MARMARA UNIVERSITY

Fen Bilimleri Enstitüsü

IMPROVING THE EFFICIENCY OF THE REVERSE ENGINEERING PROJECTS AT MARMARA UNIVERSITY COMPUTER INTEGRATED MANUFACTURING LABORATORY

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SUMMARY

The subject of this study is the efficiency increase in reverse engineering projects conducted at Marmara University CIM (Computer Integrated Manufacturing) laboratory.

There are three main parts of the study. First part explains the development of CAD/CAM applications in the industry. The second part studies and offers managerial solutions for conducting and coordinating computer aided manufacturing projects in general and reverse engineering projects at the Marmara University CIM Laboratory in particular in a more efficient way. The third part constitutes the technical part of the study which tries to find solutions to the problem of how to attack reverse engineering projects efficiently by using CAD/CAM facilities of Marmara University CIM laboratory.

In the first part a brief history of CAD/CAM is given which helps us understand the current situation and today's applications.

In the second part of the study, a managerial approach is given to the problem of computer aided production in general and the reverse engineering applications conducted at the Marmara University CIM Laboratory. General information is given about Computer aided production and Concurrent engineering. Also an ideal procedure which should be followed during a reverse engineering project is offered. By this procedure not only the efficiency is improved, but also the quality control of the processes and services performed by the Marmara University CIM laboratory is ensured.

In the third part a particular efficiency problem in the Marmara University CIM laboratory is approached from the technical point of view. Main activities of the second part of the sudy is the production of subroutines in Euklid Cad/Cam system which will reduce the time consumed in the surface generation using point data obtained from Mitutoyo measuring machine. This reduces the costs and increases the efficiency in the reverse engineering projects at the Marmara University CIM laboratory.

The projects conducted at the CIM laboratory is an application of Reverse Engineering where the starting point is a finished product or a master model.

Reverse Enginnering is a very important stage in the design process. Reverse Enginnering is used for transfering physical data to geometrical data. After this point it is possible to analyze or modify the existing design. The common practice in the mold and die industry is as follows.

In the mold and die manufacturing sector it is usually not possible to find detailed technical drawings for manufacturing. Therefore the common practice is to use sample pieces or prototypes as input for production. In Cad/Cam applications this kind of input is treated as follows;

1) Sample piece or prototype is digitized using coordinate measuring machine

2) Point data which is obtained by the measuring machine is converted to surface data by the Cad/Cam system and this surface data is used for further processing (male/female conversion, parting surface generation, expansion ratios,etc.). The main process is the generation of NC program for the CNC milling machine.

3) NC program is used at the CNC milling machine

This process is also an application of Reverse Engineering. The critical activities which will effect the efficiency in reverse engineering projects can be summarized as follows:

1) Measurement time
2) Time consumed in converting the point data to surface data
3) Milling time at the CNC milling machine

Marmara University CIM laboratory has the following hardware and software which is used for production in the mold and die manufacturing sector;

- Geoboy Mitutoyo coordinate measuring machine
- Euklid Cad/Cam system installed on HP425 workstations
- Lagun 3D CNC milling machine

The efficiency of reverse engineering depends heavily on the techniques employed during the projects. Costs can be reduced to minimum and the quality of the products and services produced can be ensured by the managerial procedures offered and the subroutines and techniques developed which contitutes the contents of this study.

ÖZET

Bu çalışmanın konusu Marmara Üniversitesi CIM (Bilgisayar Entegre imalat) laboratuarında Tersine Yürütülen Prosesler Mühendisliği (Reverse Engineering) projelerinde verim artırımıdır.

Tezin üç bölümü bulunmaktadır. Birinci bölüm endüstrideki CAD/CAM (Bilgisayar Destekli Tasarim ve imalat) uygulamalarının gelişimini anlatmaktadır.. İkinci bölümde genelde bilgisayar destekli imalat ve özelde Marmara Üniversitesi CIM (Bilgisayar Bütünleşik imalat) laboratuarında yürütülen projelerin verimli bir şekilde yürütülmesi ve koordine edilebilmesini sağlayacak yönetimsel çözümler yer almaktadır. Üçüncü bölüm ise tezin teknik yanını oluşturmaktadır. Bu bölüm Marmara Üniversitesi CIM laboratuarında tersine yürütülen prosesler yöntemi ile yapılan projelere daha verimli olarak nasıl yaklaşılacağı problemine çözümler üretmeye çalışmaktadır.

ilk bölümde günümüz koşullarını ve uygulamalarını daha iyi kavrayabilmek amacı ile CAD/CAM'in kısa tarihçesi sunulmaktadır.

Ikinci bölümde genel bilgisayar destekli imalat ve özellikle Marmara Üniversitesi CIM (Bilgisayar Bütünlesik imalat) laboratuarında yürütülen projelerin verimlilik problemlerine yonetimsel bir yaklaşım getirilmiştir. Bilgisayar destekli imalat ve eş zamanlı mühendislik (concurrent engineering) ile ilgili bilgiler verilmiştir. Ayrıca bu tür projelerde takip edilmesi gereken ideal prosedür sunulmaktadır. Bu prosedürun amacı sadece verimliliği artırmak değil, aynı zamanda Marmara Üniversitesi CIM laboratuarında yürütülen proses ve hizmetlerin kalite kontrolu emniyet altına almaktır.

Üçüncü bölümde Marmara Üniversitesi CIM laboratuarındaki mevcut verimliliği artırmaya yonelik teknik bir yaklaşım sunulmaktadır. Bu bölümün ana aktivitesi Euklid Cad/Cam sisteminde oluşturulacak olan nokta verilerini yüzey bilgilerine dönüştürülmesini saglayan yöntemler ve bu yöntemleri destekleyen alt programlardır.

Bu çalışma maliyetleri düşürmeyi ve Marmara Üniversitesi CIM laboratuarında yürütülen projelerin verimini artırmayı amaçlamaktadır.

Marmara Üniversitesi CIM laboratuarında yürütülen projeler tersine yürütülen prosesler muhendisliğinin bir uygulamasıdır. Tersine yürütülen prosesler mühendisliğinde baslangıç noktasi son ürün veya mastır modeldir.

Tersine yürütülen prosesler muhendisliği tasarım sürecinde çok önemli bir aşamadır. Tersine yürütülen prosesler muhendisliği fiziksel verilerin geometrik verilere dönüştürülmesi için kullanılır. Bu noktadan sonra analiz yapmak veya mevcut

tasarımda değişiklikler yapmak mümkün olmaktadır. Kalıpçılık sektöründeki genel uygulama aşağıdaki gibidir;

Kalıpçılık sektöründe imalat için yeterli teknik resim bulmak genellikle mümkün değildir. Bunun en önemli sebeplerinden bir tanesi parçaların genellikle 1/1 oranında dizayn edilmesidir. Bu yüzden Cad/Cam projelerindeki genel uygulama mastır model veya prototipten yola çıkmaktır. Cad/Cam uygulamalarında bu tür veriler aşağıdaki gibi değerlendirilmektedir;

1) Mastır model veya prototip koordinat ölçme makinası ile ölçülür.

2) Koordinat ölçme makinasından elde edilen nokta datası Cad/Cam sistemi kullanılarak yüzeyler oluşturulur. Bu yüzeyler daha sonra dişi-erkek çevirimi, ayırma yüzeylerinin oluşturulması, çekme paylarının verilmesi gibi işlemlerde kullanılır. En önemli işlem ise CNC freze için işleme programlarının (NC kodlar) oluşturulmasıdır.

3) Oluşturulan NC programlar CNC frezeye aktarılarak işleme başlar.

Bu işlem de Tersine yürütülen prosesler Mühendisliğinin (Reverse Engineering) bir uygulamasıdır.

Tersine yürütülen prosesler Mühendisliği projelerindeki verimliliği etkileyen en önemli unsurlar aşağıdaki gibi özetlenebilir;

1) Ölçme süresi
2) Ölçme verilerinin Cad/Cam sistemi ile yüzey bilgisine çevirilmesi
3) CNC Freze işleme süresi

Marmara Üniversitesi CIM laboratuarında kalıpçılık sektöründe üretim yapmak amacıyla aşağıdaki donanım ve yazılım mevcuttur.

- Geoboy Mitutoyo koordinat ölçme makinasi
- Euklid Cad/Cam (Bilgisayar destekli dizayn ve imalat) Sistemi
(HP425 iki workstation üzerinde)
- Lagun 3D CNC freze

Tersine yürütülen prosesler mühendisliğinin verimi projeler sırasında kullanılan yöntem ve araçlara dayalıdır. Bu çalışma ile maliyetlerin düşürülmesinin ve üretilen servis ve ürünlerin kalitesinin garanti altına alınmasının, oluşturulan yönetimsel çözümlerle ve geliştirilen teknik uygulamarla sağlanması amaçlanmıştır.

INTRODUCTION

Turkey's industrial force is getting stronger as each and every institution starts its Computer Aided applications at every single unit of their organizations, one way or the other. Today it is very common to come across managers or technical people doing their job with the help of one or more computer programs on different machines.

As a continuation of this trend CAD/CAM applications have become very popular in the industry and especiallly mold and die sector. In the die and mold sector, design and manufacturing are the main topics which are beginning to be used very intensively. Many CAD/CAM software which do analysis and milling are available in the market both on PC and Workstation basis. Their prices vary according to different parameters like their capacities, the way they handle geometrical entities, ease of use, ease of learning, support facilities, maintenance and so on.

Though many companies and institutions have purchased analysis software, a high percent of them do not use these facilities so often at least for product development and design. Most of them choose to purchase their designs from foreign countries and manufacture them in Turkey. Another choice is to make those designs here in Turkey on 1/1 scale models, (as designers prefer to work with 1/1 scale) and translate the models to computer models by the help of reverse engineering. Even if they bring the design from abroad, they may not be able to obtain a proper technical drawing or a computer model of the part, which again necessitates reverse engineering.

In Reverse Engineering, the starting point is a finished product or a master model.

Reverse Enginnering is a very important stage in the design process. Reverse Enginnering is used for transfering physical data to geometrical data. After this point it is possible to analyze or modify the existing design.

Marmara University CIM laboratory has a leading role in the Turkish mold and die sector. University and private sector relations are not at the desired level in our country. Marmara University with this leading role in the industry has established the CIM (Computer Integrated Manufacturing) laboratory which serves not only as an education institute, but also gives professional CAD/CAM service and consultancy to the industry. This is a very big step for the future as far as the relations and benefits are concerned between the university and the industry.

At Marmara University we have the software and hardware which is aimed and suitable for reverse engineering. The parts are measured for the critical cross-sections at the coordinate measuring machine. These measured points are approximated to curves on the CAD/CAM software and the geometrical surface model is produced by the help of these approximated curves. This computer model is used for NC (Numerical Code) generation which is the driving program for the CNC milling or turning machine. Therefore the model or the sample part is not only reproduced without the necessity of digitizing every point (which is a very long and inefficient process), but we obtain a computer model of the part which can be used for male-female conversions in mold and die milling or further analysed using finite element method for stress, heat transfer, etc.

Curve approximation and surface generation part of this process is quite complex. It takes quite long hours and needs a lot of experience to overcome certain problems. The objective of this study is to provide the necessary subroutines, methods and procedures which aims to help users to handle reverse engineering projects easily, reduce process times to minimum and produce high quality surfaces.

Therefore there are three main parts in this study. In the first part the history of computer aided manufacturing applications and the current situation are shortly explained. In the second part of the study, a managerial approach is given to the problem of computer aided production in general and the efficiency problem during the reverse engineering applications conducted at the Marmara University CIM Laboratory is discussed. Also a procedure for handling computer aided manufacturing projects which is a result of years of experience in this field and currently used at professional CAD/CAM companies is offered. This procedure is intended to help for the managerial part of this study. Together with the control mechanisms it offers, this procedure can not only bring a managerial relief but also ensure the quality control of the projects. Also the necessary forms and report forms are included to help the procedure to be followed easily by the users. In the third part a particular efficiency problem at the Marmara University CIM laboratory is approached from the technical point of view. The subroutines and the techniques produced which are to be used especially for reverse engineering projects are introduced.

Therefore the study as a whole aims to provide great increase in the efficiency to the CIM laboratory of Marmara University.

1.) HISTORY OF NUMERICAL CONTROL

1.1) Introduction

The key to development in the advance of automation has been the recent emergence of informatics technology, the link between electronic processing and communication technologies. Figure 1.1 illustrates developments in computers and communications and how the two can interrelate to form an integrated strategy.

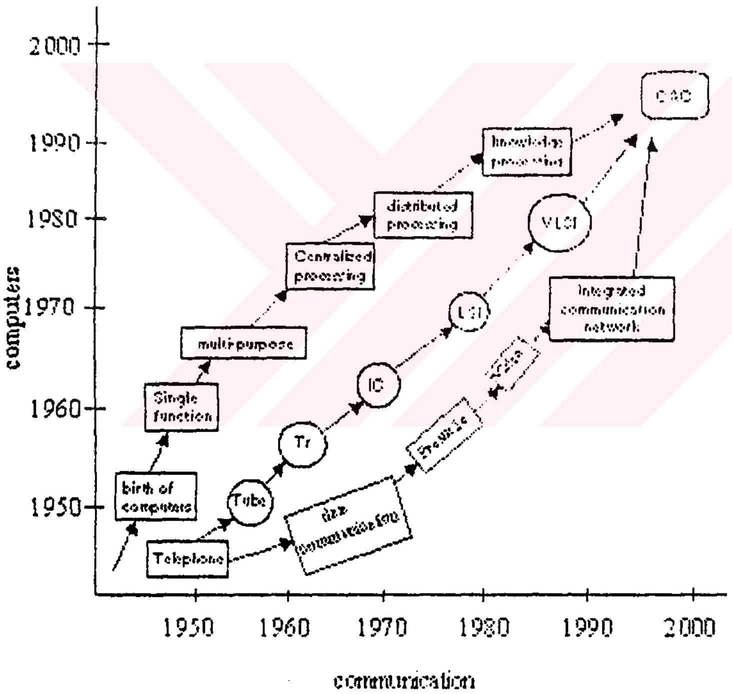


Figure 1.1

Major advances within the realm of control devices (which are being revolutionized by the introduction of informatics technology) have extended the applications of automation technology in the latter half of the twentieth century.

