Αριθμητικός Έλεγχος Εργαλειομηχανών

Ενότητα 16: Computer Aided Manufacturing

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COMPUTER NUMERICAL CONTROL OF MACHINE TOOLS

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LMS

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Objectives of section 16

- Understand Computer Aided Manufacturing (CAM) and its strategic role
- Explore CAM applications in the production
- Learn about CAM software
- Learn about the future of CAM systems

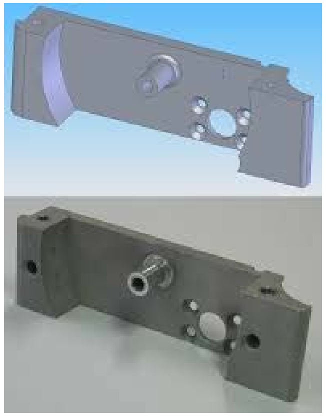
DEFINITION

- **Computer Aided Manufacturing (CAM)** can be defined as the use of computer systems to **plan**, **manage** and **control** the **operations of a manufacturing plant** through either direct or indirect computer interface with the plant's production resources
- In other words, the **use of computer system in non-design activities** but in manufacturing process is called CAM (Elanchezhian et al. 2007)

Strategic Role of CAM

- The application of CAM in the production offers advantages to a company to **develop capabilities** by combining traditional economies of scale with economies of scope resulting in the **desired flexibility and efficiency**
- Amongst other benefits provided by CAM, Post identifies the following (Post 2003):

  - Greater **supervision** of the production
  - **Fast response to changes** in market demand
  - Greater **flexibility**
  - **Product variety**
  - **Small lot-sizes**
  - **Distributed processing capability**
  - **Reduced waste**



Theory and Application

History

- The roots of **CAD**/**CAM** trail back to the beginning of civilization, when the engineers of the ancient civilizations such as Egyptians, Greeks and Romans acknowledged the importance of the graphical communication. Later on, Leonardo Da Vinci developed technics, such as cross-hatching and isometric views

- The invention of computers and xerography made possible the creation of graphics and visualization (Zeid 1991)

- In the early 1950s, shortly after the World War II, the need for complex parts led to the invention of the **Numerical Control** (**NC**) that substituted the requirements for skilled human machine operators (Chang et al. 2006)

- At the same time another invention, namely the *digital computer*, assisted the development of **NC** and provided the means for the creation of **robots**, **computer-aided design** (CAD), **computer-aided manufacturing** (**CAM**) and **flexible manufacturing systems** (**FMS**)

Theory and Application

- The utilization of **CAM** software systems began in large automotive and aerospace industries in 1950
- During the late 1950s, **APT** (**Automatically Programmed Tools**) was developed and in 1959, General Motors (GM) began to explore the potential of interactive graphics.
- By the mid-1960s, the term **Computer-Aided Design** (**CAD**) started to appear. GM announced their **DAC-1** system (**Design Aided by Computers**) in 1964
- The decade of **1970** can be characterized as the **golden era** of computer drafting and the beginning of ad hoc instrumental design applications (Zeid 1991)
- Among the first **CAD**/**CAM** systems was *UNISURF* that was developed by Pierre Bezier in 1971 for the *Renault* industry and allowed surface modelling for automotive body design and tooling (Bezier 1989)
- In 1979 the **IGES** (**Initial Graphics Exchange Specification**) was initiated and it enabled the exchange of model databases among **CAD**/**CAM** systems.

Theory and Application

- Other notably standards that were developed in the same period include (Zeid 1991):

  - **GKS. ANSI** and ISO standard that interfaces the application program with the graphics support package
  - **PHIGS**, that supports high function workstations and their related CAD/CAM applications
  - **VDI** (Virtual Device Metafile), that describes the functions needed to describe a picture
  - **NAPLPS,** that describes text and graphics in the form of sequences of bytes in ASCII code

- The computers evolved rapidly and today's systems are capable of **planning** , **scheduling**, **monitoring**, **decision-making** and generally **managing all the aspects of the manufacturing procedure**, even "think" and adapt to changes automatically (Chang et al. 2006)

