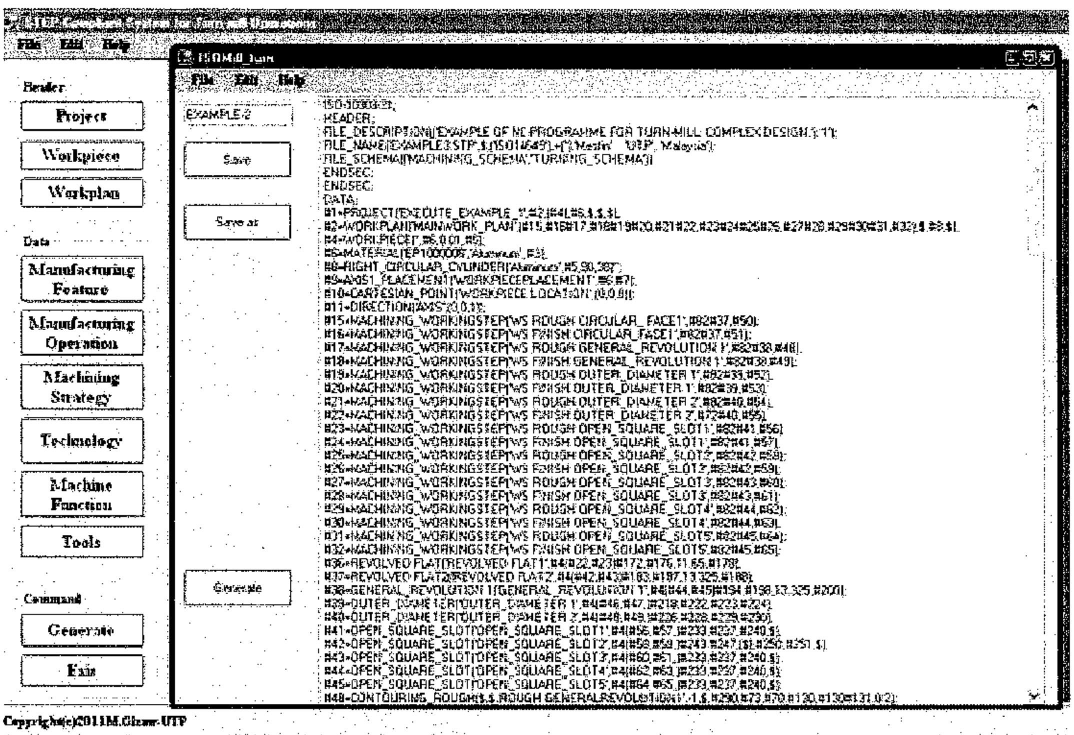


Figure 6.22 Part-21 Output File

6.8 Native STEP-NC Development for Turn-mill Machining Environment

In this section, conversion of the generic STEP-NC file developed into Native STEP-NC file. The system has been considered to a specific turn-mill manufacturing environment. This can be made by using an XML schema adapter. It has generated and updated through a user interface representing the attributes of the machining resource. The user interface that has been developed allows accessing machine tool attributes and XML schema as workstation implementation of STEP. The structure regarding this STEP implementation will be discussed in the following section where a workplan node tree is used for displaying the STEP-NC attributes representation with the data model and interface of the implementation. These interfaces have been used as means to insert or retrieve additional machine tool information which has been defined on STEP-NC machine tool data model (STEP-NCMtDm).

6.8.1 STEP-NCMtDm for Turn-mill

Functional interface has been developed using STEP and has supported converting "what to do" generic STEP-NC including manufacturing resources information designated as Native STEP-NC file.

It has been mentioned that the generic STEP-NC file is machine independent and used to develop a Native STEP-NC file that is suitable to attain machine tool resource data which can serve as an archive for machine tool STEP-NC convertor. The machine tool model used to represent the capability of the machine as dynamic and static information. The information represented by machine tool interface as shown in Figure 6.23 which has static and dynamic axis information for turn-mill machine tool. In addition the capability information of the machine constructs the manufacturing resource information required to be included in the Native STEP-NC file.

6.8.2 Machine Tool and STEP Implementation

Machine_resource interface are for modeling capabilities of specific machine tool. Turn-mill machine tool interface generally has to be comprised of information modules such as Axis Travels, Work Area, Axis specifications, Spindle information and General capacity data. In this particular case Figure 6.23 depicts an interface constructed for this thesis representing information requirement modules described. It includes machine tool features such as power of turn Table, "C" axis capability as well as main spindle power. It also gives X/Y/Z axis travels; allowable feed rate with respect to X/Y/Z axis, Traverse rate of X/Y/Z axis and spindle speed ranges. This additional information is serialized and formed an XML schema that served as to interact and included additional machine tool information in generic STEP-NC file.

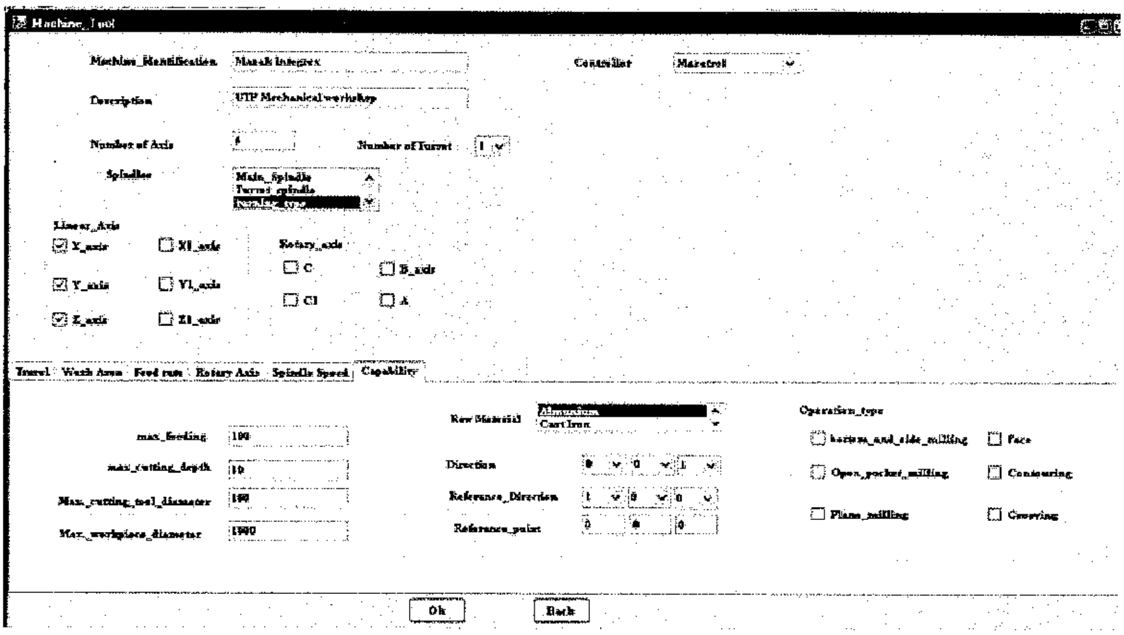


Figure 6.23 Turn-mill Machine Tool Resource Data

In a similar approach used for machine resource information cutting tool data given in Figure 6.24. The interaction of these data modeling interface for generating a Native STEP-NC file can be illustrated by the representation of workspace interface with executive workplan node tree as given in Figure 6.25. Finally, a Part-21 file format also generated comprising of specific machine resource information used for manufacturing a part model.

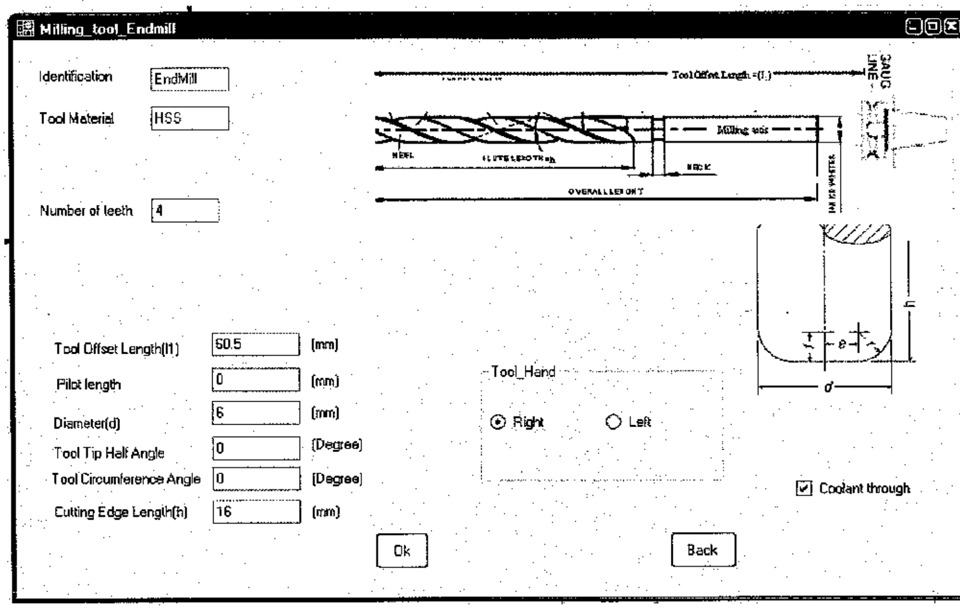


Figure 6.24 Cutting Tool Data

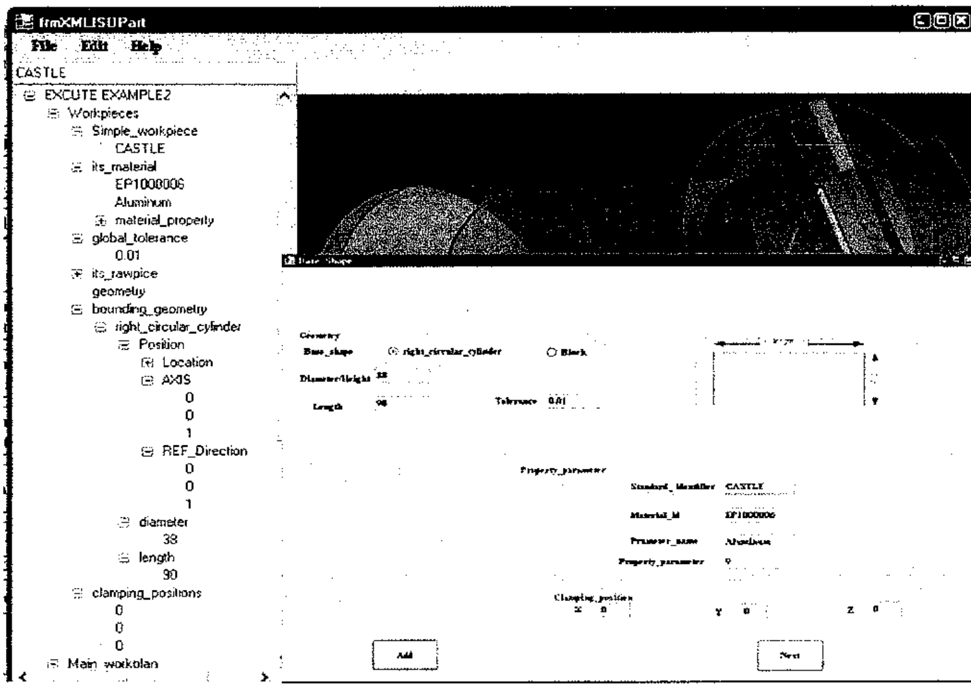


Figure 6.25 Executive workplan node tree and rawmatterial user interface

6.9 STEP-NC files of turn-mill with ISO Part 12 file

The general data structure of ISO Part 21 is maintained in both files. In case of the turn-mill file additional requirements of milling features, milling type machining operation, technology and strategies has been specified in the Figures 6.26 and 6.27. Material, dimension and clamping information for the wrokpiece has been given under workpiece data of the Figure 6.26. In both Figures the Generic process plan file indicates with red "$" the specific information which is populated by the use of the programming system algorithm and corresponding user interface to generate Native process plan data from the indicated generic data structures.