Also involved is the use of logic (control), data processing and communications within electronics technology. Soon after the Second World War, digital numerical control (NC) technology was introduced and it is from its development that modern-day automation is proceeding. NC technology originated primarily for use with machine tools but robots, testing equipment, process controllers, transfer lines, etc operate on a similar logic.

There are many definitions of NC but perhaps the simplest is that it is a technique involving coded numerical instructions for the automatic control of machines or processes. It is a method of controlling machine movements and operations with the aid of alphanumeric codes on some input medium.

NC is a part of the whole concept of automation in industrial technology as it is known today: few other new engineering and manufacturing processes have created as keen an interest, and forced so many changes in so many sectors of industry in the last two decades. NC is a natural evolution from the conventional methods of manufacturing processes, where the skills of the manual operator are replaced by the input medium.

1.2) History of numerical control

Reasons for every major change in manufacturing technology can generally be traced back to historical causes; Figure 1.2 shows the four main lines of development that led to the first NC tool.

The first attempt to regulate manufacturing processes by using some form of control input was Jacquard's Loom (1807). Jacquard used perforated cards to controlthe design of fabric; by moving hole patterns on the cards various woven designs could be produced automatically. A later development was the automatic player piano (1863) which used a perforated paper roll as the control unit.

Some machine tools were adapted relatively easily to NC,having been developed from hydraulic copying machines that already contained servomechanisms, and as a result provided designers with valuable experience. Other more conventional machines were adapted less easily to NC because of their inaccuracy.

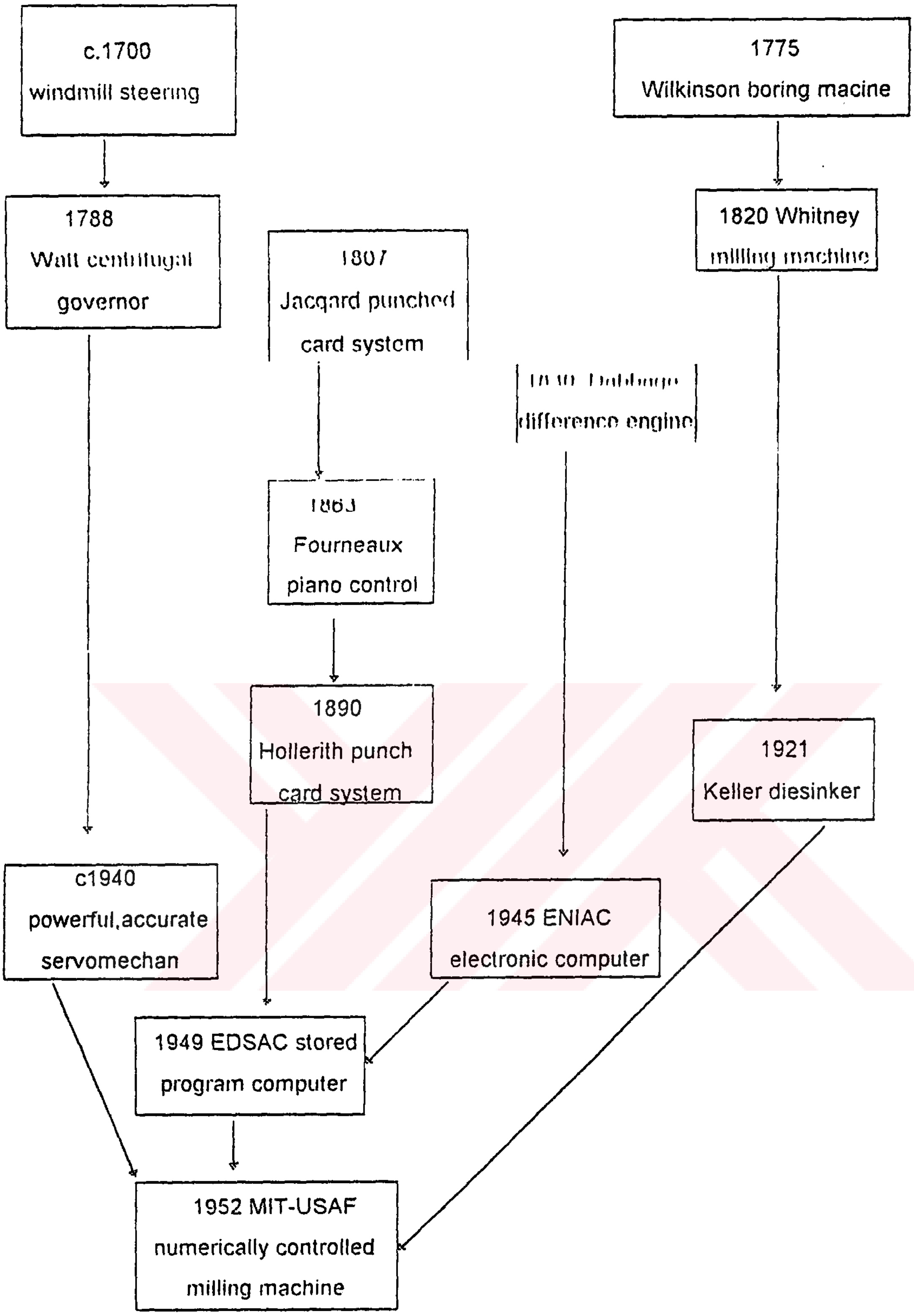


Figure 1.2

The use of NC as an answer to the problem of producing complex components required for aerospace machining came from an aircraft industry subcontractor, the Parsons Corporation of Michigan, USA. In 1947, the. parsons Corporation utilized the techniques and principles of punchcard accounting machines to check the contour of a helicopter blade airfoil pattern. The company subsequently made use of their tabulating equipment to generate a standard set of coordinate points for two-axis airfoil machining data.

In 1949, the US Air Force required more complex parts for their planes and missiles. The design was constantly being modified and improved and there was a need for research into improved productivity methods. The Parsons Corporation was awarded a study contractto design and build machine tools to meet such requirements and to help in this development, the Massachusetts Institute of Technology (MIT) was subcontracted in 1951 to design the first servo-controlled machine tool. A three-axis automatic control system was applied to a modified Cincinnati Hydrotel milling machine in 1952. The control system, programmed with machine instructions on a binary coded perforated tape, successfully executed simultaneous threeaxis cutting tool movements. Similar developments were taking place in the UK, notably at Alfred Herbert Ltd and Ferranti Ltd.

NCMT first appeared commercially on the market in 1960 and by the middle of the decade a large range of NC systems had been developed, together with programming languages to assist in the preparation of input data. During these early years of development NC systems were faced with the inherent limitations of high cost, unreliable electronics, programming difficulties and lack of flexibility.

By 1970, an NC system could provide all the necessary control functions for traditional machine tools such as lathes and milling machines. A new breed of machining centres was developed for use with NC to allow for the maximum number of machining operations on a component at a single setting. Today a wide range of NCMT's is available and may be used for producing accurate holes, contour turning and milling complex shapes that were impossible to produce by conventional machine tools.

1.3) Generations of NC machine tools

As these NC control systems were being developed, so similar rapid advances were occurring within the electronics industry (Figure 1.1). Consequently tremendous changes were made to the control units, servomechanisms, machine tool feedback systems and programming techniques. Nowadays, highly sophisticated NC machine tools are available with capabilities for tape editing, tape storage and control of the machine tool functions by software.

The first generation of NC systems was available commercially in 1954; the control unit was constructed of analogue hardwired circuitry and valve based systems. This type of control system was unreliable when fitted to conventional machine tools, and this led to a high rate of wear and inaccuracy. The majority of NCMT at this stage was of the point-to-point type.

In 1959 the second generation of NCMT was introduced, constructed of digital circuitry using individual transistors and other discrete components. The machines were designed to overcome backlash and wear and to achieve better accuracy for contouring and point-to-point machining.

The third generation of NCMT, with integrated circuit boards, was introduced in 1965. This advancement provided easier maintenance and better utilization. Machine tools were functionally better designed and cheaper machining centres were developed.

By the early 1970s, technical innovations in the electronics industry-the development of the minicomputer, the invention of the eight-bit microprocessor and the continued reduction in hardware costs-provided the means for a wider diffusion of NC systems in manufacture. This gave flexibility in that changes could be implemented in software; hardwired NC tools have now been almost totally supplemented by programmable logic control (PLC) systems, computer numerical control (CNC), both in individual machines and groups of machines, and direct numerical control (DNC). This fourth and fifth generation of minicomputers and microprocessors has brought greater memory and software flexibility to NC.

These developments in machine flexibility have an important impact on the sixth generation of NC, the integrated manufacturing system (IMS). This system is the combination of NC, CNC and DNC, with integration of transfer lines between machines and robot manipulation; as such, the manufacturing unit is self- contained.

1.4) The conventional numerical control concept

Machine tools in general are used to produce components of the required shape and size to a given accuracy and surface finish. A machine tool designed to meet these requirements must have the following functions:

1) provide sufficient power to enable the tool to remove the workpiece metal economically;

2) be able to move the tool and workpiece relative to one another in order to produce the required shape with the given degree of accuracy and surface finish.

In addition to these functions, provisions must be made for auxiliary functions such as altering spindle speeds, feed rates, etc. On a machine tool these functions are performed manually, but in numerically controlled machines they are controlled by means of electronic signals originating in the hardwired controller. Instructions for the control of a conventional NC system are punched and stored on paper tape in a suitable coded form. The paper tape reader converts these instructions into electronic signals and feeds them into a hardwired controller. The controller converts them into a suitable form for activating the drive mechanism controlling the machine tool slides and machining operations.

Figure 1.3 shows, in block diagram form, the conventional idea of NC applied to machine tools.

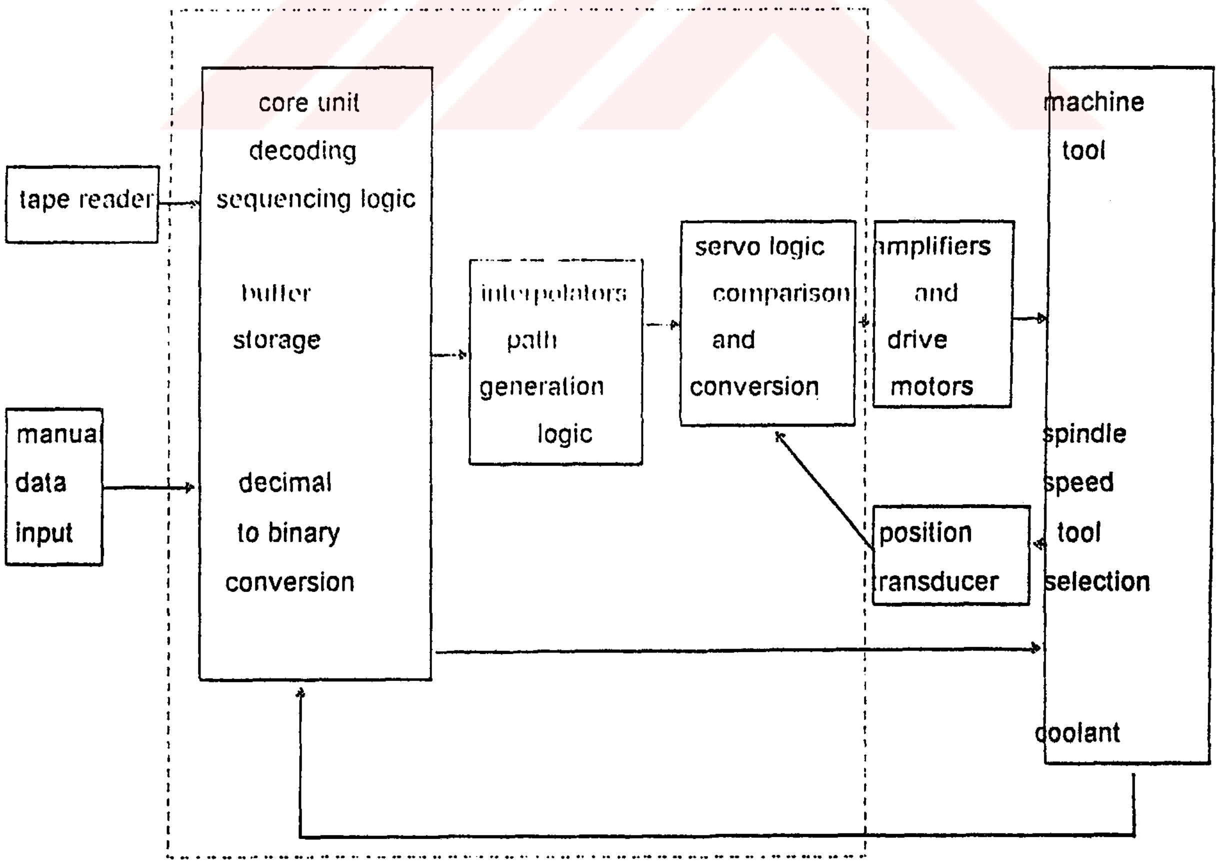


Figure 1.3

2) THE INTEGRATION OF CAD AND CAM

2.1) Introduction

After the development of the first numerical control machine tool at the Massachusetts Institute of Technology (MIT) in 1952, numerical control has progressed rapidly, in line with advancements in computer and electronic technology. Today, sophisticated computer numerical control (CNC) machine tools are available, with many advanced computerized systems being used in machine control units. The advent of numerical engineering has not only made a remarkable change in the manifacturing sector, but also in production planning and design.