Theory and Application

- The immense international competition that appeared in 1980s and the high demand for industrial products became a worldwide phenomenon, therefore, manufacturers were forced to adapt to the changes
- Small batches, reduced inventories, dynamic environment and rapid changes of the environment call for **increased flexibility** and **exploitation** of the state of the art technological achievements
- **CAM** was recognized as a solution to effectively cope with the requirements in the shop-floor level
- The **CAM** systems act as an interface between **CAD** and **NC** machines. The complex drawings created by **CAD** tools require "translation" in order to produce the coding for the **NC** machines
- Alongside with (**CAD**), robotics and **CNC**, **CAM** is exploited by the majority of the production systems nowadays .Some of the most recent developments in **CAM** systems include ***rapid prototyping***, ***micro-electromechanical systems*** (**MEMs**), ***nanotechnologie****s and* ***artificial intelligence***

Theory and Application

- The evolution of **virtual manufacturing** has led to the creation **of work-cell simulation tools** that are capable of **developing**, **simulating** and **validating** manufacturing processes

- Moreover, off-line programming of multi-device robotic and automated processes (**virtual commissioning**) offer optimization functionalities, from the concept to the implementation phase

- At the 2000s, commercial **CAM** suites provided complete solutions to **Product Lifecycle Management** (**PLM**) in multiple stages of the production, i.e. conceptualization, design (**CAD**), manufacturing (**CAM**) and engineering (**CAE**)

- A great number of **CAD** tools exist today that provide functionalities of **CAM**/**CAE** (Chryssolouris 2005)

Strategic Role of CAM

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Application of CAM in the production

- The utilization of **CAM** enables the **automation** and **computer support** of all the production activities on the **shop floor**, in order to manufacture parts designed with **computer-aided design (CAD)** and analysed with **computer-aided engineering (*CAE*)**

- The equipment on the shop-floor, such as **robots**, **controllers**, **machine tools** and **machining centres** are controlled and operated using **CAM** systems (Post 2003)

- **CAM** technologies comprise **NC machines**, **expert systems**, **machine vision**, **robots**, **lasers** and **FMS** technologies used alongside with **computer hardware**, **databases** and **communication technologies**

- **CAM** systems are tightly connected with ***CAD* systems**

Application of CAM in the production

- The **CAD** databases must reflect the manufacturing requirements such as tolerances and features

- The *part drawings must be designed having in mind* **CAM** *r*equirements. Moreover, the manufacturing systems nowadays require **high coordination** due to their ***networking* characteristics**

- Synchronization among robots, vision systems ,manufacturing cells, material handling systems and other shop floor tasks are challenging tasks that **CAM** addresses

- The role of **CAD**/**CAM** systems in the production can be as the intersection of five sets:
  - design tools,
  - manufacturing tools,
  - geometric modelling,
  - computer graphics concepts and
  - networking concepts (Zeid 1991)

Application of CAM in the production

- Apart from the fact that the **CAM** technology has brought a revolution in manufacturing systems by enabling **mass production** and **greater flexibility** (Yeung 2003)

- It has also enabled the **direct link between the three-dimensional (3D) *CAD* model and its production**

- The **data exchange** between **CAM**, **CAD** and **CAPP** is a **dynamic procedure** and takes place through various production stages

- **Data** is exchanged regarding process routes and machines between function of process route sequence and machine assignments from **CAPP** systems and identified manufacturing process and machines from **CAM** systems

- Moreover, reports regarding setup methods, fixtures and operations sequences between function of setup planning and fixture selection in **CAPP** and function of identifying setups, fixtures, getting operation sequences and machined features in **CAM** are transmitted

Application of CAM in the production

- Further to that, **information** about **cutting tools and cutting parameters** between:
  - **function of operation planning**
  - **cutting tool selection**
  - **cutting parameter selection**
  - **optimization**
  - **edit and output** in **CAPP** and function of **getting cutting tools** and **cutting parameters** in **CAM** is exchanged.

- Finally, **messages concerning process plan change suggestions** between:
  - **function of operation planning**
  - **cutting tool selection**
  - **cutting parameter selection**
  - **optimization**
  - **edit and output** in **CAPP** and function of generating **cutting path**, **CNC code** and **simulation** in **CAM** are exchanged (Ming et al. 2008).

Application of CAM in the production

- The mechanical drawing files from **CAD** applications are required from the **CAM** system in order for a part to be manufactured.

- **CAM** programs represent a **designed part as a wireframe** of two or three dimensions.