Workpiece Data

```
#1=WORKPIECE ('     $',#2, $,#5);
#2=MATERIAL (    '$''$',#3);
#3=PROPERTY_PARAMETER ('          $');
#4=RIGHT_   CIRCULAR_CYLINDER ('         $',#5, $,$)";
#5=AXIS1_PLACEMENT ('WORKPIECEPLACEMENT',#6,#7);
#6=CARTESIAN_POINT('WORKPIECE:LOCATION',(              $,$,$));
#7=DIRECTION ('AXIS', (       $, $, $));
```

```
#4=WORKPIECE('Simple Workpiece',#6,0.03,$,$,$,());
#6=MATERIAL('ST      -50','Steel',,#7);
#7=PROPERTY_PARAMETER('Elastic             Modulus   =20000');
#8=RIGHT_CIRCULAR_CYLINDER('              CASTEL ',#9,    90 ,38 )";
#9=AXIS1_PLACEMENT('WORKPIECEPLACEMENT',#10,#11);
#10=CARTESIAN_POINT('WORKPIECE:LOCATION',(0,0,0));
#11=DIRECTION('AXIS',(0,0,1));
```

Machining Features

```
#10=REVOLVED FLAT('        $',#1(#22,#23)#172,#176,         $,#178);
#11=REVOLVED FLAT('        $',#1(#31,#32)#183,#187,         $,#189);
#12=GENERAL_REVOLUTION(          $,#1(#20,#21)#194,#198,         $,#200);
#13=ROUND_HOLE(       $,#1(#26,#27,#28)#207,#215,#216,#217);
#14=OUTER_DIAMETER('        $',#1(#29,#30,)#218,#222,#223,#224);
#15=GROOVE('    $',#1(#24,#25)#226,#230,       $,#232);
#16=GROOVE('    $',#1(#33,)#236,#240,       $,#242);
```

```
#36=REVOLVED FLAT(        'REVOLVED FLAT1',#4(#50,#51)#172,#176,11.65,#178);
#37=REVOLVED FLAT2('REVOLVED FLAT2',#4(#68,#69)#183,#187,13.325,#188);
#38=GENERAL_REVOLUTION 1('GENERAL_REVOLUTION 1',#4(#48,#49)#194,#198,13.325,#200);
#39=OUTER_DIAMETER('OUTER_DIAMETER             1',#4(#52,#53,)#    218,#222,#223,#224);
#40=OUTER_DIAMETER('OUTER_DIAMETER             2',#4(#54,#55,)#226,#228,#229,#230);
#41=OUTER_DIAMETER('OUTER_DIAMETER             3',#4(#66,#67,)#234,#236,#237,#238);
#42=OPEN_SQUARE_SLOT('OPEN_SQUARE_SLOT1',#4(#56,#57,)#242,#246,#249,$);
#43=OPEN_SQUARE_SLOT          ('OPEN_SQUARE_SLOT2',#4(#58,#59,)#252,#256,($),#259,#260,$);
#44=OPEN_SQUARE_SLOT('OPEN_SQUARE_SLOT3',#4(#60,#61,)#263,#267,#271,$);
#45=OPEN_SQUARE_SLOT('OPEN_SQUARE_SLOT4',#4(#62,#63,)#274,#278,#281,$);
#46=OPEN_SQUARE_SLOT('OPEN_SQUARE_SLOT5',#4(#64,#65              )#284,#288,#291,$);
```

Machining Operation

```
#20=CONTOURING_ROUGH($,$,'           $', $,$,#280,#61,#60,#130,#130#131,          $);
#21=CONTOURING_FINISH($,$,'            $',30,$,#280,#61,#60,#130,#130#132         $;
#22= FACING_ROUGH ('     $',0,$,#280,#63,#60,#133,#134#135,             $);
#23=FACING_F    INISH($,$,'    $',0,$,#280,#63,#60,#133,#134#136,          $);
#24=GROOVING_ROUGH($,$,'           $', $,$,#285,#65,#60,#137,#137#138,          $);
#25=GROOVING_FINISH($,$,'          $', $,$,#285,#65,#60,#137,#137#138,         $);
#26=DRILLING($,$,'     $', $,$,#289,#66,#67,$,$,$,$,#141);
#27=REAMING($,$,'      $',0,$,#293,#69,#67,$,$,$,$,#141,.T.,$,$);

#33=CUTTING_IN($,$,      $,$,$,#297,#70,#60,$,#142,#142,#143,          $);
```

```
#48=CONTOURING_ROUGH($,$,'ROUGH GENERALREVOLUTION1',                -1,$,#290,#73,#70,#130,#130#131,0.2);
#49=CONTOURING_FINISH($,$,'FINISH GENERAL REVOLUTION 1',30,$,#290,#73,#70,#130,#130#132,0);
#50=FACING_ROUGH('FACING_ROUGHING',40,$,#290,#73,#70,#133,#134#135,0.05);
#51=FACING_FINISH('FACING_FINISHING',40,$,#290,#73,#70,#133,#134#135,0.01);
#52=CONTOURING_ROUGH($,$,'ROUGH OUTER DIAMETER2',21.67,$,#290,#73,#70,$,#130,#130,#131,0.05);
#53=CONTOURI     NG_FINISH($,$,'FINISH OUTER_DIAMETER2',40,$,#290,#73,#70,$,#130,#130,#132,0.01);
#56=BOTTOM_AND_SIDE__ROUGH_MILLING($,$,'ROUGHING
OPEN_SQUARE_SLOT1',40,$,#295,#75,#70,$,#130,#130,#135,0.05);
#57=BOTTOM_AND_SIDE__FINISH_MILLING($,$,'FINISHING
OPEN_SQUARE_SL     OT1',40,$,#295,#75,#70,$,#130,#130,#136,0.05);
#58=BOTTOM_AND_SIDE__ROUGH_MILLING($,$,'ROUGHING
OPEN_SQUARE_SLOT1',40,$,#295,#75,#70,$,#130,#130,#136,0.05);
#59=BOTTOM_AND_SIDE__FINISH_MILLING($,$,'FINISHING
OPEN_SQUARE_SLOT1',40,$,#295,#75,#70,$,#130,#13            0,#136,0.05);
#60=BOTTOM_AND_SIDE__ROUGH_MILLING($,$,'ROUGHING
OPEN_SQUARE_SLOT3',40,$,#299,#75,#70,$,#130,#130,#136,0.05);
```

Figure 6.26 Generic STEP-NC File of ISO Part 12 Example and Corresponding Turn-mill Example Part STEP-NC File

Machining Workingstep

```
#38=MACHINING_WORKINGSTEP('     $',#56,#11,#22,);
#39=MACHINING_WORKINGSTEP('     $ ',#56,#11,#23,);
#40=MACHINING_WORKINGSTEP('     $ ',#56,#12,#20,);
#41=MACHINING_WORKINGSTEP('     $ ',#56,#12,#2 1,);
#42=MACHINING_WORKINGSTEP('     $ ',#56,#15,#24,);
```

```
#15=MACHINING_WORKINGSTEP('WS ROUGH CIRCULAR_ FACE1',#82#37,#50);
#16=MACHINING_WORKINGSTEP('WS FINISH CIRCULAR_FACE1',#82#37,#51);
#17=MACHINING_WORKINGSTEP('WS ROUGH GENERAL_REVOLUTION 1',#82#38,#48);
#18=MACHINING_WORKINGSTEP('WS     FINISH GENERAL_REVOLUTION 1',#82#38,#49);
#19=MACHINING_WORKINGSTEP('WS ROUGH OUTER_DIAMETER 1',#82#39,#52);
#20=MACHINING_WORKINGSTEP('WS FINISH OUTER_DIAMETER 1',#82#39,#53);
#25=MACHINING_WORKINGSTEP('WS ROUGH OPEN_SQUARE_SLOT1',#82#42,#58);
#26=MACHINING_WORKINGSTEP('WS FINISH OPEN_SQUARE_SLOT1',#82#42,#59);
#27=MACHINING_WORKINGSTEP('WS ROUGH OPEN_SQUARE_SLOT2',#82#43,          #60);
#28=MACHINING_WORKINGSTEP('WS FINISH OPEN_SQUARE_SLOT2',#82#43,#61);
```

Machine_Function/Technology

```
#60=TURNING_MACHINE_FUNCTIONS(.T.,$,$,().F.,$,$,()$,$,$);
#61=TURNING_TECHNOLOGY(.TCP.,#62,     $,().F.,F,F,$);
#62=CONSTANT_SPINDLE_SPEED(    $ );
#63=TU RNING_TECHNOLOGY(.TCP.,#64,     $,().F.,F,F,$);
#64=CONSTANT_SPINDLE_SPEED(    $ );
#65=TURNING_TECHNOLOGY(.TCP.,#66,     $,().F.,F,F,$);
#66=CONSTANT_SPINDLE_SPEED(200 );
#67=MILLING_MACHINE_FUNCTIONS(.T.,$,$,().F.,$,$,()$,$,$);
#68=MILLING_TECHNOLOGY(   $,.TCP.,$,  $,().F.,F,F,$);
#69=MILLING_TECHNOLOGY(   $,.TCP.,$,  $,().F.,F,F,$);
#70=TURNING_TECHNOLOGY($,.TCP.,#71,     $,().F.,F,F,$);
#71=CONSTANT_SPINDLE_SPEED( );
```

```
#70=TURN_Mill_MACHINE_FUNCTIONS(.T.,$,$,(),.F.$,$,(),$,$,$,);
#71=TURN_TECHNOLOGY($,.TCP.,#62,0.300,().F.,F,F,$);
#72=CONSTANT_SPINDLE_SPEED(0 );
#73=TURNING_TECHNOLOGY(.TCP.,#64,0.300,().F.,F,F,$);
#74=CONSTANT_SPINDLE_SPEED(0 );
#75=MILLING_TECHNOLOGY(.TCP.,#66,0.300,().F.,F,F,$);
#82=PLANE('SECURITY PLANE',#119,);
#130=PLUNGE_RAMP($,45);
#131=UNIDIRECTIONAL_TURNING($,$,(3),$,$,$,$,6       ,$,$);
#132=UNIDIRECTIONAL_TURNING($,$,(3),$,$,$,$,6       ,$,$);
#135=BIDIRECTIONAL_MILLING($,$,(0,0,1),$,$,$,$,0       ,$,$);
#133=PLUNGE_RAMP($,40 );
#134=PLUNGE_RAMP($,30 );
#136=UNIDIRECTIONAL_MI    LLING($,$,(0,0,1),$,$,$,$,0    ,$,$);
#137=PLUNGE_RAMP($,30 );
```