Numerical control development is just one phase in the overall application of computers in the manufacturing and marketing processes. Computer technology has been applied successfully to individual aspects of manufacturing and many computer aided manufacture (CAM) systems have resulted. A CAM systems covers many aspects of manufacturing by introducing a hierarchial computer structure to monitor and control the various phases of the manufacturing process.

A CAM systems spans two major areas related to product realization (Figure 1.1):

1) Manufacturing.

2) Marketing and finance.

Each area comprises sub-tasks which are controlled directly by the computer. The hardware of a CAM system includes numerical control of machine tools (NCMT), inspection machines, computers and related devices. CAM software comprises computer programming systems that are used to monitor operations and ultimately to control the flow of.

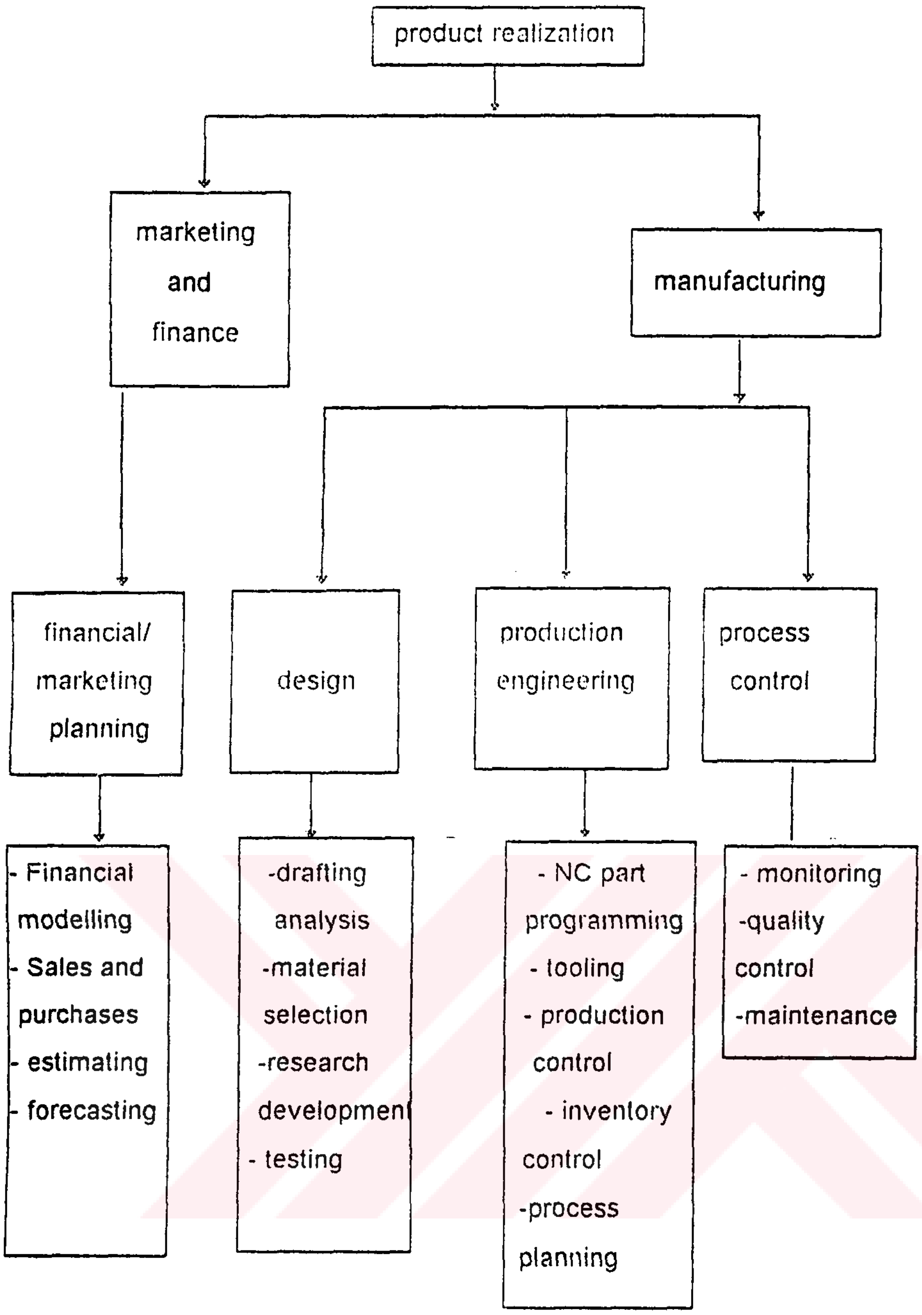


Figure 2.1

2.2) Automation and CAM

Production manufacturing requirements in terms of numerical control can be divided into four main streams:

1) job shop production: production of low quantities, often of a specialized and technologically complex product (eg prototypes, machine tools and aircraft equipment);

2) batch production: production of medium lot sizes of the same product or component, produced once or periodically (eg food products, clothing and industrial machinery);

3) mass production of discrete products: dedicated production of large quantities of one product or a small number of similar products (eg electrical appliances and automobiles);

4) continuous flow processes: continuous dedicated production of large amounts of a bulk product (eg oil refineries and chemical plants).

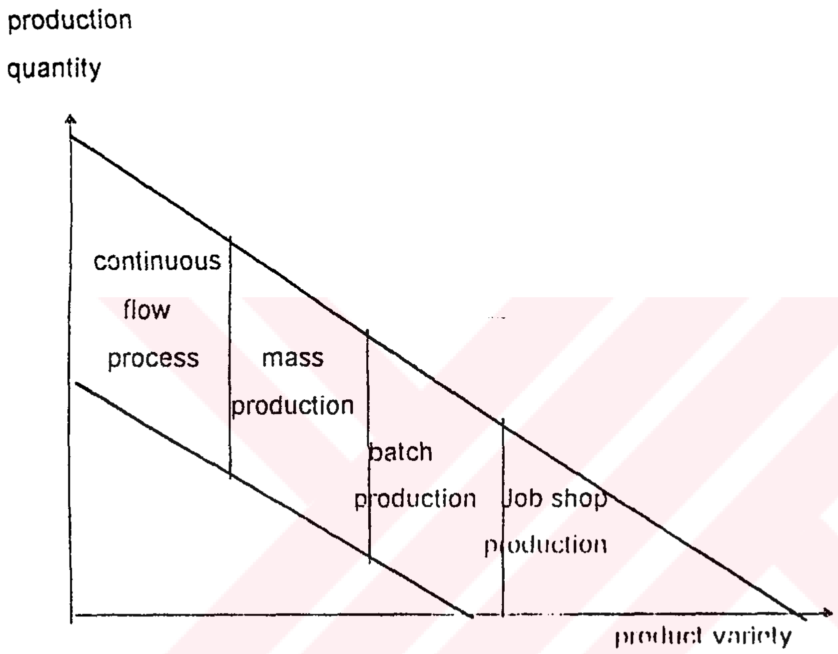


Figure 2.2

Figure 2.2 illustrates the four production types related to quantity and product variation.

While the costs of computing power continue to decrease and labour costs increase, a shift in production processes towards information technology input as a substitute for labour, energy and materials is to be expected. Hence, the intention of this book is to describe the functional aspects of a CAM system and the various technological inputs which manufacturing data and hardware. The integration of CAM with both engineering design and analysis on a computer aided design (CAD) system provides a highly automated engieering system, achieved by planning and controlling the creation of all product-related information within a single product database. This forms the standard against which to hold and to pursue a set of achievable goals which will influence future planning, purchase and implementation of all computer based tools.

The manufacturing element can be subdivided into three categories: design; production engineering; and process control. The design module will encompass the drafting of mathematical product analysis (stress analysis, loading calculations, etc), selection of the optimum materials (both from metallurgical and cost benefit viewpoints), research and development of new techniques (with emphasis on product manufacture), and testing of the design specifications to ensure design standards are maintained Production engineering encompasses the generation of NC part programs, process planning (generates a listing of the operation sequence required to process a particular product or component), and production control (covers the requirements of planning, scheduling and work standards of the individual components and sub-assemblies that make up the product). Process control involves on-line monitoring of the production process to obtain feedback information for quality control (assuring that the quality of the product and its components meet the standards required by the designer) and maintenance (planned to minimize stoppages in production) purposes.

The marketing and finance module covers financial accounting (sales ledger, purchase ledger, P\L accounts, balance sheets, etc) and additionally includes financial planning and marketing of the product. This in turn can be subdivided into modelling (simulation), estimating sales and despatch, and forecasting of future product demand (however, as this forms part of an integrated factory control system, it does not affect the CAM system).

CAM can therefore be defined as the use of computer systems to plan, manage and control the operations of a manufacturing plant througheither direct or indirect computer interface with the plant's production resources. can be used to enhance it in order to achieve greater factory automation. The main inputs to a CAM system (illustrated in Figure 2.3) include CAD, computer process control monitoring, communications networking, robotics and artificial intelligence.

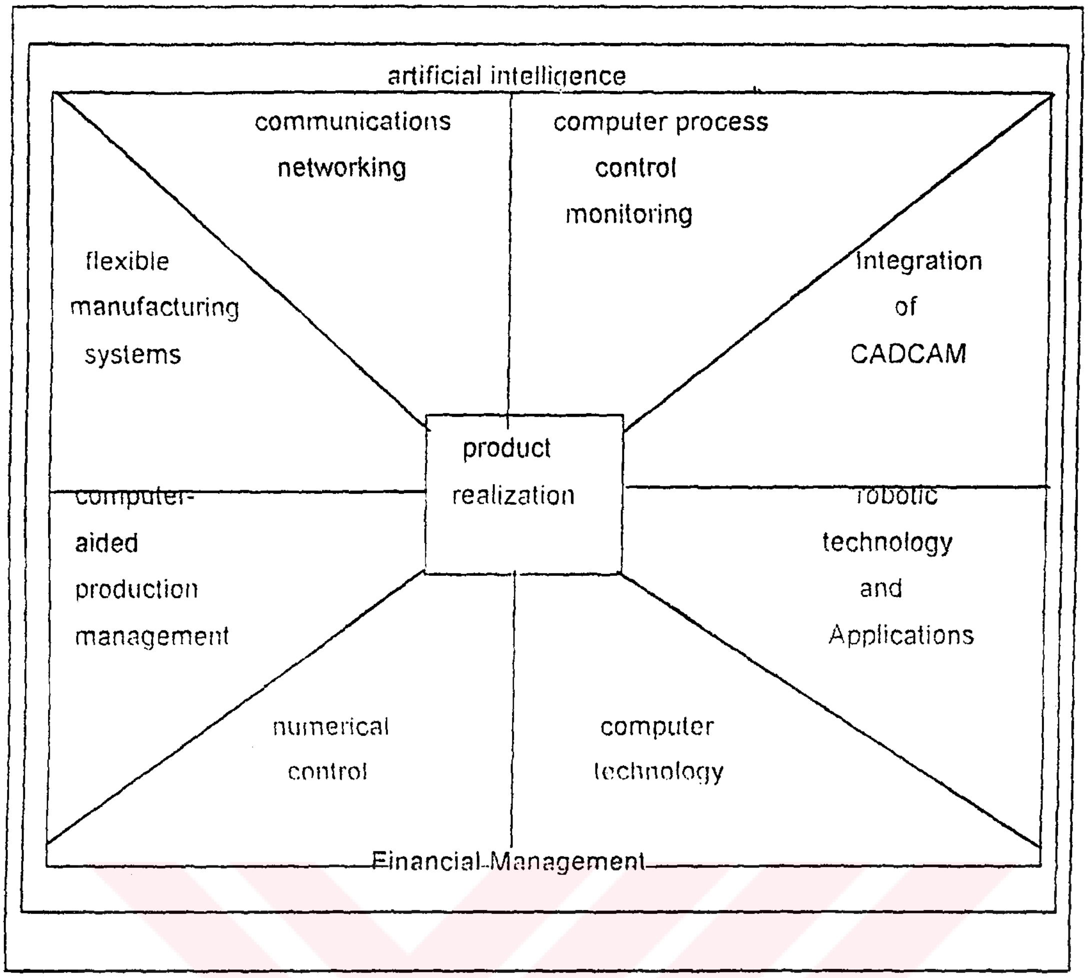


Figure 2.3

For a number of years, computer aided design (CAD) and computer aided manufacture (CAM) have existed separately. The activities within CAD have been centred around analysing and optimizing particular designs, finite element analysis being one example. Within CAM, the data processing capabilities of computers have been exploited for production scheduling and inventory control, while the mathematical capabilities have been exploited for aiding the production of NC tapes. Until fairly recently, CAD and CAM had been developed seperately within the design and production functions of companies, each function seeking to exploit computers in its own way.

The coming of CADCAM system has been heralded as a significant turning point for industry; because such systems will permit the integration of CAD and CAM, considerable productivity gains should result. If used effectively, the system will also give companies the benefit of much shorter lead times which will improve market response. The integration of CAD and CAM takes place through using the stored geometry of components and the CADCAM system at many other stages in the production cycle.

As two technologies of CAD and CAM are now being combined into unified CADCAM systems, a design can be developed and the manufacturing process controlled from start to finish, within a single system. Such capabilities are presently available on the most sophisticated CADCAM systems in a few large manufacturing operations. But more and more plants are gaining this capability, and experts predict that unified systems will lead to what forward-looking managers have long envisioned: the automated factory.

2.3) The evolution of CADCAM

This evolving CADCAM technology will result ultimately in the integration of many diverse technical areas that have developed separately over the past thirty years. Initially, CAD systems were primarily automated draughting stations in which computer-controlled plotters produced engineering drawings. The systems were later linked to graphic display terminals where a geometric model describing the part shape could be created, and the resulting database in the computer was used to produce drawings. Graphic terminals allowed the user to communicate with the computer in pictures instead of raw columns of numbers, and thus allowed accesss to the computer by users untrained in programming.