- The *NC* programmer needs to **define auxiliary geometry** during the programming course and since the **CAM** program do not offer model editing abilities the need is presented for the **CAM** system to be **combined** with a **CAD** system (Seames 2002)

- **Numerical Control** refers to a system that includes **hardware and software and control machine tools** and other production equipment **via numerical input** (Post 2003)

- **NC** is a method of **automatically operating a manufacturing machine** based on a **code of letters**, **numbers**, and **special characters**

Numerical Control (NC) and CAM

- **Numerical Control** refers to a **system that includes hardware and software and control machine tools** and **other production equipment via numerical input** (Post 2003)

- **NC** is a **method of automatically operating a manufacturing machine based on a code of letters, numbers, and special characters**

- In 1947, John Parson of the Parsons Group, began experimenting with the idea of using **tree-axis curvature data to control machine tool motion** for the production of aircraft components. The project was funded by the US Air Force

- In 1951 MIT (Massachusetts Institute of Technology),USA, assumed the project and the first **NC** machine was developed in 1950s at MIT (Seames 2002)

Numerical Control (NC) and CAM

- The evolution of computers, led to the creation of **Computer Numerical Control** (**CNC**) in the 1970s

- The **difference** in **NC** and **CNC** lies in the **controller technology**

- While, **NC** functions **need to be designed and implemented in hardware circuits**, **CNC** functions can be implemented in **CAM** **software**

- The coding of the early **NC** machines and todays **CNC**s is performed using the same standards, namely **G**&**M** **codes** formalized as the **ISO 6893 standard** (International Standards Organization 1982)

Numerical Control (NC) and CAM

- The codes were **stored in magnetic tapes**, the most common of which were ¼ - inch computer grade cassette tape

- The **Electronics Industries Association** (**EIA**) developed standards for tape format and coding (Seames 2002)

- Moreover, to ensure the **interoperability** and the **seamless data exchange** between the different stages of the chain that utilize different commercial tools and technologies, the **STEP** standards have been developed and formalized into **ISO10303** (International Standards Organization 1994)

- and evolved later to **ISO14649**(International Standards Organization 2003) and **ISO10303-AP238** (International Standards Organization 2004) commonly known as **STEP NC**

Numerical Control (NC) and CAM

- The improvements in the computer technology led to the creation of **Direct Numerical Control** (**DNC**)

- **DNC** involves a computer that acts as a partial of full controller to one or more NC machines

- Further to that, improvements in the field led to the creation of **Distributed Numerical Control**, where several CNC machines are linked together inside a network allowing the gathering and storing of upstream and downstream shop-floor information

Flexible Manufacturing Systems (FMS) and CAM

- A **flexible manufacturing system** (**FMS**) is a **reprogrammable manufacturing system** capable of producing a **variety of products automatically** (Chryssolouris 2005)

- An **FMS** employs **programmable electronic controls** that, in some cases, can be set up for random parts sequences **without incurring any set-up time between parts**

- Inside **FMSs**, the production components **require adaptability to a variety of product processing requirements** and therefore, CNC turning/machining centers and robotic workstations comprise the majority of equipment in these systems (Chryssolouris 2005)

- **CAM** systems, **NC** and **robotics** offer **reprogramming capabilities** at the machine level with minimum setup time

- An **FMS** comprise the following features: Interchangeable and/or specific machining units, Various work pieces within a component range, Usually free component selection

Flexible Manufacturing Systems (FMS) and CAM

- The main challenge in the installation of a **FMS** lies to the control of the **complex network of equipment** and shop floor activities of such a system

- By utilizing state of the art **CAM** systems, the implementation of **FMS** becomes feasible due to the benefits that **CAM** systems provide

- The deployment of an **FMS** with integrated **CAD**/**CAM** systems offer a variety of benefits such as:

  - improved productivity through higher machine utilization,
  - shorter lead times,
  - more reliable production (self-correcting production and uniform quality),
  - reduced work-in-progress (Koenig 1990)

- Moreover, by integrating **CAPP systems** into **FMS**, the **process plans can be created rapidly and consistently** and total **new processes can be developed** as fast as plans similar to those for existing components (Rehg and Kraebber 2005)

CAM software

- **CAM** software can be divided into **2D** and **3D applications.** The **2D** means that the **CAM** system imports a **2D drawing file** from a **CAD** system and **calculates a tool path** with all movements taking place on a constant Z-level

- **Several tool paths on different Z-levels** can be combined to **create a 3D result**, which is then called **2.5D machining**

- A **3D CAM system** in contrast imports a full **3D CAD model and calculates tool paths** to create a **3D result**

- A second distinction of **CAM** systems is between simple and **high-end CAM software**

- The **high-end CAM software** targets large enterprises that require **absolute control of the manufacturing parameters** in order to produce an optimum result

- **High-end systems** include functionalities that support **a fourth or for full 5 axis machining**, **constant tool loading features**, automatic step-over **calculation, automatic detection** and **removal of rest material** and **rendered machining simulations**