Placements & Length

```
(* ***** Placements / Lengths ***** *)
#103=SETUP('',#104,#105,#106);
#104=CARTESIAN_POINT('SETUP 1:LOCATION',(       $,$,$,));
#105=DIRECTION('AXIS',(   $,$,$,));
#106=DIRECTION('REF_DIRECTION',(     $,$,$,));
#107=AXIS2_PLACEMENT_3D(    'WORKPIECE','#108,'#109,'#110,);
#108=CARTESIAN_POINT('WORKPIECE1:LOCATION',(        $,$,$));
#109=DIRECTION('AXIS',(1,0,0,));
#110=DIRECTION('REF_DIRECTION',(0,0,1,));
#111=AXIS2_PLACEMENT_3D('SETUP 2','#111,'#112,'#113,);
#112=CARTESIAN_POINT('SETUP 2:LOCATI     ON',( $,$,$));
#113=DIRECTION('AXIS',(   $,$,$));
#114=DIRECTION('REF_DIRECTION',(     $,$,$));

ENDSEC;
END-ISO-10303 -21;
```

```
#103=AXIS2_PLACEMENT_3D('SET_UP1 ','#104,'#105,'#106,);
#104=CARTESIAN_POINT(   'SET_UP1:LOCATION',(0,0,0,));
#105=DIRECTION('AXIS',(1,0,0,));
#106=DIRECTION('REF_DIRECTION',(0,0,1,));
#107=AXIS2_PLACEMENT_3D('SIMPLE_WORKPIECE ','#108,'#109,'#110,);
#108=CARTESIAN_POINT('SIMPLE_WORKPIECE:LOCATION',(0,0,0,));
#109=DIRECTION('AXIS',   (1,0,0,));
#110=DIRECTION('REF_DIRECTION',(0,0,1,));
#111=AXIS2_PLACEMENT_3D('SET_UP2 ','#111,'#112,'#113,);
#112=CARTESIAN_POINT('SET_UP2:LOCATION',(0,0,0,));
#113=DIRECTION('AXIS',(1,0,0,));
#114=DIRECTION('REF_DIRECTION',(0,0,1,));
#119=AXIS2_PLACEM   ENT_3D('SECURITY PLANE ','#120,'#121,'#122,);
#120=CARTESIAN_POINT('SECPLANE:LOCATION',(0,0,150,));
#121=DIRECTION('AXIS',(1,0,0,));
#122=DIRECTION('REF_DIRECTION',(0,0,1,));

ENDSEC;
END-ISO-10303 -21;
```

Figure 6.27 STEP-NC File ISO Part 12 Example and Corresponding Turn-mill Example Part STEP-NC File

6.10 Summary

This chapter has executed STEP compliant system for turn-mill operations (SCSTMO). It has given basic information about the development tools, the architect and the work flow chart of the programming system proposed. Then it included explanations regarding its functional modules, background assumptions, the design and information model on which the proposed system fulfils to ascertain the research objectives indicated in section 1.7.

The section discusses how Part 21 output of the proposed system related to its design, manufacturing and machine tool implementation procedures formulated on the basses of concurrent design and process planning with the corresponding utilization of ISO 14649 data model.

The chapter also included a Part-12 example as a prototype system to validate the functions of SCSTMO. The requirements to SCSTMO description began considering geometrical parameters of workpiece and forming part design by feature addition using the feature library developed. The programming system capability on generating process plan for turn-mill operations with regard to a user defined or reading a Part-21 file has been discussed. Part 21 physical file and the programming system interface compliance with STEP-NC have been briefly outlined successfully on case studies. Finally, the chapter discussed the adoption of STEP-NCmtDM for establishing a Native STEP-NC on turn-mill machine resource and a corresponding workplan node tree.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter summarizes concise description and draws conclusion of the research accomplishments covered by this thesis. It delivers arguments and perspective of previous research output and contribution. It describes main achievements of STEP-compliant approach for turn-mill operations. Finally, recommendations on future requirements of STEP-compliant system in regard to next generation machine tool controller.

7.2 Conclusion of the Research

The motivation of the research is extending implementation of ISO 14649 data model for turn-mill operations. It has a major contribution in generating a STEP-NC process plan on a dual domain of manufacturing perspective. The research reported in this thesis proposed an approach that amalgamate ISO 14649 data model which has been solely used for a single domain specific applications of either turning or milling. These previous implementation has been developed independently. ISO 10303 AP 224 mechanical product description plays a major role for the conformance of generated process plan with ISO 10303 Part 21 file.

Complexity and importance of turn-mill machine makes standard product data utilization mandatory, since it assists for ease of part programming and machine capacity utilization efficiency.

Therefore; ISO 14649 data model amalgamated implementation on turn-mill machine enhances the requirement of manufacturing integration and interoperability to shop floor level. This also provides a means for application of intelligence manufacturing methodology on the additional configuration of the machine.

The methodology used in this thesis is based on object-oriented approach defined for the EXPRESS classes of ISO 14649 data model. The requirement of turn-mill machining capacity representation has been addressed by Serialization function. The integration and interoperability of the system is maintained by Serialization, De-serialization and XPath functions. They can generate an XML schema. That can be accessed and edited by appropriate interfaces. They can also maintain the data exchange and data sharing methodologies of STEP.

The methodology proposed in this research has been analyses and tested in a computer system with STEP-NC approach. The system was accomplished by using Visual Basic dot Net 2005 environment with SQL server. The following conclusions are the main accomplishments with respect to the overall objective of the system:-

I. The research provided STEP-NC file on requirements of turn-mill operations by amalgamated ISO 14649 data model. This STEP-implementation analyzed and documented on the process flow of turn-mill capacity as equivalent to positioned five-axis configuration with turning and milling machining capability. It supports the employment of ISO 14649 data model for creating generic Part 21 file format.

II. STEP Interface provided exhaustive modules of design and manufacturing interactive interfaces that support requirements of turn-mill manufacturing operations. It addresses generation and representation of information exchange between "CAD" and "CNC" since the programming system constructed by manufacturing feature description of AP 224 and object oriented class inheritance structure of the new CNC controller data model (ISO 14649) and able to generate neutral file in XML and text format. These file format can be generated on user defined manufacturing feature entities or extract related entities from a feature based digital machine tool outputs which ascertains the interoperability of the system with regard to positioned five axis machining equivalence of turn-mill manufacturing. This evaluation and synthesis of the extended system has been tested and analyzed on adoption of ISO 14649 and ISO 10303 AP224 standards for turn-mill machining operations.

III. Workingstep architect has been realized and has supported STEP implementation on a project bases. It has utilized application reference model (ARM) of turning and milling technologies in unit amalgamation and has established information exchange and sharing on requirements of the design and manufacturing module of turn-mill environment. The content of the information maintains conformance to STEP AP's. It has validated that ISO 14649 machining features and machining operations class encapsulated on unit design and manufacturing information requirement module able to represent turn-mill machining.

Finally the contribution of the research is highlighted by the Dual domain STEP implementation model which is able to deliver a process plan document in Part 21 file, a machine tool model complaint to the developed data model and its typical utilization of Visual Basic dot Net with XML schemas for a STEP-NC interface on turn-mill manufacturing environment.

The first limitation is on STEP implementation for turn-mill operation. The implementation does not address full capacity of turn-mill machine rather it is limited to 2.5-axis machining data of turning and positioned five-axis configuration milling in ISO14649. Since ISO 14649 data model specification is developed on feature placement. That makes the system unable to work beyond positioned five-axis milling configuration.

The implementation model is also limited to generating a STEP-NC process plan file for turn-mill operation. It is mainly focused on the integration and interoperability of the process plan. However; there is additional decision support methods requirement of algorithms for identifying process variation parameters, for inspection and optimization of machining operations.

7.3 Recommendations and Future Research

The primary objective of the research has been establishment of STEP-NC interface on turn-mill operations with concurrent engineering approach using ISO 14649 data model. It comprises of developing a product and manufacturing model framework in STEP and a proposed system enabling generation of process plan data exchange of "manufacturing rich" information between design and CNC machining which supports interoperability in turn-mill component manufacturing. However; the current machine tool hardware development allows different machine tool configuration and composite feature manufacturing that additional specification to the current consideration of ISO 14649 data model. In order to meet such requirements future researches needs to include the following:

i. The experimental system provided an interface for various capability options of turn-mill operations but it needs extension work to incorporate hybrid intelligent process planning methodology for achieving optimization and inspection provisions along with integration and interoperability.

ii. The experimental system can be extended to shopfloor application for customised process plan suitable for automation with regard to enable specific machine cell flexible manufacturing based on classification of the products and accompanied process planning requirements beyond prototype components

iii. As it has been indicated a machine tool data model contributes towards Native STEP-NC planning file generation. It has potential future research opportunity to promote feature driven turn-mill machine tools. That can be achieved by investigation of possibility of tool-path generation and interpolation function interlink with machine tool data model and machine tool kinematics. This leads to efficient tool path generation independent to CAM systems.

iv. The experimental system is based on object-oriented methodology which supports a workingstep to represent a micro level process plan achieved by STEP modularity. In this research, the system uses XML schemas to represent the information blocks of the modules that can contribute to investigate the machining environment on a various scale and serves corresponding investigation for constructing function block.

v. The experimental system used STEP-NC standards which are limited to positioned 5-axis configurations but it is necessary to extend the system for compound feature and continuous feature representation beyond sequential process representation to account for continuous 5-axis operations which leads turn-mill machining for complete compliant with ISO14649.

The recommended future extensions of the experimental system can be analyzed with respect to optimization, tool-path generation and interpolation and promoting utilization of AP-238 that enhances the importance of the research towards industrial application on full scale integration.

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LIST OF PAPERS AND PULICATIONS

Journals/Conference proceedings

1. Design of STEP-compliant System for Turn-mill Operations using XML, Gizaw,M. Ahmad Majdi BA Rani, Yusof, Y. Publication: Journal of Applied Sciences,vol.11,issue 7, pp. 1171-1177. 2011

2. Investigating ISO 14649 for STEP-Compliant Turn-mill Operations, Gizaw,M.; BA Rani, Ahmad Majdi; Yusof, Y. Proceedings of National Postgraduate Symposium 2009 Universiti Teknologi PETRONAS

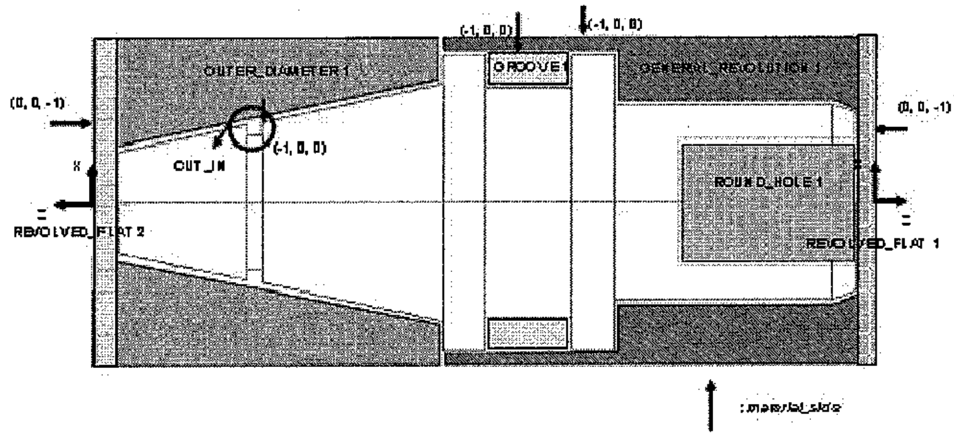
3. STEP based Product Data model for turn-mill operations, Gizaw,M., BA Rani, Ahmad Majdi; Yusof, Y. Proceedings of National Postgraduate Symposium 2011 Universiti Teknologi PETRONAS,

4. STEP Implementation on turn-mill manufacturing environment, Ahmad Majdi BA Rani, Gizaw,M., Yusof, Y. World Academy of science, Engineering and Technology, International Conference on Industrial Engineering, Bangkok 2011

5. Adoption of STEP-Compliant System on Turn-mill Operations,Gizaw,M., Ahmad Majdi BA Rani, Yusof, Y. International journal of Computer integrated Manufacturing, 2012(under review)

6. Intelligence Machining Operations Selection & turn-mill STEP process plan ,Gizaw,M., Ahmad Majdi BA Rani, Yusof, Y. ESTCON,ISPER 2012