Now, advanced systems based on interactive graphic treminals have analytical capabilities which permit the part to be evaluated with techniques such as the finite element method. Kinematic programs allow the motion of mechanisms to be studied.

Concurrently with the development of CAD technology, CAM advances were also being made, mostly in numerical control. Until recently, experienced programmers were required to produce and verify NC instructions. But now, instructions can be produced automatically for complex shapes, and tool paths can be verified quickly with computer simulation. In addition, these systems may also have limited process planning features for determining a sequence of fabrication steps and factory management capabilities for directing the flow of work and materials through the factory. The newest feature of CAM is robotics, a field in which automated manipulator arms handle tools and workpieces.

A major milestone was the combination of the CAD features- geometric modelling, draughting, finite element analysis, and kinematics-into a unified system with the CAM capability of automatic NC tape preparation. This advancement finally bridged the gap between the technologies and made it possible for an engineer to go from an initial concept to the finished part with one system. Not only have CADCAM capabilities increased dramatically over the years, but the cost of these systems has decreased, allowing what was exotic and prohibitively expensive a few years ago to become commonplace. Only ten years ago, a computer and the required graphics equipment for a CADCAM system cost several million pounds and could be afforded only by a few automotive and aerospace giants. Now, equivalent systems cost a few hundred thousand pounds, even as low as fifty thousand pounds, and are within the budget of most substantial manufacturers. The combination of economic and technical development has led to the gradual permeation of CADCAM into general industry. Major users of the most sophisticated systems are still large aerospace and automotive companies, but a growing number of other manufacturers are starting to use computer system to design and fabricate products ranging from fasteners and beverage bottles to tin cans and electric motors.

2.4) The concept of integration

Integration, in the context of CADCAM, is defined as the automatic linking of previously discrete stages of design and production processes. There are basically there key features to the concept of integration:

1) data can be transferred automatically between different modules and user groups within the sytem;

2) there is a standard entry to any part of the system. The system is controlled by an overall `executive' so that it provides all the facilities of user security checking and control of data flow between modules;

3) the modules are designed with a common user interface. The common structure is identical; the same word means the same thing; menus are driven in a compatible way; prompts are consistent in their meaning and style; error messages and help systems are compatible.

These features are the visible ones but there is also a whole set of hidden factors concerning software engineering and the use of common software tools across an integrated system which make it inherently more flexible for future expansion and upgradeability.

The benefits of CAD arise from the improved integration within the organization, enabling all personnel to work with a common database, with the benefit that information created in one department need not be duplicated in another department but can be accessed as required. For example, if a component requiring NC machining is designed by using CAD techniques, then the production engineer can also use the geometric data describing the component, which were created by the designer, in order to produce a control tape for the NC machine via an APT or similar program. It is also possible to integrate production control and material scheduling more closely within the design process.

Integration on a wide scale is clearly apparent in certain construction companies using CAD methods where, for example, architects and structural engineers are using common databases for draughting requirements. The storing of information, and access to that information, are benefits derived from the use of CAD techniques. Storing information in computer data banks can be cost-effective. If many departments within a firm can become linked into computer database systems, then the generation of large amounts of documentation can be reduced.

2.5) Fundamentals of CAD

CAD involves any type of design activity which makes use of the computer to develop, analyse, or modify an engineering drawing. It is a discipline that provides the required know-how in computer hardware and software, in systems analysis and in engineering methodology for specifying, designing, implementing, introducing and using computer based systems for design purposes. In the context of CAD, design is not only the more-or-less intuitively guided creation of new information by the designer, but it also comprises analysis, presentation of results, simulation and optimization. These are essential constituents of the iterative process, leading to a feasible and, one hopes, optimal design.

2.5.1) CAD Functions

Briefly, CAD functions may be grouped into four categories: geometric modelling, engineering analysis, kinematics, and automatic draughting.

The geometric model is the most critical feature of any CADCAM system. Many other CADCAM functions, such as finite element analysis, automatic draughting and NC tape preparation, depend on the geometric data of the model as a starting point. Ever since the emergence of the CAD concept, a lot of work has been done in developing the geometric model of a part. Most modelling today is done with wire frame models with two-, two and a half-, or threedimensional capability. However, the more sophisticated three-dimensional solid modelling technique has been developed to obtain a better representation of the part shape.

After the geometric model is created, some CAD systems can move directly to analysis, calculating the weight, volume, surface area, moment of inertia, or centre of gravity of a part. In some cases, by specifying conditions, the CAD system can then generate the finite element model from a geometric model. Besides, some CAD systems have kinematic features for plotting or animating the motion of linkage mechanism. Such analysis can ensure that moving compounds do not impact on other parts of the structure. On the other hand, with autamatic draughting, detailed engineering drawings may be produced automatically with automatic scaling and dimensioning features. The geometric data can be retrieved from the database and from a menu with drawing functions such as size and location of lines, ares, text, cross-hatching, and dimensions.

2.5.2) Interactive Graphics Systems

In general, a typical interactive graphic design station configuration includes a processor, a graphics display, input devices, and hard-copy output devices. Figure 6.1 depicts an interactive graphics system for CAD applications. The processor is the computer in the system which is used to drive all the peripheral equipment and run the programs. The most visible part of the system is the graphics terminal. There are three main types of cathode ray tube (CRT) used in graphics display terminals, namely: the storage tube which maintains a steady image on the screen; the refresh tube in which the picture is rewritten on the screen at the rate of between 10 and 60 frames a second; and the raster scan which uses techniques similar to those employed in a domestic television. On the other hand, input devices such as light pen, digitizing tablet with pen, joystick, or keyboard can be used; while hard-copy output devices can be a printer and a plotter. Available in the present market are high-speed drum plotters or flatbed plotters using pens, electrostatic plotters, and microfilm plotters.

There are four main types of interactive graphics systems: local I\O systems; intelligent terminal systems; intelligent satellite systems; and local stand-alone systems. The first three types are basically remote host systems.

Local I\O systems provide locally the input and output devices, not even containing their controllers. An interface for the line to the remote host is obviously required. With many terminals attached to a host (which is generally already busy processing batch programs) and with a high degree of interaction (as is typical for CAD applications) the host is likely to be overloaded and unable to provide acceptable response times.

Intelligent terminal systems provide the controllers for input and output by themselves. They contain (hardware or micro- programmed) I\O processing facilities for performing the I\O timing. They also contain a processor for executing the device driver routines (low-level software), most of the systems routines, and possibly a small section of the application program (medium-level software), eg for syntactic analysis of the input and prompting. In any case, intelligent terminal systems are able to do some stand-alone, low-level picture editing and to buffer the user's actions locally for a later updating of the remote host's database.

Intelligent satellite systems can be viewed as very wellequipped intelligent terminals. They can hold locally all systems routines and nearly the whole application program. Access to the host will be used for taking advantage .of its more powerful hardware facilities (especially memory and special hardware processors) and peripherals, and for accessing the external data and software. Control over the execution of the application program may be local, as well as the organizing facility of the network system. Medium-sized application programs may be executed totally on the satellite without any back-up from the host.

Local stand-alone systems may be intelligent satellites, or even intelligent terminals if they are sufficiently well equipped (including, for instance, secondary storage like floppy disks and also a hard-copy device). It is generally good practice in CAD to provide some stand-alone capabilities to the local installations of remote host systems in any case. In a fully established CAD environment it is usually likely to find local processing power, and hard-copy capability plus a back-up connection to a larger control host computer or computer network.

2.5.3) CADCAM database

In general, CADCAM systems are intended to control various kinds of manufacturing activities, such as product planning, analysis and synthesis, process and operation planning and so on. These new database application systems have some different kinds of requirements from conventional database application systems.

1) CADCAM systems must manage various kinds of data which are organized into drawings, machine data such as jigs, tools, fixtures and machine characteristics, process organization and resource data, bills of material, and design analysis data evaluation etc. These data interrelationships are more complex and closely integrated.

2) The database must be extremely large, probably of the order of several tens of gigabytes, in order to store drawings or shape description of parts in the order of several thousand bytes. In spite of the great amount of data to be managed, high speed response time for designer's requests is required, because most CADCAM applications are executed in real-time and conversational mode.

3) The database system must not force the designer to keep the syntax depending on database architecture. It is desirable to provide designer-system communication in high level terms,such as entity representation and/or three-dimensional solid graphical representation.

4) Tentative and iterative design processes must be supported. The design process, in general, is the trial and error process, and designers may desire to re-try the design using intermediate design data resulting from a predesign stage.

5) Some parts of data structures in CADCAM application fields may be unable to be defined until actually carrying out the design. On the other hand, most business databases have a static data structure, which can be predefined.

6) The know-how for designing the product and the manufacturing process thereof are under control of the individual designer. To establish a systematic product design and to make it easy to use, this knowledge must be managed within the CADCAM system.

7) A distributed database management mechanism must be taken into account, which logically manages the integrated CADCAM database, but physically manages the sub-divided database.

8) A dynamic data structure control mechanism must also be taken into account, which has the capability for designers to define the data structure at any time, and manages the interaction between the dynamically defined data structures and the predefined data structures.

2.6) CAD/CAM and improvements in productivity

DRAUGHTING

Drawings with recurring features or drawings that are frequently updated are much more efficiently draughted with a CAD system.

DOCUMENTATION

Bills of material and technical illustrations are very quickly produced if they can be derived from data already stored in a CAD system.

DESIGN

Calculations of area, volume, weight, deformation, thermal flux, and so on are best performed by a computer. CAD system can either perform these calculations themselves or prepare input for larger computers from graphical data already stored in the CAD system. Also, design tasks that involve fitting together or housing a number of parts are very efficiently done with some CAD systems.

ESTIMATING

The ability of some CAD systems to associate, store and recall graphical and text data has been put to good use by engineering estimators. Experience has shown that this approach is more productive than manual methods and captures more cost information.

ORDER ENTRY

Some manufacturers have found that a lot of time can be saved by integrating order entry with their CAD system. Major savings can occur in this area where an order must be tied to specific engineering drawings.

MANUFACTURING

Many CADCAM systems include software for producing NC tapes and other items used for planning the manufacturing process from information entered and stored in the system during the design phase. This greatly reduces the effort necessary to get a part into production.

SCHEDULING

Improved scheduling and shop loading because of standardization of operation sequences, tooling and machine tool selection.

LABOUR

Reduced labour cost in preparing planning data and other paperwork (routing sheets, tool lists, materials requirements lists and so on).

MARKET RESPONSE

CADCAM systems allow a quick response to changing market demands because product changes and improvements can be made without costly downtime. For example, a drawing file can be called up on a designer's workstation,product changes can be made, and with very little effort a new tape can be produced to control the machine process used to make the product.

METHOD SELECTION

Improved productivity caused by better methods, better tool selection and optimum speeds\feeds.

2.7) Defining CAD/CAM project objectives

There are many reasons for introducing CADCAM which can vary from a need to improve the speed and quality of draughting to taking a small step towards a completely integrated design and manufacturing concept. The people involved in the introduction of a CADCAM system should therefore set objectives which are concrete, openly declared and, wherever possible, quantified. However, setting objectives requires a careful review of strategic issues which will include:

1) the needs of the market;
2) its sensitivity to speed of response, quality, reliability and cost;
3) the scope for doing the job in a different way;
4) the direction and pace of change which is desired;
5) the capacity of the existing organization to adapt to this pace;
6) the scope for, and desirability of, removing organizational boundaries between, say, design, jig and tool design and estimating functions;
7) the long-and medium-term philosophy for introducing new technology.

Staff who participate in these discussions are better oriented than those who don't and are likely to be more committed to success. To get good value from both man and machine the company must therefore think clearly about its overall strategy and how the installation of CADCAM equipment can support it. Involvement in this pre-planning process is a powerful means of preparing staff for the change and of ensuring that the project is properly directed from the start.

Company-wide strategic planning is needed and the real problem during this transition period will be to balance the `power' among data processing, design, manufacturing and senior management. The effects of CADCAM on various areas of a company's business are outlined in Figure 2.4.

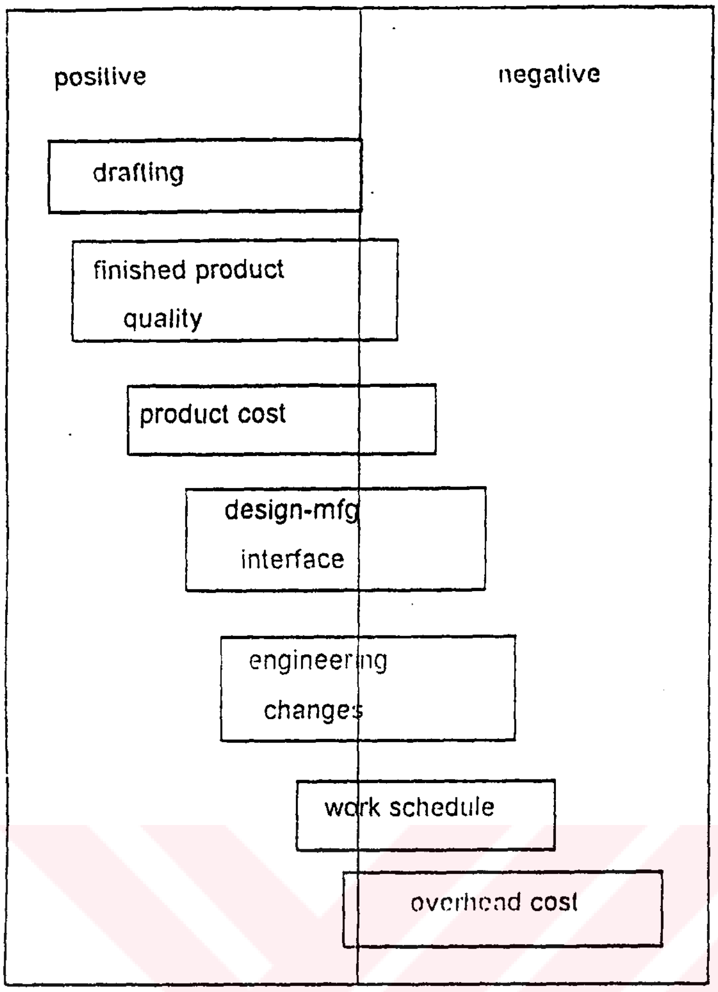


Figure 2.4

2.8) Procedures to be followed in a CADCAM implementation

1) The first part of a CADCAM implementation for CADCAM must be made relatively simple;

2) the products, as well as the implementation for CADCAM must be engineered;

3) a maintenance program must be planned well;

4) backing must be obtained from the highest level of corporate management;

5) maintenance people who appreciate the hazards of poor hardware and software maintenance must be employed for the job;

6) it must be ensured that the maintenance and training program provides the necessary tools to do the job;

7) security must be designed into the system from the beginning;

8) the system for database management must be designed before implementation;

9) system and job operating procedures and day-to-day system management should be defined from the beginning;

10) drawing release procedures must be developed before the system is implemented;

11) file discipline must be established in the initial phases of system design;

12) network planning must take into account future expansion;

13) a task accounting package must be built into the system to measure future effectiveness;

14) an audit trail must be built into the system;

15) finally, particular attention must be paid to the interface design for management systems, shop floor systems, and engineering database systems.