CAM software survey

- Software vendors are currently developing integrated **CAD**/**CAM** systems, further enhancing the capabilities of today's **CAM** applications
- The solutions provided by the leading **CAD**/**CAM** vendors, offer **high-end features**, like:
  - parametric modelling for solid shapes
  - 2 ½ to 5 axis machining tool path generation
  - networking and collaborative design features
  - post processing capabilities
  - re-sequencing of operations
  - simulation and optimization of NURBS interpolation and
  - generative machining and
  - assisted manufacturing that captures manufacturing and process know-how and automates repetitive NC functions

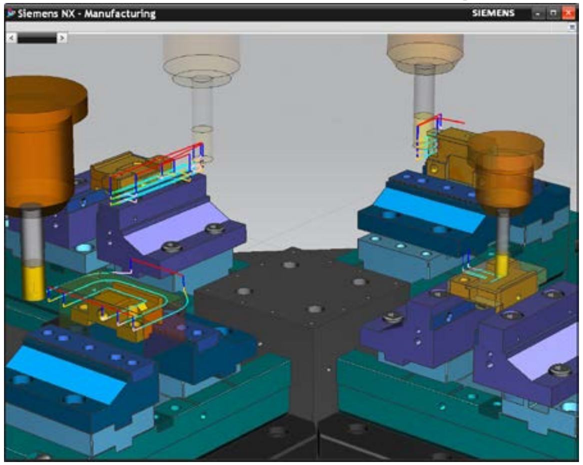

FIGURE 1 CAM Multi-Stage Machining

CAM software survey

CAM and related technologies Vendors Market share in 2009

- For 2009, **Dassault Systèmes** was the market leader on the basis of both direct vendor revenues received and end-user payments for CAM software and services
- **Delcam** was the leader in terms of industrial seats shipped
- **Planit Holdings** was the leader on the basis of industrial seats installed
- **Siemens** PLM Software's NX was the leader in industrial seats shipped by brand
- **CNC Software's** Mastercam was the leader in both industrial and educational seats installed by brand name
- **OPEN MIND Technologies** was named as the most rapidly-growing vendor, although their revenue growth rate was only 1.6%

Future of CAM systems

- The manufacturing environment is characterized by **ever changing dynamics** and **evolution**
- The **production procedure** is based more and more on **virtual simulations** and **networking features**, in factory level as well as and global level
- The **need** is presented **for effective coordination**, **collaboration** and **communication** amongst all the aspects of production, **from humans to machines**
- The future **CAM** systems need to **focus on collaborative technics, effective communication and efficient data exchange**
- Moreover, **Artificial Intelligence** (**AI**) will allow the development of **“thinking” tools** and the exploitation of **AI** in the **CAM** systems will offer **automatic optimization of NC tool paths** and benefit from knowledge-based systems
- Adding to that, **self-evolving robots** are a fairly new concept and will have positive impact on **CAM** systems

Future of CAM systems

- The development of **self-evolving robots** can bring on **CAM** advantages on more economical approach to robotics

- The **cost of designing and building a robot will be reduced** from millions of dollars to just a few thousand dollars

- In the future, the use of **these inexpensive robots to assemble parts, clean up spills, and perform many other specific tasks in a factory will become a reality** (Post 2003)

- Moreover , **Virtual commissioning** is a new concept that addresses the complexity of the production systems and the need for short ramp-up time

- In the **Virtual commissioning** approach, **virtual prototypes are used for the commissioning of control software** in **parallel to the manufacture and assembly of the particular production system** (Reinhart and Wunsch 2007)

Future of CAM systems

- **Virtual commissioning** is **tightly connected** with **CAD**/**CAM** software and the advances in the second impact the first

- Finally, **digital manufacturing** incorporates technologies for the virtual representation of:
  - factories
  - buildings
  - resources
  - machine systems equipment
  - labour staff and their skills, as well as
  - for the closer integration of product ,and
  - process development through modelling and simulation

- **The implementation of digital manufacturing is relying on state of the art CAD/CAM and CAPP systems and their evolution** (Chryssolouris et al 2008)

Cross references

- Computer Aided Technologies (CAx)
- Computer Aided Design (CAD)
- Computer Aided Engineering (CAE)
- Computer Integrated Manufacturing (CIM)
- Flexible Manufacturing Systems (FMS)
- Computer Aided Process Planning (CAPP)
- Numerical Control (NC)
- Computer Numerical Control (CNC)

End of Section

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