APPENDIX A: ISO 14649 PHYSICAL FILE



Appendix A1 ISO 14649 Physical File Part-12 Example part

10/17/2011 1:59:11 PM

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('EXAMPLE OF NC PROGRAMME FOR TURNING: COMPLEX
DESIGN.'),'1');
FILE_NAME('EXAMPLE1.STP',$,('ISO14649'),+(''),'Mesfin' 'UTP', 'Malaysia');
FILE_SCHEMA(('MACHINING_SCHEMA','TURNING_SCHEMA'));
ENDSEC;
DATA;
(* ***************************************************** *)
(****** Workpiece definition ***** *)
#1=WORKPIECE('SIMPLE WORKPIECE',#2,0.010,#5);
#2=MATERIAL('ST-50','STEEL',,#3);
#3=PROPERTY_PARAMETER ('E=200000N/M2');
#4=RIGHT_CIRCULAR_CYLINDER ('WORKPIECE PIECE',#5,33,22)";
#5=AXIS1_PLACEMENT('WORKPIECEPLACEMENT',#6,#7);
#6=CARTESIAN_POINT('WORKPIECE:LOCATION',(4,5,3));
#7=DIRECTION('AXIS',(0,0,1));
```

```
(* ****************************************************** *)
(* ***** Manufacturing features ***** *)
#10=REVOLVED FLAT('WS ROUGH CIRCULAR_ FACE 2',#1(#22,#23)#172,#176,21,#178);
#11=REVOLVED FLAT('WS FINISH CIRCULAR_ FACE 2',#1(#31,#32)#183,#187,12,#189);
#12=GENERAL_REVOLUTION('WS ROUGH GENERAL_REVOLUTION
1',#1(#20,#21)#194,#198,21,#200);
#13=ROUND_HOLE('WS REAMING',#1(#26,#27,#28)#207,#215,#216,#217);
#14=OUTER_DIAMETER('',#1(#29,#30,)#218,#222,#223,#224);
#15=GROOVE('WS ROUGH GROOVE 1',#1(#24,#25)#226,#230,35,#232);
#16=GROOVE('WS FINISH CUT_IN',#1(#33,)#236,#240,30,#242);
(* ****************************************************** *)
(* ***** Turning operations ***** *)
#20=CONTOURING_ROUGH($,$,'ROUGH
GENERALREVOLUTION1',30,$,#280,#61,#60,#130,#130#131,0.5);
#21=CONTOURING_FINISH($,$,'WS FINISH GENERAL_REVOLUTION
1',30,$,#280,#61,#60,#130,#130#132,0.5);
#22=REVOLVED FLAT('ROUGH CIRCULAR FACE 2',0,$,#280,#63,#60,#133,#134#135,0.5);
#23=FACING_FINISH($,$,'FINISH CIRCULAR FACE 2',0,$,#280,#63,#60,#133,#134#136,0.0);
#24=GROOVING_ROUGH($,$,'ROUGH GROOVE 1',30,$,#285,#65,#60,#137,#137#138,0.5);
#25=GROOVING_FINISH($,$,'FINISH GROOVE 1'',30,$,#285,#65,#60,#137,#137#138,0);
#26=DRILLING($,$,'DRILL HOLE1',30,$,#289,#66,#67,$,$,$,$,#141);
#27=REAMING($,$,'REAM HOLE1',0,$,#293,#69,#67,$,$,$,$,#141,.T.,$,$);
#29=CONTOURING_ROUGH($,$,'ROUGH OUTER DIAMETER
1',30,$,#280,#61,#60,$,#130,#130,#131,0.1);
#30=CONTOURING_FINISH($,$,'FINISH OUTER_DIAMETER
1',30,$,#280,#61,#60,$,#130,#130,#131,0.1);
#31=FACING_ROUGH($,$,'ROUGH CIRCULAR FACE 2',50,$,#280,#63,#60,$,#133,#134,#135,0.0);
#32=FACING_FINISH($,$,'FINISH CIRCULAR FACE 2',50,$,#280,#63,#60,$,#133,#134,#136,0.5);
#33=CUTTING_IN($,$,'CUTTING IN 1',30,$,#297,#70,#60,$,#142,#142,#143,0);
(* ****************************************************** *)
(* ***** Project ***** *)
#34=PROJECT('TURNING EXAMPLE 1',#35(#1,)$,$,$);
#35=WORKPLAN('MAIN WORKPLAN',(#36,#37,)$,#52,$);
#36=WORKPLAN('WORK PLAN FOR SETUP1',(#38,#39,#40,#41,#42,#43,#44,#45)$,$,$);
#37=WORKPLAN('WORK PLAN FOR SETUP2',(#47,#48,#49,#50,#51,#52,#44,#45)$,$,$);
#38=MACHINING_WORKINGSTEP('WS ROUGH CIRCULAR_ FACE 2',#56,#11,#22,);
#39=MACHINING_WORKINGSTEP('WS FINISH CIRCULAR_ FACE 2',#56,#11,#23,);
```

```
#40=MACHINING_WORKINGSTEP('WS ROUGH GENERAL_REVOLUTION 1',#56,#12,#20,);
#41=MACHINING_WORKINGSTEP('WS FINISH GENERAL_REVOLUTION 1',#56,#12,#21,);
#42=MACHINING_WORKINGSTEP('WS ROUGH GROOVE 1',#56,#15,#24,);
#43=MACHINING_WORKINGSTEP('WS FINISH GROOVE 1',#56,#15,#25,);
#44=MACHINING_WORKINGSTEP('WS DRILLING',#56,#13,#26,);
#45=MACHINING_WORKINGSTEP('WS REAMING',#56,#13,#27,);
#47=MACHINING_WORKINGSTEP('WS ROUGH CIRCULAR FACE 1',#56,#10,#30,);
#48=MACHINING_WORKINGSTEP('WS FINISH CIRCULAR FACE 1',#56,#10,#31,);
#49=MACHINING_WORKINGSTEP('WS ROUGH CIRCULAR_ FACE 2',#56,#10,#31,);
#50=MACHINING_WORKINGSTEP('WS FINISH CIRCULAR_ FACE 2',#56,#10,#31,);
#51=MACHINING_WORKINGSTEP('WS FINISH CUT_IN',#56,#16,#32,);
#52=SETUP('',#103,#56,(#53),);
#53=WORKPIECE_SETUP(#1,#107,$,$,$);
#54=SETUP('SET_UP1',#111,#56,(#55),);
#55=WORKPIECE_SETUP(#1,#115,$,$,$);
#56=PLANE(#1,#107,$,$,$);
(* **************************************************** *)
(* ***** Functions / Technology ***** *)
#60=TURNING_MACHINE_FUNCTIONS(.T.,$,$,().F.,$,$,()$,$,$);
#61=TURNING_TECHNOLOGY(.TCP.,#62,0.300,().F.,F,F,$);
#62=CONSTANT_SPINDLE_SPEED(500 );
#63=TURNING_TECHNOLOGY(.TCP.,#64,0.300,().F.,F,F,$);
#64=CONSTANT_SPINDLE_SPEED(500 );
#65=TURNING_TECHNOLOGY(.TCP.,#66,0.300,().F.,F,F,$);
#66=CONSTANT_SPINDLE_SPEED(200 );
#67=MILLING_MACHINE_FUNCTIONS(.T.,$,$,().F.,$,$,()$,$,$);
#68=MILLING_TECHNOLOGY(0.300,.TCP.,$,16.00,().F.,F,F,$);
#69=MILLING_TECHNOLOGY(0.300,.TCP.,$,18.00,().F.,F,F,$);
#70=TURNING_TECHNOLOGY($,.TCP.,#71,0.300,().F.,F,F,$);
#71=CONSTANT_SPINDLE_SPEED( );
(* **************************************************** *)
(* ***** Strategies ***** *)
#130=PLUNGE_RAMP($,45);
#131=UNIDIRECTIONAL_TURNING($,$,(1),$,$,$,$,3$,$);
#132=UNIDIRECTIONAL_TURNING($,$,(1),$,$,$,$,3$,$);
#133=PLUNGE_RAMP($,);
#134=PLUNGE_RAMP($,45);
```

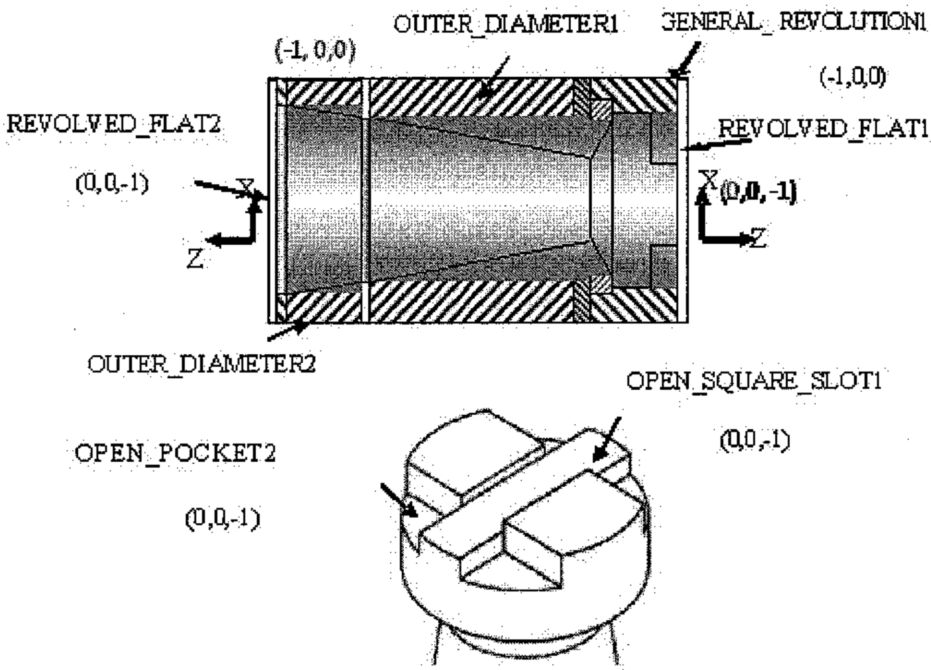
```
#131=UNIDIRECTIONAL_TURNING($,$,(1),$,$,$,$,3$,$);
#132=UNIDIRECTIONAL_TURNING($,$,(1),$,$,$,$,3$,$);
#137=PLUNGE_TOOL_AXIS($);
#138=MULTISTEP_GROOVING_STRATEGY($,.T.,(3.000),$,$,$,$,5,3);
#139=CONTOUR_TURNING($,.F.,(1),$,$,$);
#140=DRILLING_TYPE_STRATEGY(75.000,50.000,,5,75.000,40.000,$);
#141=DRILLING_TYPE_STRATEGY($,$,,$,$,,$,$);
#142=PLUNGE_TOOL_AXIS ($);
#143=GROOVING_STRATEGY($,.T.,(3.000),$,$,$,$,5,3);
(* ***************************************************** *)
(* ***** Placements / Lengths ***** *)
#103=SETUP('',#104,#105,#106);
#104=CARTESIAN_POINT('SETUP 1:LOCATION',(0,0,-2.5,));
#105=DIRECTION(''AXIS',(1,0,0,));
#106=DIRECTION(''REF_DIRECTION',(0,0,1,));
#107=AXIS2_PLACEMENT_3D(''WORKPIECE',''#108,''#109,''#110,);
#108=CARTESIAN_POINT('WORKPIECE1:LOCATION',(0,0,-2.5,));
#109=DIRECTION(''AXIS',(1,0,0,));
#110=DIRECTION(''REF_DIRECTION',(0,0,1,));
#111=AXIS2_PLACEMENT_3D('SETUP 2',''#111,''#112,''#113,);
#112=CARTESIAN_POINT('SETUP 2:LOCATION',(0,0,-2.5,));
#113=DIRECTION(''AXIS',(1,0,0,));
#114=DIRECTION(''REF_DIRECTION',(0,0,1,));
#115=AXIS2_PLACEMENT_3D(''WORKPIECE1',''#116,''#117,''#118,);
#116=CARTESIAN_POINT('WORKPIECE1:LOCATION',(0,0,-2.5,));
#117=DIRECTION(''AXIS',(1,0,0,));
#118=DIRECTION(''REF_DIRECTION',(0,0,1,));
#119=AXIS2_PLACEMENT_3D('SECURITY PLANE',''#120,''#121,''#122,);
#120=CARTESIAN_POINT('SECPLANE:LOCATION',(0,0,-2.5,));
#121=DIRECTION(''AXIS',(1,0,0,));
#122=DIRECTION(''REF_DIRECTION',(0,0,1,));
#172=AXIS2_PLACEMENT_3D('PLACEMENTEND FACE 1',''#173,''#174,''#175,);
#173=CARTESIAN_POINT('END FACE 1:LOCATION',(0,0,-2.5,));
#174=DIRECTION(''AXIS',(1,0,0,));
#175=DIRECTION(''REF_DIRECTION',(0,0,1,));
#176=DIRECTION(''MATERIAL_SIDE',(0,0,-1,));
#178=LINEAR_PROFILE('REVOLVED_FLAT_RADIUS',#179,21);
```