3) COMPUTER AIDED PRODUCTION MANAGEMENT

3.1) Introduction

Computer aided production management (CAPM) is a term used to refer to all aspects of computer application in production, as well as interfaces between production and marketing, design and finance. Whatever other objectives a manufacturing company may have, its two perpetual shortterm objectives are likely to be obtaining orders and executing them to the satisfactions of the customers. CAPM is applied in order to execute customers' orders efficiently and economically. Its main concerns are therefore:

1) knowing at all times what delivery dates can be offered realistically, taking into account existing commitments;

2) planning future capacity to meet sales opportunities;

3) ensuring that the right materials are ordered;

4) ensuring that work-in-progress through the manufacturing stages in the right sequence;

5) providing flexibility to meet changing customer requirements or priorities without incurring excessive inventory.

By contrast, CADCAM is concerned with the technical functions involved in the execution of customers' orders; CAD with the design and specification of the products and CAM with computer control of the manufacturing processes. CAPM is concerned with systems, whereas CAM is concerned with the manufacturing plant.

3.2) Objectives of CAPM

The normal objectives of CAPM are, simply stated:

1) to enable delivery periods to be offered which are short enough not to lose the company valuable business;

2) to deliver customers' orders by the quoted dates;

3) to utilize the company's plant and manpower resources in such a way as will achieve the required output on time at the lowest possible cost;

4) to plan and control the levels of stoock and work-in- progress at the minimum consistent with the above objectives;

5) to change manufacturing capacity as necessary and in time to achieve the objectives in the face of a changing volume and mix of business;

6) to provide systematic planning and control of the procurement of matarial and its progress through the stages of manufacture as a background against which to deal with unexpected events;

7) to provide job satisfaction.

The best way to achieve these objectives varies enormously with, for instance, the complexity of the product and whether the company makes a large volume of each product or small quantities to meet individual customer's specifications. CAPM provides the opportunity for these objectives to become valuable benefits. Their realization still depends on management's knowledge of what is going on and its will to manage on the basis of knowledge and understanding. Computerization makes that easier; it also makes it more satisfying. For years this area of production management (ie production control in its broadest sense)has been a losing battle in many companies. With many computer systems it still is, but it need not be. That has now been demonstrated in a wide variety of industries, including the notorious batch and jobbing types of engineering.

3.3.1) Concurrent Engineering- Tools for Managing and Measuring

Concurrent engineering is a comprehensive management process for new product development. The process is structured ; yet quite fast, flexible, and entrepreneurial. The process will put stress on organization cultures and personnel, but it generates excitement, energy, and confidence. Dedication to concurrent philosophies and principles will absolutely result in reduced time-to-market, improved product quality and reliability, and satisfied customers. Concurrent/Simultaneous enginering goals cannot be realized without the early involvement of all functions involved in new product development activities. Today, many companies are forming multifunctional teams as a solution to rapid product development goals and improved product quality. Many of these teams receive "team building" training, and then they get "turned loose" to show how well team approaches work. It is unrealistic to think that these teams will be significantly more successful than other organizational approaches, without building a process around them that is appropriate for this "new type of organization structure and product development process".

Concurrent engineering/integrated product development concepts are not new and revolutionary. Many of these practices have been used by organizations in the past. But as the size and complexity of companies increased, industry lost many of these practices. In the competitive world of the Nineties, companies must aggresively improve the way that they develop products. While the concepts are simple, the implementation of these practices and the process of changing a company's culture is challenging. Success can be achieved with a well-planned and managed effort. Management must understand not only the concepts of CE/IPD, but the process of managing change within the organization. The responsibility for making these major changes in culture, organization, business process and technology can not be delegated. Proactive management involvement, leadership, and attention to detail will pay off.

Unsuccessful or disappointing efforts to implement CE/IPD can be traced to one or more of the following pitfalls :

- Limited CE/IPD perspective - management believes they have achieved it
- Not a high priority; treated as a fad
- Lack of understanding of how to manage change, involve employees, or change the culture
- Teams formed, but no guidance given on roles, responsibilities, reporting relationships, etc.
- No management leadership or follow-up - imperative lost
- Lack of time or investment in training, process improvement, systems, or guidelines
- No plan, accepted responsibilities, or coordination
- Policies & reward systems not re-aligned to support CE/IPD

The implementation effort should be planned and lead from the top down, but implemented from the bottom up. Company personnel should be involved into implementation of CE/IPD to develop ownership. Employee involvement must be based on cummunicating the proper goals and providing necessary training in the concepts and skills. When executive management makes continuous improvement a high priority, initiatives such as concurrent engineering can be achieved.

3.3.2) Concurrent Engineering Today

The basic tenets of concurrent engineering-doing things simultaneously, focusing on the process, converting hierarchical organizations into teams- are still valid. Indeed, experts report that the majority of manufacturing companies are doing something something along these lines. The goals, of course, are dramatic improvements in time to market, costs annd product quality and performance as well as to do more with less.

One of the primary people issues is the formation of teams. Anyone who is affected by a certain product, or comes into contact with that product along the development path, should probably be involved with the team. Such teams include design engineers, analysts, manufacturing engineers as well as production personnel, customers, and even suppliers.Teams are often used to help make the transition to concurrent enginnering. For teams to be effective, they must not be overriden by management. Training also plays an important role in CE.

Training in the tools of CE-CAD/CAM/CAE- seems only logical, but some companies make the mistake of going cheap on CAD training. Perhaps even more important is training in nontechnical areas. As engineers move to a team, they have to have training for critical skills such as problem solving, learning to disagree so they can learn to agree, and so on.

A hot buzzword in the business press is "re-engineering", meaning, in short, to revamp the processes by which you satisfy customer needs. Often cited are the Japanese, who focus on continually improving the product development process, from which high-quality, competitive products naturally emerge. By many accounts, CE means re-engineering of the product development process.

Nobody likes change. The tools are there, the people are there, the real issue is how you organize it and implement it. If you do not deal with the organizational issues, you are doomed to failure.

To be sure, it is easy to equate CE and technology. Experts say CE can be practiced without CAD/CAM, but just try and find a company that is doing so. Nonetheless, technology is only part of CE. The enlightment is that everyone now understands that CE is the application of people and how they relate to the technology and processes.

Software, hardware and networks make CE practical in today's world of multinational corporations, multi-partner projects and virtual corporations, multi partner projects and virtual corporations.

Reducing time to market is often reported as one of the primary goals of concurrent development programs. However, while short product development times are clearly better than long ones- and while there are obvious advantages to being first to market- the greatest value of concurrent development , and which receives far too little attention, is an increase in product quality.

The true benefit of concurrent development is improved quality.

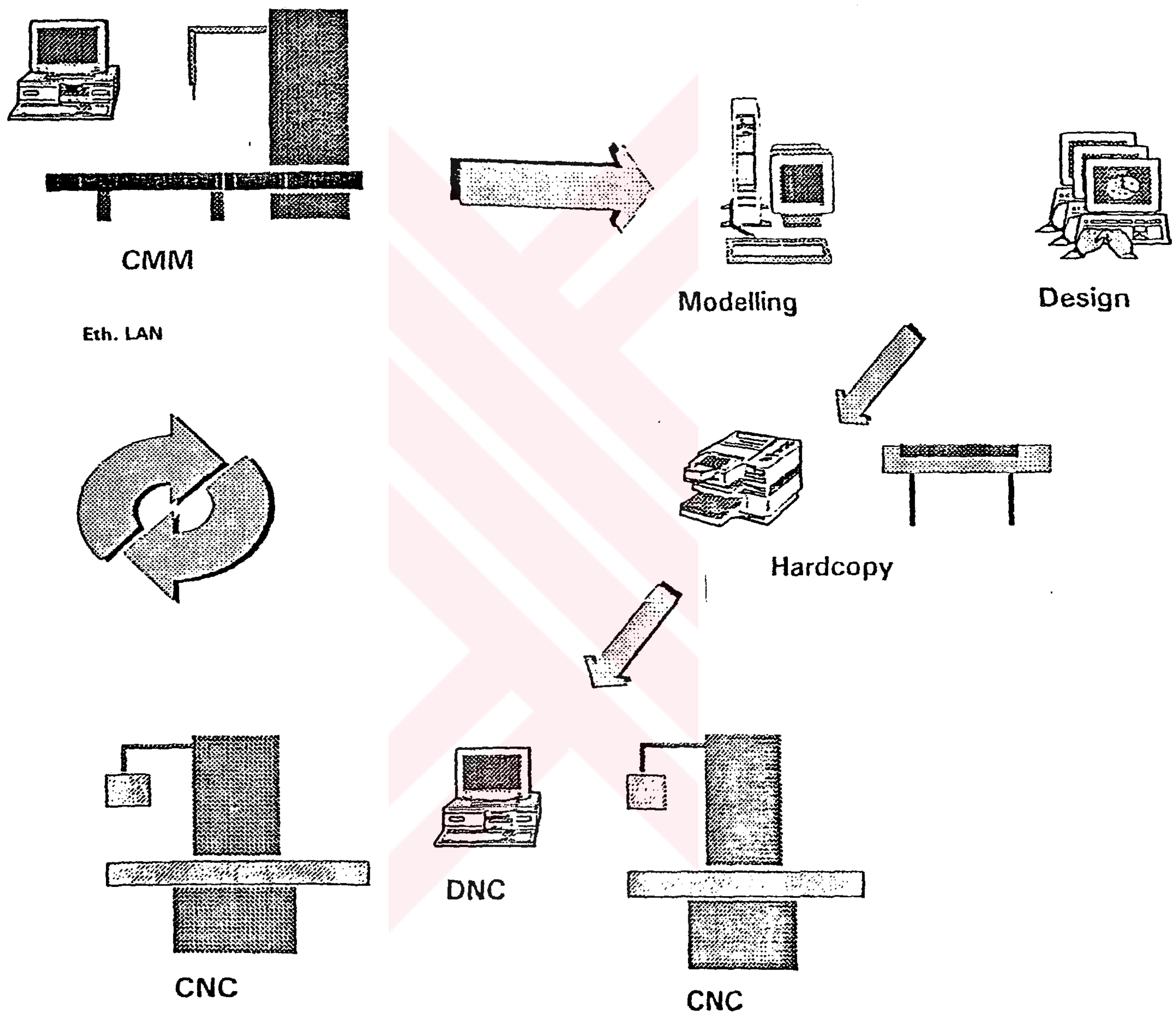
Concurrent development produces better product definitions, avoiding a common development miscue, through the involvement of all parts of the organization in the initial stages of definition.

Concurrent development allows us to develop multiple generations of a product concurrently, reducing the chance that development teams will produce orphans that have little chance of surviving competitive retaliation.

Concurrent development fosters a climate for cultural change. It invigorates the organization as the knowledge, and hence effectiveness, of the team members increase.

Substantial employee training in project management and team building must accompany concurrent development. Employees are asked to communicate and function differently from the past and often need additional skills to do this effectively.

Marmara University CIM Laboratory



3.4) Suggested Procedure for an Efficient CAD/CAM Project

Reverse engineering projects necessitates very careful study of the pieces, methodological work and perfect organization. Team work is the keyword for beginning such a project.

Four different groups of people are necessary for a succesfull project. The first group is the computer modelling group who will produce the surface model of the die and the mold and the NC program for the milling machine. The second group is responsible for coordinate measuring and will work according to the orders which will arrive from the computer modelling group. The third party is the CNC operator group. This group will be responsible for studying the part to be milled and prepare a milling request for the computer modelling group which explains the tools and the fashion of milling. Of course, they will also be responsible from the milling operation itself. The forth group is the project management group who will organize the groups to work as a team according to the procedure and the time table of the project. They will also coordinate the customer contact and relations as well as keeping track of the efficiency parameters of the project.

These four groups of people are the guarantee for high quality, fast, reliable and efficient CAD/CAM service.

What exactly these four groups of people should do before and during the course of the project is given by the procedure below;

3.5) EUKLID Modelling Procedure

This procedure is aimed towards methodological working in CAD/CAM projects and also tries to ensure quality at each stage of the project, starting from the first contact with the customer until the end of the project. As the objective of this master study is to provide efficiency for the reverse engineering projects using CAD/CAM technology, this procedure is revised specially for reverse engineering projects. During the process, some forms and reports are used. These forms and reports are included at the appendix of this study.

- Log paper is kept by the project manager (CAD/CAM service project form). The stages of the project is written down on this report. This paper is necessary for a second modeller who may be involved in the project later.