```
#179=AXIS2_PLACEMENT_3D('PLACEMENT  END FACE 1',"#180,"#181,"#182,);
#180=CARTESIAN_POINT('END FACE 1:LOCATION',(0,0,0,));
#181=DIRECTION("AXIS',(1,0,0,));
#182=DIRECTION("REF_DIRECTION',(0,0,1,));
#183=AXIS2_PLACEMENT_3D('PLACEMENTREVOLVED FLAT 2',"#173,"#174,"#175,);
#184=CARTESIAN_POINT('REVOLVED FLAT 2:LOCATION',(0,0,-2.5,));
#185=DIRECTION("AXIS',(1,0,0,));
#186=DIRECTION("REF_DIRECTION',(0,0,1,));
#187=DIRECTION("MATERIAL_SIDE',(0,0,-1,));
#189=LINEAR_PROFILE('REVOLVED_FLAT_RADIUS',#190,12);
#190=AXIS2_PLACEMENT_3D('LINEAR_PROFILE',"#191,"#192,"#193,);
#191=CARTESIAN_POINT('END FACE 1:LOCATION',(0,0,0,));
#192=DIRECTION("AXIS',(1,0,0,));
#193=DIRECTION("REF_DIRECTION',(0,0,1,));
#194=AXIS2_PLACEMENT_3D('PLACEMENTWS ROUGH GENERAL_REVOLUTION
1',"#173,"#174,"#175,);
#195=CARTESIAN_POINT('WS ROUGH GENERAL_REVOLUTION 1:LOCATION',(0,0,-2.5,));
#196=DIRECTION("AXIS',(0,0,1,));
#197=DIRECTION("REF_DIRECTION',(0,0,1,));
#198=DIRECTION("MATERIAL_SIDE',(0,0,1,));
#200=GENERAL_PROFILE($,#201);
#201=POLYLINE('',#202,"#203,"#204,"#205,"#206);
#202=CARTESIAN_POINT('',(21,0.0,0.0));
#203=CARTESIAN_POINT('',(23,0.0,5));
#204=CARTESIAN_POINT('',(23,0.0,55));
#205=CARTESIAN_POINT('',(35,0.0,55));
#206=CARTESIAN_POINT('',(35,0.0,95));
#207=AXIS2_PLACEMENT_3D('PLACEMENTHOLE3',"#208,"#209,"#210,);
#208=DIRECTION("',(0,0,1,));
#209=DIRECTION("',(0,0,1,));
#210=CARTESIAN_POINT(':LOCATION',(0,0,-40,));
#211=AXIS2_PLACEMENT_3D('',"#212,"#213,"#214,);
#212=CARTESIAN_POINT('',(0,0,-40,));
#213=DIRECTION("',(0,0,1,));
#214=DIRECTION("',(0,0,1,));
#215=LINEAR_PROFILE('',#211);
#216=TOLERANCED_LENGTH_MEASURE(30,#251);
```

```
#217=FLAT_HOLE_BOTTOM();
#218=AXIS2_PLACEMENT_3D('PLACEMENTOUTER_DIAMETER 1',"#291,"#220,"#221,);
#219=CARTESIAN_POINT('OUTER_DIAMETER 1:LOCATION',(0,0,-77.5,));
#220=DIRECTION("AXIS',(0,0,1,));
#221=DIRECTION("REF_DIRECTION',(0,0,1,));
#222=TOLERANCED_LENGTH_MEASURE(75,#251);
#223=TOLERANCED_LENGTH_MEASURE(56,#251);
#224=DIAMETER_TAPER(",#225);
#225=TOLERANCED_LENGTH_MEASURE(24,#251);
#226=AXIS2_PLACEMENT_3D('PLACEMENTGROOVE 1',"#227,"#228,"#229,);
#227=CARTESIAN_POINT('GROOVE 1 :LOCATION',(0,0,-67.5,));
#228=DIRECTION("AXIS',(1,0,0,));
#229=DIRECTION("REF_DIRECTION',(0,0,1,));
#230=DIRECTION("MATERIAL_SIDE',(0,0,-1,));
#232=SQUARE_U_PROFILE(,"#233,#2340,#235,0);
#233=TOLERANCED_LENGTH_MEASURE(20,#251);
#234=TOLERANCED_LENGTH_MEASURE(0,#251);
#235=TOLERANCED_LENGTH_MEASURE(0,#251);
#236=AXIS2_PLACEMENT_3D('PLACEMENTCUT_IN 1',"#237,"#238,"#239,);
#237=CARTESIAN_POINT('CUT_IN 1:LOCATION',(0,0,-35.5,));
#238=DIRECTION("AXIS',(1,0,0,));
#239=DIRECTION("REF_DIRECTION',(0,0,1,));
#240=DIRECTION("MATERIAL_SIDE',(0,1,0,));
#242=SQUARE_U_PROFILE(#243,#244,0,#245,0);
#243=TOLERANCED_LENGTH_MEASURE(20,#251);
#244=TOLERANCED_LENGTH_MEASURE(0,#251);
#245=TOLERANCED_LENGTH_MEASURE(0,#251);
#251=PLUS_MINUS_VALUE((24,24,#251);
#280=TURNING_MACHINE_TOOL(#281,(#283 ),120,40,$ );
#281=GENERAL_TURNING_TOOL(#282,.LEFT.,120,40,.CW. );
#282=TOOL_DIMENSION($,$,$,$,33,33,33,3333,33,.CW. );
#283=CUTTING_COMPONENT(33,$,$,$,$ );
#285=TURNING_MACHINE_TOOL(#286,(#288 ),120,40,$ );
#286=GROOVING_TURNING_TOOL(#287,.LEFT.,40,60,.CW.,33,$ );
#287=TOOL_DIMENSION($,$,$,$,33,33,33,3333,33,.CW. );
#288=CUTTING_COMPONENT(33,$,$,$,$ );
#289=MILLING_CUTTING_TOOL(33,#290,(#283 ),120,40,$ );
```

```
#290=TWIST_DRILL(#290,.RIGHT.,.F.,33 );
#291= MILLING_TOOL_DIMENSION(33$,33,33,33,33,33,33 );
#292=CUTTING_COMPONENT(33,$,$,$,$ );
#293=MILLING_CUTTING_TOOL(33,#294,(#296 ),100,$,$ );
#294=REAMER(#295,33,$,.F.,$,$ );
#295=MILLING_TOOL_DIMENSION(33,$,$,$,$,$,$ );
#296=CUTTING_COMPONENT(33,$,$,$,$ );
#297=TURNING_MACHINE_TOOL(#298,(#300 ),$,$,$ );
#298=USER_DEFINED_TURNING_TOOL(#299,.LEFT.,40,60,.CW.,33,$ );
#299=TOOL_DIMENSION(33,$,$,$,$,$,$$,$ );
#300=CUTTING_COMPONENT(33,$,$,$,$ );
ENDSEC;
END-ISO-10303-21;
```

Appendix A2 ISO 14649 Physical File for Case study part



6/8/2012 11:54:32 AM

ISO-10303-21;

HEADER;

FILE_DESCRIPTION(('EXAMPLE OF NC PROGRAMME FOR TURN-MILL: COMPLEX DESIGN.'),'1');

FILE_NAME('EXAMPLE3.STP',$,('ISO14649'),+(''),'Mesfin' 'UTP', 'Malaysia');

FILE_SCHEMA(('MACHINING_SCHEMA','TURNING_SCHEMA'));

ENDSEC;

DATA;

#1=PROJECT('EXCUTE_EXAMPLE_1',#2,(#4),#6,$,$,$);

#2=WORKPLAN('MAINWORK_PLAN',(#15,#16#17,#18#19#20,#21#22,#23#24#25#26,#27#28,#29#30#31,#32),$,#12,$);

#4=WORKPIECE('SimpleWorkpiece',#6,0.03,$,$,$,());

#6=MATERIAL('ST-50','Steel',,#7);

#7=PROPERTY_PARAMETER('Elasticmodule=20000');

#8=RIGHT_CIRCULAR_CYLINDER('Steel',#9,120,52)";

#9=AXIS1_PLACEMENT('WORKPIECEPLACEMENT',#10,#11);

#10=CARTESIAN_POINT('WORKPIECE:LOCATION',(0,0,0));

#11=DIRECTION('AXIS',(0,0,1));

#15=MACHINING_WORKINGSTEP('WS ROUGH CIRCULAR_ FACE1',#82#37,#50);

#16=MACHINING_WORKINGSTEP('WS FINISH CIRCULAR_FACE1',#82#37,#51);

#17=MACHINING_WORKINGSTEP('WS ROUGH GENERAL_REVOLUTION 1',#82#38,#48);

#18=MACHINING_WORKINGSTEP('WS FINISH GENERAL_REVOLUTION 1',#82#38,#49);

#19=MACHINING_WORKINGSTEP('WS ROUGH OUTER_DIAMETER 1',#82#39,#52);

#20=MACHINING_WORKINGSTEP('WS FINISH OUTER_DIAMETER 1',#82#39,#53);

#21=MACHINING_WORKINGSTEP('WS ROUGH OUTER_DIAMETER 2',#82#41,#54);

#22=MACHINING_WORKINGSTEP('WS FINISH OUTER_DIAMETER 2',#82#41,#55);

#23=MACHINING_WORKINGSTEP('WS ROUGH OUTER_DIAMETER 3',#82#40,#56);

#24=MACHINING_WORKINGSTEP('WS FINISH OUTER_DIAMETER 3',#82#40,#57);

#25=MACHINING_WORKINGSTEP('WS ROUGH OPEN_POCKET1',#82#42,#58);

#26=MACHINING_WORKINGSTEP('WS FINISH OPEN_POCKET1',#82#42,#59);

#27=MACHINING_WORKINGSTEP('WS ROUGH OPEN_POCKET2',#82#43,#60);

#28=MACHINING_WORKINGSTEP('WS FINISH OPEN_POCKET2',#82#43,#61);

#29=MACHINING_WORKINGSTEP('WS ROUGH OPEN_POCKET3',#82#44,#62);

#30=MACHINING_WORKINGSTEP('WS FINISH OPEN_POCKET3',#82#44,#63);

#31=MACHINING_WORKINGSTEP('WS ROUGH OPEN_POCKET4',#82#45,#64);

#32=MACHINING_WORKINGSTEP('WS FINISH OPEN_POCKET4',#82#45,#65);

#33=MACHINING_WORKINGSTEP('WS ROUGH OPEN_SQUARE_SLOT1',#82#46,#66);

#34=MACHINING_WORKINGSTEP('WS FINISH OPEN_SQUARE_SLOT1',#82#46,#67);

#36=REVOLVED FLAT('REVOLVED FLAT1',#4(#50,#51)#172,#176,11.65,#178);

#37=REVOLVED FLAT2('REVOLVED FLAT2',#4(#68,#69)#183,#187,13.325,#188);

#38=GENERAL_REVOLUTION 1('GENERAL_REVOLUTION 1',#4(#48,#49)#194,#198,13.325,#200);

#39=OUTER_DIAMETER('OUTER_DIAMETER 2',#4(#52,#53,)#218,#222,#223,#224);

#40=OUTER_DIAMETER('OUTER_DIAMETER 1',#4(#54,#55,)#226,#228,#229,#230);

#41=OUTER_DIAMETER('OUTER_DIAMETER3',#4(#66,#67,)#234,#236,#237,#238);

#42=OPEN_SQUARE_SLOT('OPEN_SQUARE_SLOT1',#4(#56,#57,)#242,#246,#249,$);

#43=OPEN_POCKET('OPEN_POCKET1',#4(#58,#59,)#252,#256,($),#261,#262,$);

#44=OPEN_POCKET('OPEN_POCKET 2',#4(#60,#61,)#275,#279,($),#261,#284,$);

#45=OPEN_POCKET('OPEN_POCKET 3',#4(#62,#63,)#297,#301,($),#261,#306,$);

#46=OPEN_POCKET('OPEN_POCKET4',#4(#64,#65,)#319,#323,($),#261,#328,$);

#48=CONTOURING_ROUGH($,$,'ROUGH GENERALREVOLUTION1',-1,$,#379,#73,#70,#350,#350#351,0.2);

#49=CONTOURING_FINISH($,$,'FINISH GENERAL REVOLUTION 1',30,$,#379,#73,#70,#350,#350#352,0);

#50=FACING_ROUGH('FACING_ROUGHING',40,$,#379,#73,#70,#353,#354#355,0.05);

#51=FACING_FINISH('FACING_FINISHING',40,$,#379,#73,#70,#353,#354#355,0.01);

#52=CONTOURING_ROUGH($,$,'ROUGH OUTER DIAMETER2',21.67,$,#379,#73,#70,$,#350,#350,#351,0.05);

#53=CONTOURING_FINISH($,$,'FINISH OUTER_DIAMETER2',40,$,#379,#73,#70,$,#350,#350,#352,0.01);

#54=CONTOURING_ROUGH($,$,'ROUGH OUTER DIAMETER 1',12,$,#379,#73,#70,$,#350,#350,#351,0.05);

#55=CONTOURING_FINISH($,$,'FINISH OUTER_DIAMETER1',38,$,#379,#73,#70,$,#350,#350,#352,0.01);

#56=BOTTOM_AND_SIDE__ROUGH_MILLING($,$,'ROUGHING OPEN_SQUARE_SLOT1',40,$,#382,#75,#70,$,#350,#350,#355,0.05);

#57=BOTTOM_AND_SIDE__FINISH_MILLING($,$,'FINISHING OPEN_SQUARE_SLOT1',40,$,#382,#75,#70,$,#350,#350,#136,0.05);

#58=SIDE__ROUGH_MILLING($,$,'Side_ROUGH_milling',40,$,#382,#75,#70,$,#350,#350,#356,0.05);

#59=SIDE__FINISH_MILLING($,$,'Side_FINISH_milling',40,$,#382,#75,#70,$,#350,#350,#356,0.05);

#60=SIDE__ROUGH_MILLING($,$,'Side_ROUGH_milling',40,$,#386,#75,#70,$,#350,#350,#356,0.05);

#61=SIDE__FINISH_MILLING($,$,'Side_FINISH_milling',40,$,#386,#75,#70,$,#350,#350,#136,0.05);

#62=SIDE__ROUGH_MILLING($,$,'Side_ROUGH_milling',40,$,#386,#75,#70,$,#350,#350,#356,0.05);

#63=SIDE__FINISH_MILLING($,$,'Side_ROUGH_milling',40,$,#386,#75,#70,$,#350,#350,#356,0.05);

#64=SIDE__ROUGH_MILLING($,$,'Side_FINISH_milling',40,$,#386,#75,#70,$,#350,#350,#356,0.05);

#65=SIDE__FINISH_MILLING($,$,'Side_FINISH_milling',40,$,#386,#75,#70,$,#350,#350,#356,0.05);

#66=CONTOURING_ROUGH($,$,'ROUGH OUTER DIAMETER 3',12,$,#379,#73,#70,$,#350,#350,#351,0.05);

#67=CONTOURING_FINISH($,$,'FINISH OUTER_DIAMETER3',40,$,#379,#73,#70,$,#350,#350,#352,0.01);

#68=FACING_ROUGH('FACING_ROUGHING',40,$,#379,#73,#70,#353,#354#355,0.05);

#69=FACING_FINISH('FACING_FINISHING',40,$,#379,#73,#70,#353,#354#355,0.01);

(********Functions / Technology***********)

#70=TURN_Mill_MACHINE_FUNCTIONS(.T.,$,$,(),.F.$,$,(),$,$,$,);

#71=TURN_TECHNOLOGY($,.TCP.,#62,0.300,().F.,F,F,$);

#72=CONSTANT_SPINDLE_SPEED(0);

#73=TURNING_TECHNOLOGY(.TCP.,#64,0.300,().F.,F,F,$);

#74=CONSTANT_SPINDLE_SPEED(0);

#75=MILLING_TECHNOLOGY(.TCP.,#66,0.300,().F.,F,F,$);

#82=PLANE('SECURITY PLANE',#119,);

#350=PLUNGE_RAMP($,45);

#351=UNIDIRECTIONAL_TURNING($,$,(3),$,$,$,$,6$,$);

#352=UNIDIRECTIONAL_TURNING($,$,(3),$,$,$,$,6$,$);

#353=PLUNGE_RAMP($,40);

#354=PLUNGE_RAMP($,30);

#355=BIDIRECTIONAL_MILLING($,$,(0,0,1),$,$,$,$,0$,$);

#356=UNIDIRECTIONAL_MILLING($,$,(0,0,1),$,$,$,$,0$,$);

#357=PLUNGE_RAMP($,30);

(********Tools***********)

#379=TURNING_CUTTING_TOOL(,"#380,(#381),120,40,$);

#380=TOOL_DIMENSION($,$,$,$,0,50,3,5,0,$);

#381=CUTTING_COMPONENT(0,$,$,$,$);

#382=MILLING_CUTTING_TOOL('END_MILL5MM',#383(#384),$,$,$);

```
#383=TOOL_DIMENSION($,$,$,$,0,50,3,5,0,$);

#384=CUTTING_COMPONENT(0,#385,$,$,$);

#385=MATERIAL(' T15K6',CEMENT CARBIDE,#385,$,$,$);

#386=MILLING_CUTTING_TOOL('END_MILL5MM',#387(#388),#302,$,$);

#387=TOOL_DIMENSION($,$,$,$,0,50,3,5,0,$);

#388=CUTTING_COMPONENT(0,#389,$,$,$);

#389=NUMERIC_PARAMETER(' ELASTIC MODULUS',0.5.E11,' pa');

                    (********Placements / Lengths*********** )

#103=AXIS2_PLACEMENT_3D('SET_UP1 ',"#104,"#105,"#106,);

#104=CARTESIAN_POINT('SET_UP1:LOCATION',(0,0,0,));

#105=DIRECTION("AXIS',(1,0,0,));

#106=DIRECTION("REF_DIRECTION',(0,0,1,));

#107=AXIS2_PLACEMENT_3D('SIMPLE_WORKPIECE ',"#108,"#109,"#110,);

#108=CARTESIAN_POINT('SIMPLE_WORKPIECE:LOCATION',(0,0,0,));

#109=DIRECTION("AXIS',(1,0,0,));

#110=DIRECTION("REF_DIRECTION',(0,0,1,));

#111=AXIS2_PLACEMENT_3D('SET_UP2 ',"#111,"#112,"#113,);

#112=CARTESIAN_POINT('SET_UP2:LOCATION',(0,0,0,));

#113=DIRECTION("AXIS',(1,0,0,));

#114=DIRECTION("REF_DIRECTION',(0,0,1,));

#119=AXIS2_PLACEMENT_3D('SECURITY PLANE ',"#120,"#121,"#122,);

#120=CARTESIAN_POINT('SECPLANE:LOCATION',(0,0,150,));

#121=DIRECTION("AXIS',(1,0,0,));

#122=DIRECTION("REF_DIRECTION',(0,0,1,));

#172=AXIS2_PLACEMENT_3D('PLACEMENT REVOLVED FLAT1',"#173,"#174,"#175,);

#173=CARTESIAN_POINT('REVOLVED FLAT1:LOCATION',(0,0,0,));

#174=DIRECTION("AXIS',(0,0,-1,));

#175=DIRECTION("REF_DIRECTION',(0,0,1,));
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```
#176=DIRECTION("MATERIAL_SIDE',(0,0,-1,));
#178=LINEAR_PROFILE('REVOLVED_FLAT_RADIUS',#179,11.825);
#179=AXIS2_PLACEMENT_3D('PLACEMENT  REVOLVED FLAT1',"#180,"#181,"#182,);
#180=CARTESIAN_POINT('REVOLVED FLAT1:LOCATION',(0,0,0,));
#181=DIRECTION("AXIS',(0,0,-1,));
#182=DIRECTION("REF_DIRECTION',(0,0,1,));
#183=AXIS2_PLACEMENT_3D('PLACEMENT  REVOLVED FLAT2',"#173,"#174,"#175,);
#184=CARTESIAN_POINT('REVOLVED FLAT2:LOCATION',(0,0,-2,));
#185=DIRECTION("AXIS',(0,0,-1,));
#186=DIRECTION("REF_DIRECTION',(0,0,1,));
#187=DIRECTION("MATERIAL_SIDE',(0,0,-1,));
#188=LINEAR_PROFILE('REVOLVED_FLAT_RADIUS',#189,11.65);
#189=AXIS2_PLACEMENT_3D('PLACEMENT  REVOLVED FLAT2',"#190,"#191,"#192,);
#190=CARTESIAN_POINT('REVOLVED FLAT2:LOCATION',(0,0,-2,));
#191=DIRECTION("AXIS',(0,0,-1,));
#192=DIRECTION("REF_DIRECTION',(0,0,1,));
#194=AXIS2_PLACEMENT_3D('PLACEMENTGENERAL_REVOLUTION 1',"#195,"#196,"#197,);
#195=CARTESIAN_POINT('GENERAL_REVOLUTION 1:LOCATION',(0,0,0,));
#196=DIRECTION("AXIS',(1,0,0,));
#197=DIRECTION("REF_DIRECTION',(0,0,1,));
#198=DIRECTION("MATERIAL_SIDE',(0,0,-1,));
#200=GENERAL_PROFILE($,#201);
#201=POLYLINE('',#202,"#203,"#204,"#205);
#202=CARTESIAN_POINT('',(10.5,0,0));
#203=CARTESIAN_POINT('',(10.5,0,4));
#204=CARTESIAN_POINT('',(10.5,0,12));
#205=CARTESIAN_POINT('',(14,0,12));
#206=CARTESIAN_POINT('',(14,0,16));
```