CAD/CAM SERVICE PROJECT FORM

Project No............... ....
Part Name..............: ....
Company....... ....: ....
Project Manager......: ....
Project Start...........: ....
Deadline.................: ....
Work Flow..............:

	Responsible	Est. Time	Real Time	Est. Date	Real Date
CMM					
EUKLID					
I-DEAS					
NC					

Total Time					

-Cause:...

Meetings:

-Part Analysis ....: ....
-Modelling ....: ....
-Milling ....: ....
Data Storage Info. : ....
Data Transfer Info : ....

Modelling and Milling Stages:

Date	Work Done	Responsible
....	....	....
....	....	....

Figure 3.1 Log Book of the Project

3.4.1) Part Analysis Meetings

a) After the agreement, a meeting is held between at least two Euklid modellers and the customer representative. Minutes of the meeting is kept in written form and signed by both sides.

/ /19

MINUTES OF THE MEETING

Project No ....: ....

Part Name...............: ....

Company.................: ....

Project Manager......: ....

Sign

Sign

Figure 3.2 Minutes of the meeting

b) Internal meeting is held between the Euklid modellers. The method of modelling the part is discusseed and the action items are defined"and written on the process planning form.

PROCESS PLAN FORM

Project No ....

Part Name...............: ....

Company.................: ....

Project Manager......: ....

Date	Work Done	Responsible
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....

Notes:

....

....

....

Sign Sign

Figure 3.3 Process Plan Form

3.4.2) CMM Report

During the part analysis meeting where the modellers decide how to model the part, they also define the contours and the critical cross-sections they need for modelling. They request these data from the CMM group by filling the CMM Measuring Request Form.

CMM MEASURING REQUEST FORM

☐ CMM: ....

☐ CMM: ....

Requester..........: ....

Project No ....: ....

Part Name..........: ....

Measurement Type ....: a) Scanning ☐

Delta X=

Delta Y=

b) Contour ☐

c) Coordinate ☐

d) Control ☐

Associate Drawing ....:

Figure 3.4 CMM Measuring Request Form

3.4.3) Surface Report

Csegs are produced with the measured points by the approximation module. These csegs are checked and compared with the measured points on the Cseg Deviation Report and asked for approval.

CSEG DEVIATION REPORT

Project No ....

Part Name...............: ....

Company................: ....

Project Manager......: ....

CSEG	DEVIATION (max)	Appr.

Figure 3.5 Cseg Deviation Report

Some kinks or irregularities on the base surfaces which are produced using the approximated csegs may show up. These may a lot of problems and waste of time during the surface connections and especially milling. These irregularities should be eliminated at this stage.

Surfaces are also checked and compared with the curves for any deviations by taking cross-sections.

CROSS-SECTION DEVIATION REPORT

Project No ....: ....

Part Name...............: ....

Company.................: ....

Project Manager......: ....

<u>SECTION</u> <u>DEVIATION</u> <u>(max)</u> <u>Appr.</u>

Figure 3.6 Cross-section Deviation Report

Probe compensation and Male-Female conversion should be done by parasurf. Expansion ratios are given.

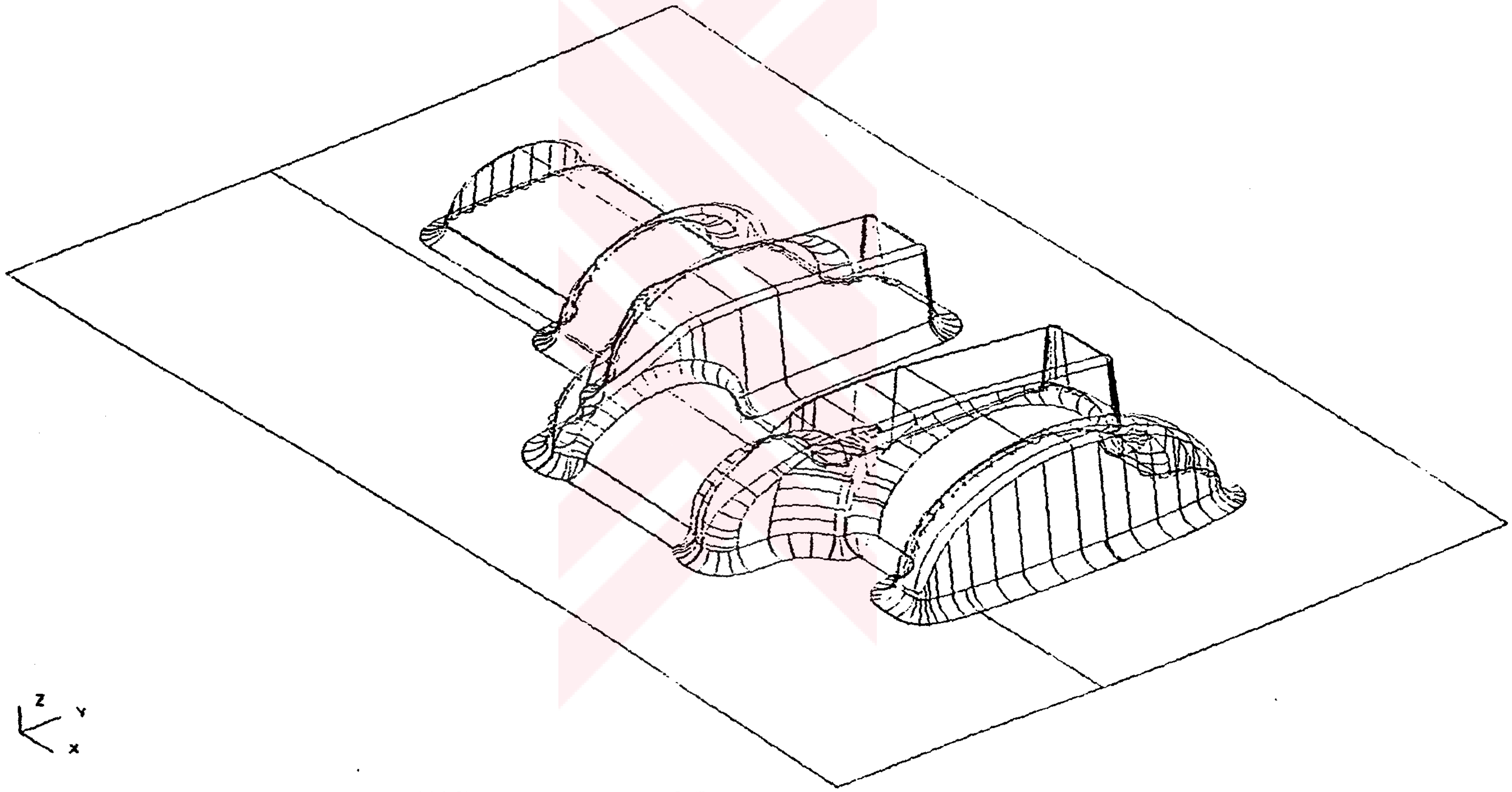
Male and female parts are put on each other and the cross- sections are checked by a second modeller other than the person who generated the surfaces. The results are written on the Cross- section Control Report and asked for approval. Only after this approval, the modeller can start the milling program.

3.4.4) Milling

Before starting the milling program, a milling program is held between the modellers and the milling operators. Minutes of the meeting is written down as Milling Request Form by the milling operators and handed to the modeller.

The modeller prepares the milling program and this milling program is watched for simulation by a second modeller.

Euklid Cad/Cam System



4) EUKLID AND METHODS

4.1) Introduction

EUKLID is an integrated 3D CAD/CAM solution which is particularly suited for the design of tools, moulds and patterns as well as various tasks in the design of components. The disadvantages of the system's high degree of integration are:

-- Geometry can be used both in the plane (2D) and in spatial designs (3D) without conversion or intermediate steps.

-- The same basic geometry can be used to control all the manufacturing and quality assurance systems.

The software and computer concepts are modular; they permit an assembly that is geared to and tailor made for operation.

4.2) Introduction to Bezier's Cseg Theory

Conventional nonparametric representations can be written in the

form $y = f(x)$

This equation says that y is a function of x or in other words:

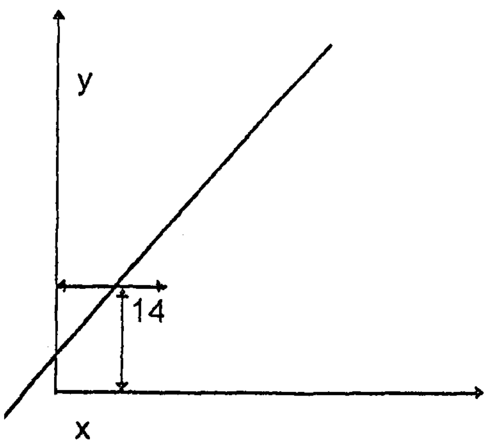
y is dependent on x.

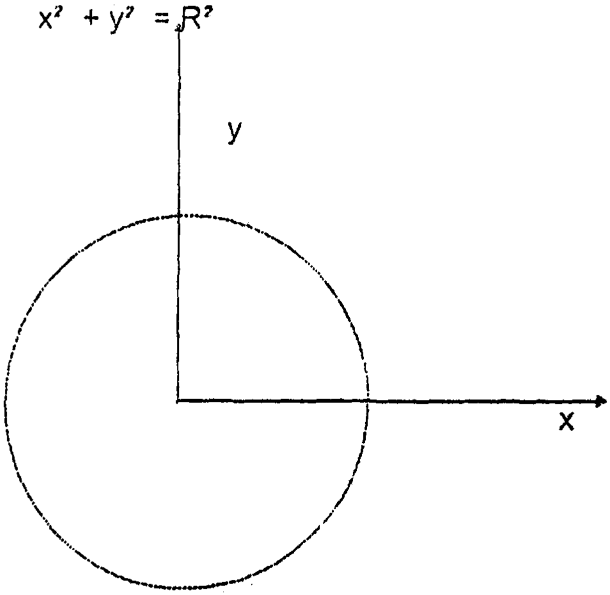
Nonparametric representations like this are very common, e.g.

equations of a straight line or circle:

Equation of a straight line: $y = 1.2x + 14$

Equation of a circle: $x^2 + y^2 = R^2$





Figures 4.1 and 4.2

Nonparametric representations have a major disadvantage: they are not always unique. Let us look at the equation of a circle: for a given value of x (e.g. x=4), there are two solutions for y. This means that nonparametric representations are unsuitable for geometric problems.

4.3) Parametric Representation

Parametric representations use not only the coordinates x, y and z but also an additional parameter in their equations.

An example from everyday life: on a flight from London to Zurich, you travelled a certain route. Let us use this route as an example of a three-dimensional space curve. Your journey also took a long time, which we shall assume to be 4 hours.

We plot the space curve and time axis on one graph; the take-off time is given the value t=0:

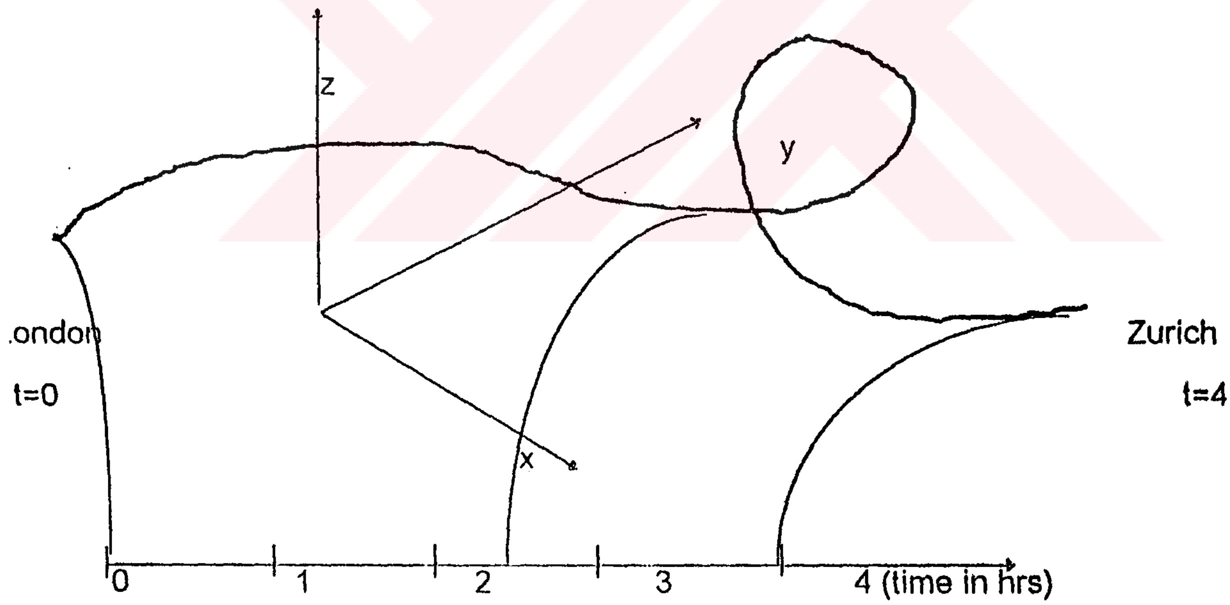


Figure 4.3

As you see, we have already introduced an additional parameter to our example, namely the time axis with the parameter t.

This additional parameter gives us a real advantage: at a given moment on your journey, e.g. 2.52 hours after take-off, you were at a precisely defined point on the space curve. The time axis has therefore helped us attain uniqueness.

Euklid uses the Bezier representation for all kinds of space curves. This is a parametric representation and uses the additional parameter t as in the everyday example shown above.

4.4) Bezier Control Points ; An Example of Construction

In EUKLID, just a few control points - also called Bezier points

- and the parameter t define a Bezier cseg.

As an introduction to Bezier control points let us look at an example of construction. This example is designed to show (without mathematical proof) how a curve can be constructed from a few points:

4 points P0, P1, P2 and P4 are given.