```
#218=AXIS2_PLACEMENT_3D('PLACEMENTOUTER_DIAMETER 1',"#219,"#220,"#221,);
#219=CARTESIAN_POINT('OUTER_DIAMETER 1:LOCATION',(0,0,20.5,));
#220=DIRECTION("AXIS',(0,0,-1,));
#221=DIRECTION("REF_DIRECTION',(1,0,0,));
#222=TOLERANCED_LENGTH_MEASURE(27,#251);
#223=TOLERANCED_LENGTH_MEASURE(10.03,#251);
#224=DIAMETER_TAPER(#225);
#225=TOLERANCED_LENGTH_MEASURE(21.17,#251);
#226=AXIS2_PLACEMENT_3D('PLACEMENTOUTER_DIAMETER3',"#227,"#228,"#229,);
#227=CARTESIAN_POINT('OUTER_DIAMETER3:LOCATION',(0,0,-38.17,));
#228=DIRECTION("AXIS',(0,0,-1,));
#229=DIRECTION("REF_DIRECTION',(1,0,0,));
#230=TOLERANCED_LENGTH_MEASURE(21.7,#251);
#231=TOLERANCED_LENGTH_MEASURE(25.67,#251);
#232=DIAMETER_TAPER(#233);
#233=TOLERANCED_LENGTH_MEASURE(14,#251);
#234=AXIS2_PLACEMENT_3D('PLACEMENTOUTER_DIAMETER 2',"#235,"#236,"#237,);
#235=CARTESIAN_POINT('OUTER_DIAMETER 2:LOCATION',(0,0,-38.17,));
#236=DIRECTION("AXIS',(0,0,-1,));
#237=DIRECTION("REF_DIRECTION',(1,0,0,));
#238=TOLERANCED_LENGTH_MEASURE(27,#251);
#239=TOLERANCED_LENGTH_MEASURE(25.67,#251);
#240=DIAMETER_TAPER(#241);
#241=TOLERANCED_LENGTH_MEASURE(21.17,#251);
#242=AXIS2_PLACEMENT_3D('PLACEMENTOPEN_SQUARE_SLOT1',"#243,"#244,"#245,);
#243=CARTESIAN_POINT('OPEN_SQUARE_SLOT1:LOCATION',(0,0,0,));
#244=DIRECTION("AXIS',(0,0,-1,));
#245=DIRECTION("REF_DIRECTION',(0,0,1,));
```

```
#246=ELEMENTARY_SURFACE('OPEN_SQUARE_SLOT1:DEPTH',#247);
#247=AXIS2_PLACEMENT_3D('OPEN_SQUARE_SLOT1DEPTH',"#248,$,$,);
#248=CARTESIAN_POINT('OPEN_SQUARE_SLOT1:DEPTH',(0,0,-5,));
#249=GENERAL_PATH(#250#251);
#250=AXIS2_PLACEMENT_3D('OPEN_SQUARE_SLOT1COURSE OF TRAVEL',"#242,$,$,);
#251=TOLERANCED_LENGTH_MEASURE('OPEN_SQUARE_SLOT1:LINEAR_PATH',(9.325,#251));
#252=AXIS2_PLACEMENT_3D('PLACEMENTOpen_Pocket1',"#253,"#254,"#255,);
#253=CARTESIAN_POINT('OPEN_POCKET1 Profile:LOCATION',(5,-2.5,0,));
#254=DIRECTION('AXIS',(1,0,0,));
#255=DIRECTION("REF_DIRECTION',(0,0,1,));
#256=ELEMENTARY_SURFACE('Open_Pocket1:DEPTH',#257);
#257=AXIS2_PLACEMENT_3D('OPEN_POCKET1 DEPTH',"#258,#259,#260,);
#258=CARTESIAN_POINT('Open_Pocket1:PROFILE DEPTH",(0,0,3,));
#259=DIRECTION('AXIS',(1,0,0,));
#260=DIRECTION("REF_DIRECTION',(0,0,1,));
#261=PLANAR_POCKET_BOTTOM_CONDITION();
#262=GENERAL_PROFILE($,#263);
#263=COMPOSITE_CURVE('OPEN_POCKET1'(#264,"#268,"#266,);
#264=POLY LINE("#265,"#266,"#267,);
#265=CARTESIAN_POINT(",(2.5,5,0,));
#266=CARTESIAN_POINT(",(2.5,2.5,2.5,));
#267=CARTESIAN_POINT(",(12,5,0,));
#268=COMPONENET_CURVE_SEGMENT(.CONSTANT_SEGEMENT_GRADIENT.,".T.,#269);
#269=TRIMED_CURVE(",#270),(PARAMETER_VALUE180,"PARAMETER_VALUE90);
#270=CIRCLE(",#271),3,);
#271=AXIS2_PLACEMENT_3D(",#272,#273,#274,);
#272=CARTESIAN_POINT(",(2.5,5,0,));
#273=DIRECTION('AXIS',(1,0,0,));
```

```
#274=DIRECTION("REF_DIRECTION',(0,0,1,));

#275=AXIS2_PLACEMENT_3D('PLACEMENT OPEN_POCKET 2',#276,#277,#278);

#276=CARTESIAN_POINT('Open_Pocket 2Profile:LOCATION',(-5,-2.5,0,));

#277=DIRECTION('AXIS',(1,0,0,));

#278=DIRECTION("REF_DIRECTION',(0,0,1,));

#279=ELEMENTARY_SURFACE('OPEN_POCKET 2:DEPTH',#280);

#280=AXIS2_PLACEMENT_3D('OPEN_POCKET 2DEPTH',"#281,282,283,);

#281=CARTESIAN_POINT('OPEN_POCKET 2:PROFILE DEPTH",(0,0,3,));

#282=DIRECTION('AXIS',(1,0,0,));

#283=DIRECTION("REF_DIRECTION',(0,0,1,));

#284=GENERAL_PROFILE($,#285);

#285=COMPOSITE_CURVE('OPEN_POCKET 2'(#286,"#287,"#289,);

#286=POLY LINE("#288,"#289,"#290,);

#287=CARTESIAN_POINT(",(2.5,-5,0,));

#288=CARTESIAN_POINT(",(2.5,2.5,2.5,));

#289=CARTESIAN_POINT(",(12,-5,0,));

#290=COMPONENET_CURVE_SEGMENT(.CONSTANT_SEGEMENT_GRADIENT.,".T.,#291);

#291=TRIMED_CURVE(",#292),(PARAMETER_VALUE180,"PARAMETER_VALUE90);

#292=CIRCLE(",#293),3,);

#293=AXIS2_PLACEMENT_3D(",#293,#294,#295,);

#294=CARTESIAN_POINT(",(2.5,-5,0,));

#295=DIRECTION('AXIS',(1,0,0,));

#296=DIRECTION("REF_DIRECTION',(0,0,1,));

#297=AXIS2_PLACEMENT_3D('PLACEMENTOpen_Pocket 3',#298,#299,#300);

#298=CARTESIAN_POINT('Open_Pocket 3Profile:LOCATION',(-5,2.5,0,));

#299=DIRECTION('AXIS',(1,0,0,));

#300=DIRECTION("REF_DIRECTION',(0,0,1,));

#301=ELEMENTARY_SURFACE('OPEN_POCKET 3:DEPTH',#302);
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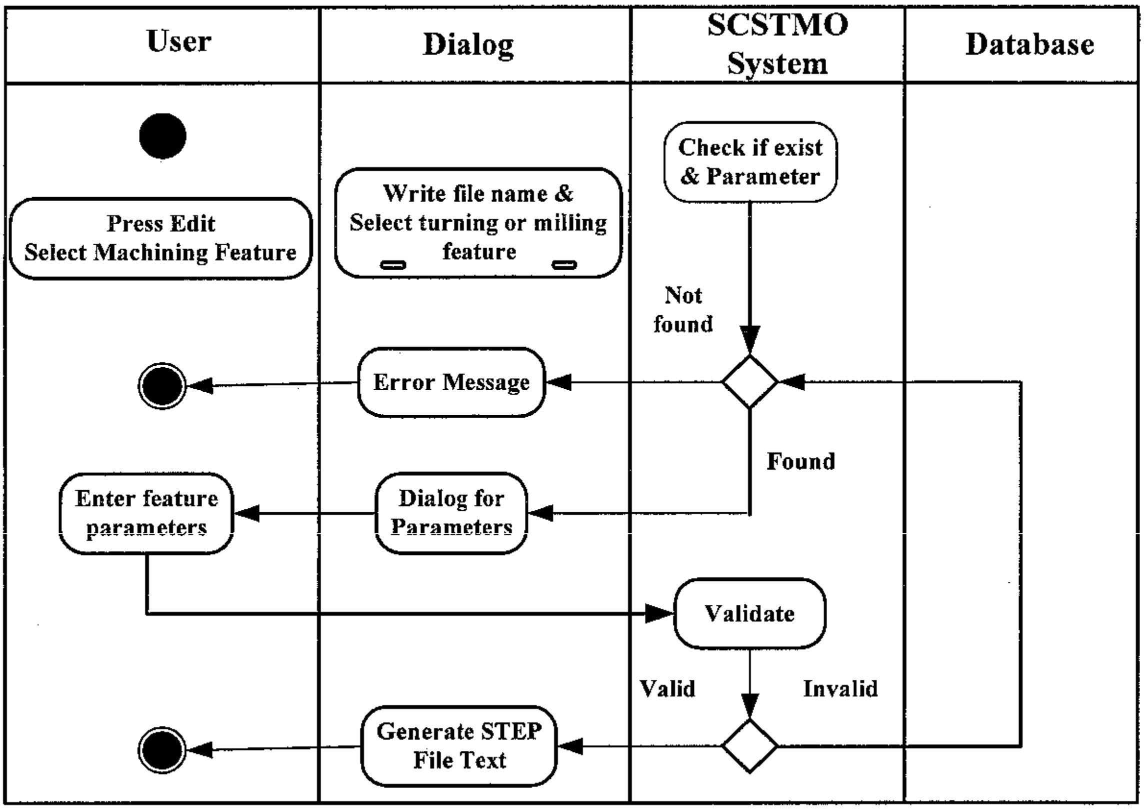
```
#302=AXIS2_PLACEMENT_3D('OPEN_POCKET 3DEPTH',"#303,304,305,);
#303=CARTESIAN_POINT('OPEN_POCKET 3:PROFILE DEPTH",(0,0,3,));
#304=DIRECTION('AXIS',(1,0,0,));
#305=DIRECTION("REF_DIRECTION',(0,0,1,));
#306=GENERAL_PROFILE($,#307);
#307=COMPOSITE_CURVE('OPEN_POCKET 3'(#308,"#312,);
#308=POLY LINE("#309,"#310,"#311,);
#309=CARTESIAN_POINT(",(-2.5,-5,0,));
#310=CARTESIAN_POINT(",(-2.5,-2.5,-2.5,));
#311=CARTESIAN_POINT(",(-12,-5,0,));
#312=COMPONENET_CURVE_SEGMENT(.CONSTANT_SEGEMENT_GRADIENT.,".T.,#313);
#313=TRIMED_CURVE(",#314),(PARAMETER_VALUE180,"PARAMETER_VALUE90);
#314=CIRCLE(",#315),3,);
#315=AXIS2_PLACEMENT_3D(",#316,#317,#318,);
#316=CARTESIAN_POINT(",(-2.5,-5,0,));
#317=DIRECTION('AXIS',(1,0,0,));
#318=DIRECTION("REF_DIRECTION',(0,0,1,));
#319=AXIS2_PLACEMENT_3D('PLACEMEOPEN_POCKET_4',#320,#321,#322);
#320=CARTESIAN_POINT('OPEN_POCKET_4Profile:LOCATION',(5,2.5,0,));
#321=DIRECTION('AXIS',(1,0,0,));
#322=DIRECTION("REF_DIRECTION',(0,0,1,));
#323=ELEMENTARY_SURFACE('OPEN_POCKET_4:DEPTH',#324);
#324=AXIS2_PLACEMENT_3D('OPEN_POCKET_4DEPTH',"#325,326,327,);
#325=CARTESIAN_POINT('OPEN_POCKET_4:PROFILE DEPTH",(0,0,3,));
#326=DIRECTION('AXIS',(1,0,0,));
#327=DIRECTION("REF_DIRECTION',(0,0,1,));
#328=GENERAL_PROFILE($,#329);
#329=COMPOSITE_CURVE('OPEN_POCKET_4'(#330,"#312,);
```

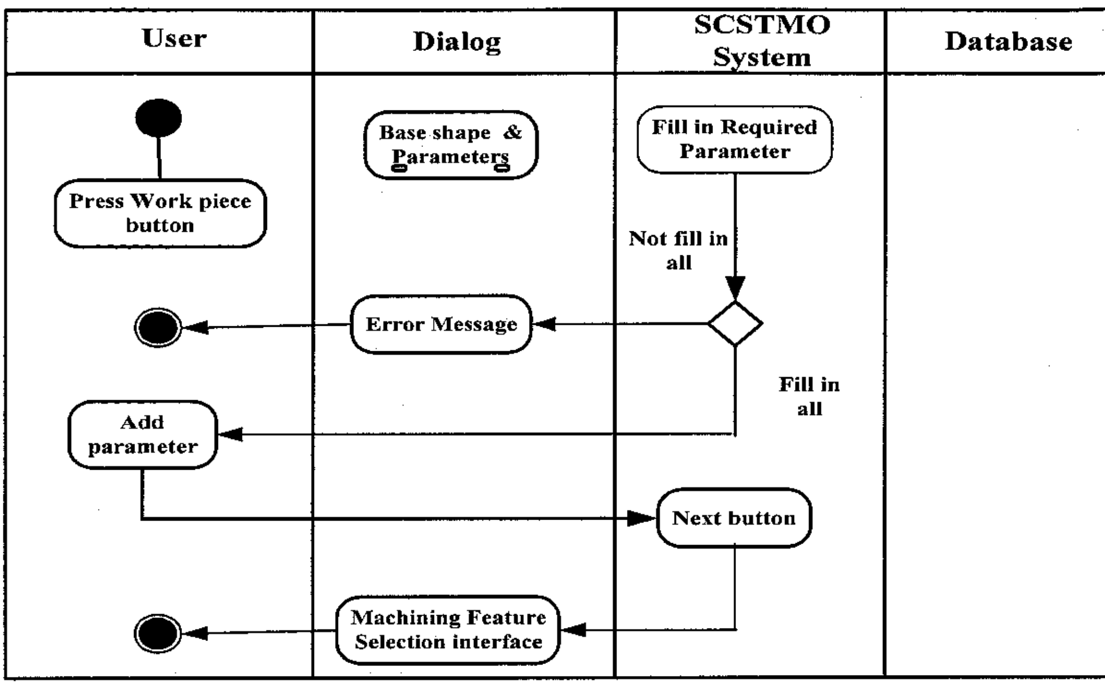
```
#330=POLY LINE("#331,"#332,"#333,);

#331=CARTESIAN_POINT(",(-2.5,5,0,));

#332=CARTESIAN_POINT(",(-2.5,-2.5,-2.5,));

#333=CARTESIAN_POINT(",(-12,5,0,));

#334=COMPONENET_CURVE_SEGMENT(.CONSTANT_SEGEMENT_GRADIENT.,".T.,#335);

#335=TRIMED_CURVE(",#36),(PARAMETER_VALUE180,"PARAMETER_VALUE90);

#336=CIRCLE(",#337),3,);

#337=AXIS2_PLACEMENT_3D(",#338,#339,#340,);

#338=CARTESIAN_POINT(",(-2.5,5,0,));

#339=DIRECTION('AXIS',(1,0,0,));

#340=DIRECTION("REF_DIRECTION',(0,0,1,));

ENDSEC;

END-ISO-10303-21;
```

APPENDIX B: ACTIVITY DIAGRAMS

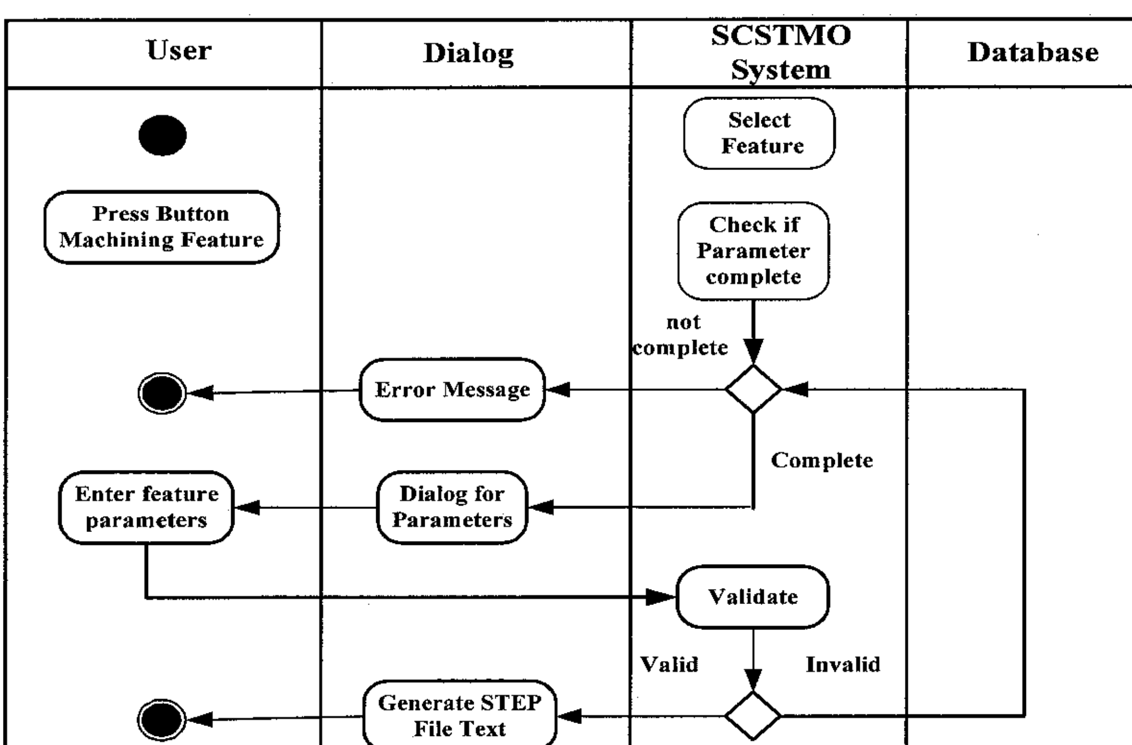
Activity Diagrams- STEP File Editing



Activity Diagrams- Base shape Parameter



Activity Diagrams- New Feature



APPENDIX C: MACHINING FEATURE

Machining Feature List of CASTEL

Feature-Name	**Feature-ID**	**Feature-Size**	**Location**	**Orientation**
Revolved Flat	R.F1	D=38 ,L=5	X=0,Y=0,Z=5	X-Z side
Revolved Flat	R.F2	D=38 ,L=5	X=0,Y=0,Z=5	X-Z side
GENERAL_REVOLUTION	G.R1	D=23.65,L=15.3	X=0,Y=0,Z=4	X-Z
OUTER_DIAMETER	O.D1	D=38,L=25.67	X=23.65,Y=0,Z=15.3 to 41	X-Z
OUTER_DIAMETER	O.D 2	D=26.65,L=10.03	X=0,Y=0,Z=41 to51	X-Z
OPEN_SQUARE_SLOT1	O.Sq1	L=23.65,W=5,H=3	X=0,Y=0,Z=5	X-Z
OPEN_POCKET1	O.P1	L=9.3,W=6.8,H=1	X=5,Y=-2.5,Z=0	X-Z
OPEN_POCKET2	O.P 2	L=9.3,W=6.8,H=1	X=-5,Y=-2.5,Z=0	X-Z
OPEN_POCKET3	O.P3	L=9.3,W=6.8,H=1	X=-5,Y=2.5,Z=0	X-Z
OPEN_POCKET4	O.P4	L=9.3,W=6.8,H=1	X=5,Y=2.5,Z=0	X-Z

APPENDIX D: EXPRESS REPRESENTATIONS

D.1. Product data representation

```
Public Class STEP_XML_224
  Inherits SerializableData

  <XmlIgnore()> Public Items As New ArrayList

  Public Function AddMachining_feature() As machining_feature
    'Declare
    Dim newMachining_feature As New machining_feature
    'Add
    Items.Add(newMachining_feature)

    'Return
    Return newMachining_feature
  End Function
  'Works with items collection as an array
  Public Property Machining_feature() As machining_feature()
    Get
      'New Array
      Dim machining_featureArray(Items.Count - 1) As Machining_feature
      Items.CopyTo(machining_featureArray)
      Return machining_featureArray
    End Get
    Set(ByVal Value As machining_feature())
      'Reset array list
      Items.Clear()
      'Any values?
      If Not Value Is Nothing Then
        'process array and populate items
        Dim machining_feature As machining_feature
        For Each machining_feature In Value
          Items.Add(machining_feature)
        Next
      End If
    End Set
  End Property

End Class
```

Serialization function for Maching_feature files generation

```
Public Class workpiece
  Inherits SerializableData
  Public its_id As String
  Public its_material As New material
  Public global_tolerance As New shape_tolerance

  Public bounding_geometry As New bounding_geometry_select
  Public clamping_positions As New placement
  End Class
```

Workpiece class

```
Public Class Abstractmachining_feature
  Inherits SerializableData
   Public milling_feature As New Abstractmilling_feature
  Public turning_feature As New Abstractturning_feature
  Public depth As New elementary_surface
  Public thread As New Abstractthread
End Class
```

(ABS) machining_feature class

D.2. Manufacturing Process data representation

```
Imports System.Xml.Serialization
Public Class processplan
   Inherits SerializableData
   'Members
   <XmlIgnore()> Public Items As New ArrayList

   'Add new Main_workplan
   Public Function AddMain_workplan() As Main_workplan

      'Declare its members
      Dim newMain_workplan As New Main_workplan

      Items.Add(newMain_workplan)

      'Return
      Return newMain_workplan

   End Function
```

Serialization function for workplan files generation

```
Public Class Abstractworkingstep
   Inherits SerializableData
   'oneof
   Public machining_workingstep As New machining_workingsteps
   Public Rapid_movement As New Rapid_movement
   'Public its_secplane As New elementary_surface
End Class
```

(ABS)Workingstep class

```
Public Class machining_workingsteps
   'Inherits Main_workplan
   Public its_tolerance As New length_measure
   Public its_id As String
   'Public its_secplane As String
   'elementary_surface
   Public its_feature As New Manufacturing_feature
   Public its_operation As New AbstractMachining_operation
   'Public.Rapid_movement As New Rapid_movement
   Public its_effect_name As New its_effect
End Class
```

Machining_workingsteps class

```
Public Class AbstractMachining_operation

   Public operation_id, retract_plane As String
   Public milling_machining_operation As New Abstructmilling_machining_operation
   Public turning_machining_operation As New Abstructturning_machining_operation
   Public its_machining_strategy As New two5D_machining_strategy
   Public start_point As cartesian_point

   Public its_machining_tool As New Abstractmachining_tool
   Public its_technology As New Abstracttechnology
   Public its_machine_functions As New Abstractmachine_functions
   Public its_machine_tool As New Abstractmachine_tool
End Class
```

(ABS) Machining_operation

class