In addition, the parameter t should have a value of 0 at the beginning of the curve and 1 at the end of the curve. We will use this data to construct a Bezier curve!

How to proceed:

1. As a first step, we want to construct the curve point at

t=0.4:

- The four points are joined in turn (in the example by dashed lines).
- One dividing point is plotted on each of these three connecting lines at a point 4/10 (=0.4) along the lines. This gives us three new points.
- These three points are then joined in turn (in the example by dotted lines).
- One dividing point is in turn plotted on each of these two connecting lines at a point 4/10 along the lines. We get two new points.
- These two points are joined one last time (in the example by a solid line).
- The dividing point at 4/10 along the last connecting line produces one point.

This point is the required point on the curve at t=0.4!

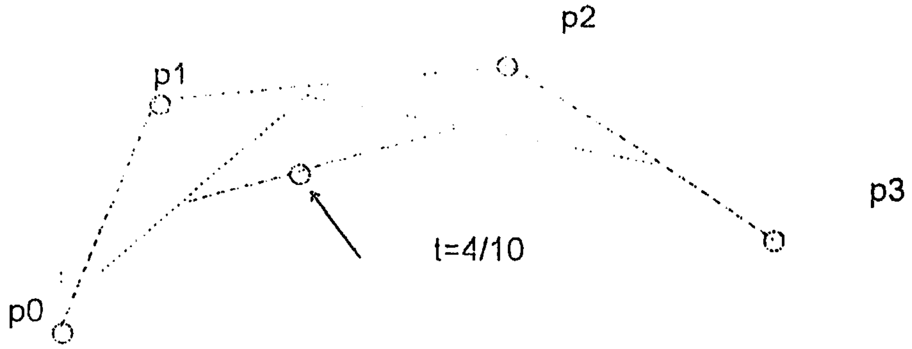


Figure 4.4

2. As next steps, we go on to construct the curve points at t=0, t=0.2, t=0.6, t=0.8 and t=1. The dividing points now lie at 0/10, 2/10, 6/10, 8/10 and 10/10. Result:

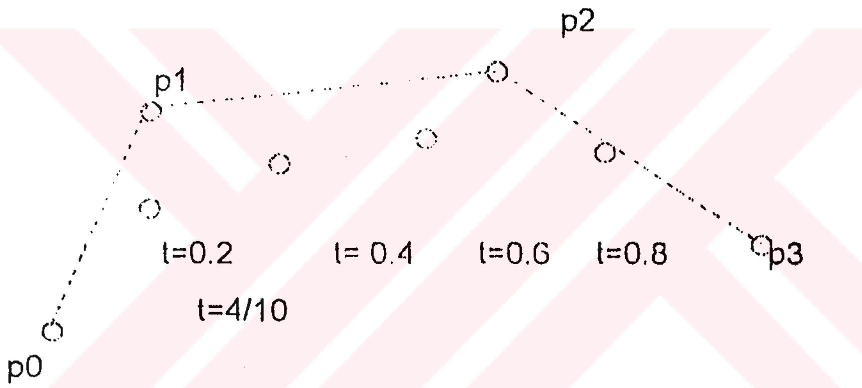


Figure 4.5

3. If we were to construct altogether 100 points at t=0.00, t=0.01, t=0.02, t=0.03 and so on to t=0.99, t=1.00, we would get the following picture:

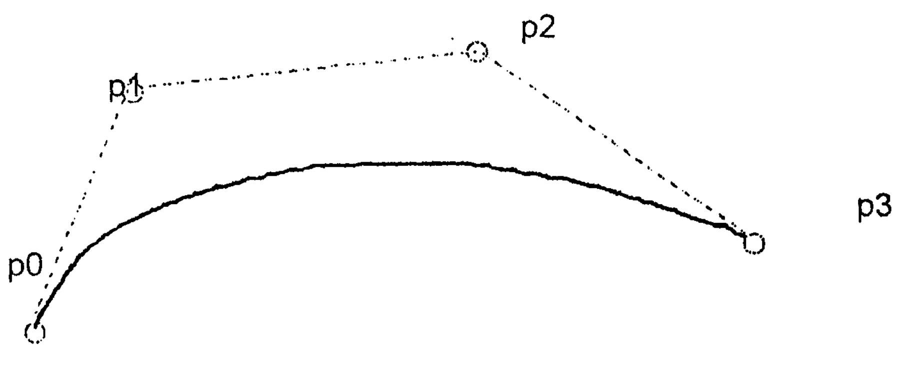


Figure 4.6

Conclusions from the Construction Example

1. A curve of any shape can be formed with the help of a few control points.

2. We could construct a curve of any accuracy by using t-values with more decimal places, e.g. t=0.45297521.

3. If we move one of the Bezier control points, the dividing points and thus the whole path of the curve changes. Every Bezier point influences the entire curve.

4. The only exceptions in this respect are the starting and end points of the curve: we construct the dividing point 0 at the t- value 0.0 and so always get the control point P0 itself, totally independent of all other control points.

We always construct the dividing point 1 at the last curve point (t=1.0) and so get the control point P3 itself, totally independent of all other control points. In other words, the curve always begins with the first control point and ends with the last control point.

4.5) The Bezier Method: The Formula

The method named after Pierre Bezier constructs the required curve in the way described above. The points on the curve can also be computed directly using a formula. The formula is:

$$p(n) = \sum p(k) \times B(t)$$

where:

P(t) is the required curve point (or to be more precise its vector) at the value t.

t t is the parameter value, with values between 0 and 1.

B (t) This expression stands for the Bernstein polynomial and is merely an abbreviation for the expression:

$$B(t) = (n)\ t\ (1-t)n-k$$

where:

n represents the order: 1,2,3,4...

The order depends on the number of control points. The following rule applies: n = control points - 1. Hence, the preceding example of construction with 4 points was a curve of third order (n=3).

k is an index, beginning at zero up to a maximum of n:

0,1,2,....n.

(n) binomial coefficient

Pk Is the particular Bezier control point. The numbering of the points (see k above) begins with P0, then P1,P2 to Pn..

Strictly speaking, this formula means that the required point (to be more precise its vector) at e.g. t=0.4 can be calculated as the sum of the vectors of the four Bezier control points. Each of these vectors is multiplied by a factor - the Bernstein polynomial - the weight of the Individual vectors. Summarizing a Few Important Aspects of the Bezier Method

1. A curve of any shape can be calculated by means of a few points and the formula given above.

2. The calculation requires a lot of work and can either be done by very many people working with pocket calculators for many hours or by a computer in no time.

3. The accuracy depends on the computer's compiling accuracy.

4. In our example, a curve defined with mathematical precision is stored by means of only four control points - and the knowledge of the Bezier method.

5. If we move one of the Bezier control points, the whole path of the curve changes. Every Bezier point influences the entire curve.

Without proof: a control point's effect upon the curve (its weight) is greatest in its proximity. As a general rule, the maximum weight reaches about 1/3. This means that if a control point is moved (e.g. P2 by 30 mm.), the curve will change by about 10 mm. in its proximity.

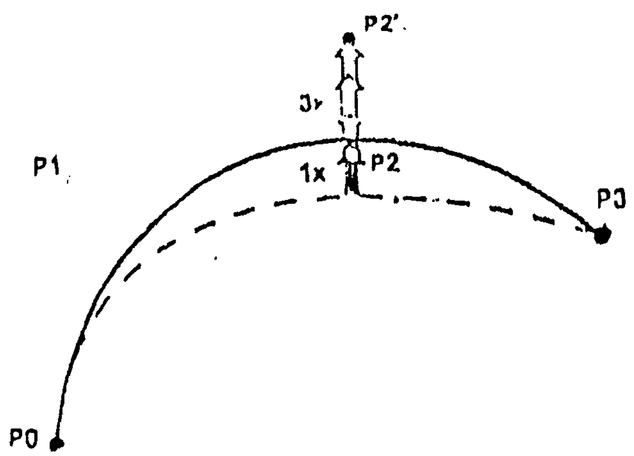


Figure 4.7

Further away, the influence of the changed point does decrease but will still remain noticeable (up to the starting and end points themselves).

The only exceptions in this respect are the starting"and end points of the curve: at t-value 0.0, the Bernstein polynomial results in weight 1 for the control point P0 and weight 0 for all other control points. This means that the required point corresponds to the point P0 itself, totally irrespective of all other control points.

At the last point on the curve (t=1.0), the Bernstein polynomial results in weight 1 for the control point Pn and weight 0 for all other control points. This means that the required point corresponds to the point Pn itself, totally irrespective of all other control points.

In other words, the curve always begins at the first control point and ends with the last control point.

7. The number of points and the order are closely associated: if the order is n, then n+1 points are necessary.

8. Without proof: the tangent in the first point of the curve passes through the control points P0 and P1. The tangent in the last point of the curve is also determined by the two limit points, in this case n=3).

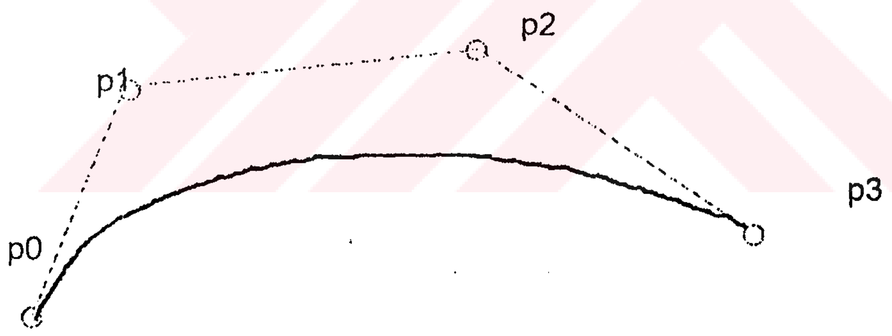


Figure 4.8

9. Yet again without proof: the first three or last three points always determine the curvature in the starting or end point of the curve.

4.6) Surfaces

EUKLID represents all surfaces with Bernstein polynomials following the Bezier method. This applies both to simple surfaces such as planes or cylinders and to free-form surfaces of all kinds. With this method, the surfaces are defined with mathematical precision. Every point on a surface as well as tangents, normals, curvature can be calculated exactly at any time.

4.7) Brief Introduction to Bezier Surfaces

We have got to know the additional parameter t (from 0 to 1) with Bezier cseg. This additional parameter enables any point on the curve to be referenced uniquely.

The theory of Bezier surfaces goes one step further - working from the Bezier cseg. Let us look at a Bezier surface, its parameter area and Bezier points:

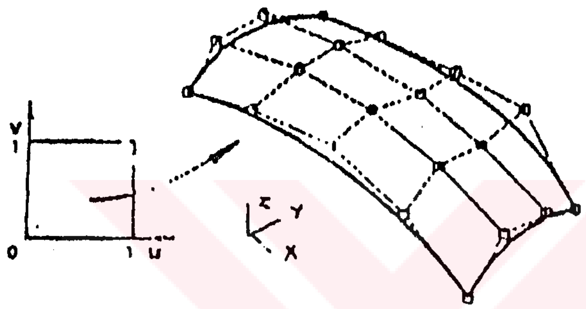


Figure 4.9

Compared with curves, the surfaces have one dimension more. Consequently, the arameter t would not be enough to attain uniqueness again. Therefore, we have to troduce two parameters and call them parameter u and parameter v.

ne two parameters u and v form a rectangular parameter area. We talk of a patch ither than a segment (as with the cseg). One patch includes in the direction u and in e direction v one unity.

The arrow symbolizes the unique correspondence between the parameter area u,v id the surface. Exactly like between the parameter t and cseg.

I rows of 5 Bezier points are drawn over the surface (i.e. a total of 20). The front five ints in the first row define the foremost boundary of the surface - so these five points termine a space curve, a cseg. The back three rows of points determine the ditional dimension of the surface so to speak, working from this boundary curve.

The Formula:

As for the CSEG, a formula is also used to calculate the surface. This calculates every point on the surface as a function of the given Bezier points and the required parameter values u and v.

$$P(u,v) = \Sigma \Sigma \ P \times B\ (u) \times B\ (v)$$

u and v are the two parameter areas, n and m are the order in the direction of u and v respectively, k and j are consecutive indices for the control points (between 0 and a maximum of n or m). The two Bernstein polynomials B are described in the cseg Bezier theory.

The corresponding formula for a cseg includes a sum of vectors, each multiplied by their weight. The surface formula differs only in the way that this sum is taken to produce a second sum, representing the additional dimension of the surface.

4.8) Strategies in CAD/CAM Technology

Toolmakers and designers of moulds and patterns are struggling with the same difficult market conditions and fierce competition: the pressure on prices from countries with a lower wage scale is relentlessly mounting. If a company wants to survive this, it has to specialize in complex and highly sophisticated products while at the same time increasing its flexibility for ever smaller batch sizes and shorter throughput times. On top of that, demands for quality and precision are steadily increasing because the protection of our environment requires long-lasting products built along modular lines.

This mounting pressure on prices must be countered by increasing productivity while at the same time taking rationalization measures. These goals can only be reached by switching over to timely automated production. Morover, Industrial automation also taps new resources for innovative and creative thinking, thus increasing the chances to cope successfully with the future. But this cannot be realized overnight or just bought "off the rack". A step by step implementation along modular lines specific to companies must be initiated. As a. rule, the worst bottlenecks for toolmakers and designers of moulds and patterns are not to be found in the handling of administrative work but in the manufacturing methods. This is therefore the area which sould be automated first of all.

New technologies are capital-intensive, which makes the risk of a wrong investment particularly high. For this reason the implementation should not only be carried out step by step but should also be based on a clear, longterm concept.

4.9.1) A Summary of Curve and Surface Approximation

The EUKLID CAD/CAM system is specialized for the manufacturing, particularly milling of parts with extremely high surface quality. This requires a complete and mathematically exact definition of surfaces.

Whether a model or a cloud of curves is at disposal, in every case the surfaces are defined by single point coordinates. With the EUKLID approximation module you may approximate curves and surfaces originating from a cloud of points. The accuracy depends on the topology and the original data. It may be controlled by the selection of partitions, number of patches and their order.

The points generated by a measuring machine (or digitizing/scanning system of a milling machine) are converted by a preprocessor into input-data for the EUKLID system.

If data is captured from mylar drawings on a digitizing table, a user friendly dialogue-driven solution is available. Sectional curves out of two views are digitized and passed to EUKLID, where the distortions are corrected and 3D points or curves created. If the digitizing process takes place elsewhere, the respective data may be read into EUKLID via standardized interfaces (i.e. VDA-FS).

Next step is the creation of a B-spline curve, passing through a defined point-list. The number of segments may be freely chosen, while segment borders are defined automatically. The order is 3 by default, but it may be set higher. The user may pre-define the grade of polynomes, accuracy, smoothness, as well as other conditions. Additionally the number of iterance steps (maximum 50) may be defined. As soon as the required tolerance or the number of iterance steps is attained, the system ends the approximation process. The curve(s) with the original points and the distortion, is presented graphically and may be printed out in listings.

Before the creation of approximated surfaces, it must be checked, whether those are sufficiently uniform or constant to be treated in one step. Otherwise they must be divided into various surfaces, that have to be approximated separately and later trimmed and filleted in an additional step.

4.9.2) Techniques of Surface Correction

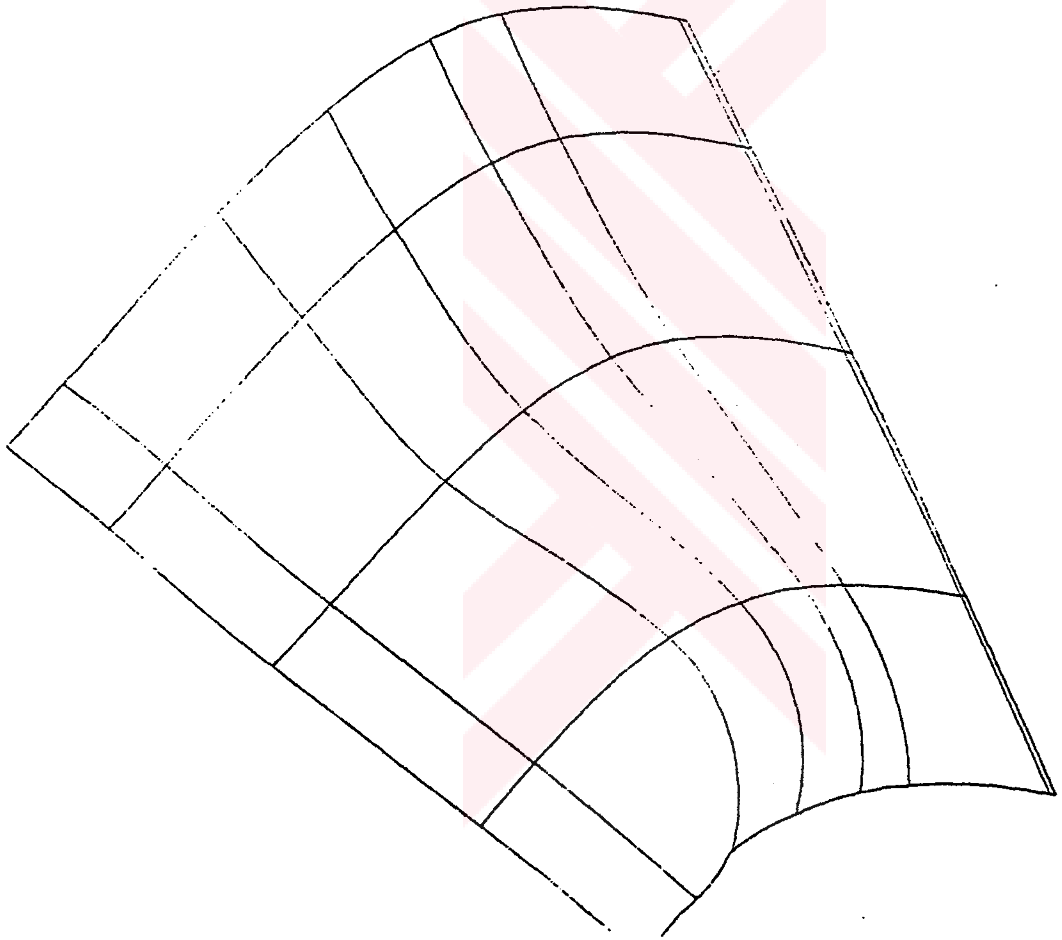
Once the surface is generated with the csegs which were arranged by the help of the command CSCOMP, we can use it for further correction and obtain a satisfactory surface quality. The importance of surface quality comes from the complexity of the processes which will be applied on these surfaces. A sound surface structure shortens the time spent for the rest of the operations throughout the reverse engineering project.

Three methods for surface correction have been developed. The first two methods assume the following: The cross-section CESGs were produced with the approximation module Bspappt from the coordinate points. These coordinate points are the digitized data which arrived from the Mitutoyo CNC measuring machine. Also they assume that the CSEG segment numbers were equalized with CSCOMP and the surface was generated with INTERSURF. This surface is called the primary surface.

Method 1:

A straight line cseg is generated which has segment points every x milimeters, vhere x is the segment length suitable for the surface This cseg is generated automatically by the subroutine after pointing the vertex points of the region which will e corrected on the pimary surface. A surface is generated with INTERSURF by opying the straight line cseg and translating in the z_direction. This INTERSURF and he primary surface is cut by a CURVECUT to obtain a 3D cseg which will replace the ross_section cseg which was produced directly with the approximation of the oordinate points from the measuring machine. Generation of the 3D csegs is repeated r each cross_section of the primary surface. Once the 3D csegs are produced, this ethod has two options for further development.

Wavy Surface



The number of segments of the 3D csegs are most probably not equal. Here the subroutine uses INTERSEG for eualizing the number of segments of the 3D csegs. This method uses grid points as a reference for choosing the final segment points which will be left on the cseg. That means the subroutine will check each segment point on each 3D cseg for the equality with the grid points. The presence of a segment point which will match each grid points is assured with generating the 3D cseg by cutting the primary surface with the INTERSURF which was generated with the straight line csegs with the segment points which match the grid points.

This will cause the 3D cseg to be left with the segment points which match with the grid points.

After this rearrangement, the 3D csegs are joined by INTERSURF to generate the final surface which have regular and smooth segments.

Method 2:

This second method also uses the same assumptions as the first method. To summarize shortly, the csegs are produced by the approximation module and the number of segments are arranged by CSCOMP for equality. The primary surface is generated with these csegs.

In this method a 2D matrix is produced with the help of the following information about the primary surface: a) The approximate length and the width of the primary surface. b) the desired length and width of the segments.

This matrix is used for producing perpendicular lines through the coordinates generated by the help of the matrix. The piercing points of the lines and the primary surface gives us points which we can easily join and use as corrected cross_section csegs. And these csegs are joined with INTERSURF to produce the final corrected cseg.

Method 3:

I have developed a third method for producing a regular surface other than method 1, because grid points may not be suitable for rearranging a surface which have sharp curves or steep ups and downs.

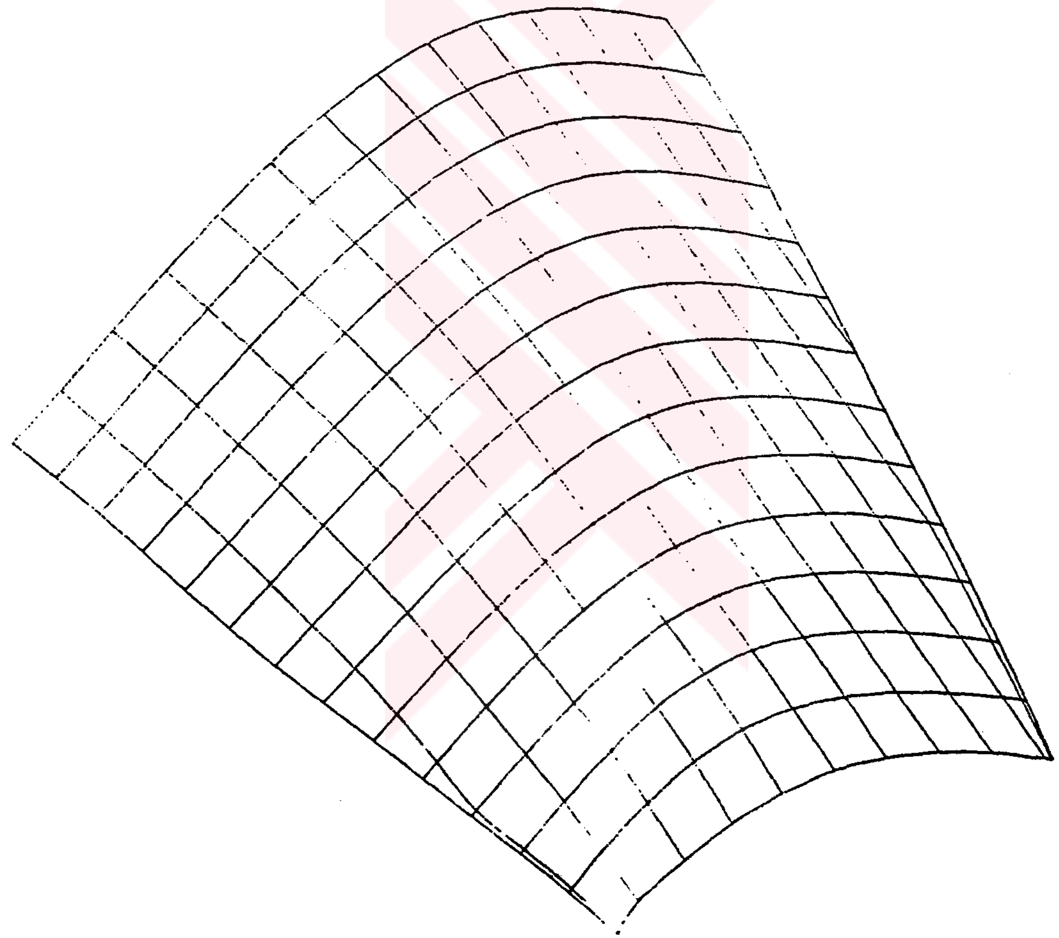
In method 3, there is no need for generating a primary surface. It only assumes that the cross section csegs were produced with the approximation module.

The cross_section csegs are splitted by CSPLIT through the segment points which have equal length in between. The length is given by the users. The resulting cross_sections have segments of equal length and equal number of segments. These csegs are used for generating the surface with intersurf. In this method you may prefer to give the desired number of segments or the desired length of each segment.

Another option of this method is to give the desired number of segments of the csegs.

All these methods were produced as subroutines and loaded to the HP 425t machines at Marmara University CIM laboratory and available for Euklid users who will conduct especially reverse engineering projects.

Subroutine 3: Surface Correction



CONCLUSION

Three main parts are emphasized in this study. In the first part the history of computer aided manufacturing applications and the current situation are shortly explained. In the second part managerial solutions to the computer aided production is discussed in general and in particular a procedure for handling computer aided manufacturing projects which is a result of years of experience in this field and currently used at professional CAD/CAM companies is offered. Together with the control mechanisms it offers, this procedure aims to bring a managerial relief but also ensures the quality control of the projects. Also the necessary forms and report forms are included to help the procedure to be followed easily by the users. In the third part the subroutines and the techniques produced which are to be used especially for reverse engineering projects at the Marmara University CIM laboratory are introduced.

Therefore, Marmara University CIM laboratory can not only improve its image as a leading institution in the Turkish industry, but also educate, train and use highly qualified engineers who experience bringing CAD/CAM solutions to real life industrial problems. They can also experience and be trained to work in an environment where efficiency and quality control concepts are the main issues and provided by the methods and procedures which were offered by this study.

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LIST OF FIGURES

APPENDIX

CAD/CAM SERVİS PROJE TAKİP FORMU

Proje No ...... : ....
Parça adı ..... : ....
Firma .... : ....
Contact .... : ....
Proje yöneticisi: ....
Proje başlangıcı: ....
Teslim tarihi ..: ....

İş Akışı ....:

		Sorumlu kisi	Tahmini süre	Gerçek süre	Tahmini tarih	Gerçek tarih
CMM						
CMM						
EUKLID						
Isleme						
Toplam süre						

-Gecikme sebebi: ....
....

Toplantılar:
-parça....: ....
-modelleme: ....
-işleme...: ....

Veri saklama bilgileri : ....
Veri transfer bilgileri: ....

Modelleme ve işleme safhaları:

Tarih	Yapılan iş	Sorumlu
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TUTANAK

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Firma .... : ....
Sorumlu .... : ....

<u>İmza</u> <u>İmza</u>

/ /19

CMM ÖLÇÜM İSTEK FORMU

☐ CMM : ....
☐ CMM : ....

Ölçümü isteyen : ....
Proje No ......: ....
Parça Adı .....: ....

Ölçüm tipi ....: a) Tarama....: ☐
Tarama aralığı X= Y=

b) Kontur....: ☐

c) Koordınat.: ☐

d) Kontrol...: ☐

İlgili kroki ..:

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MODELLEME CSEG RAPORU

Proje No .... : ....
Parça adı ...... : ....
Sorumlu .... : ....

CSEG	SAPMA(max.)	KABUL/RED

İmza

MODELLEME KESİT KONTROL RAPORU

Proje No .... : ....
Parça adı ...... : ....
Sorumlu .... : ....

KESİT	SAPMA(max.)	KABUL/RED

İmza

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PROSES PLANLAMA FORMU

Proje No .... : ....
Parça adı ...... : ....
Firma .... : ....
Proje yöneticisi : ....

Tarih	Yapılacak iş	Sorumlu
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