Industrial Automation
(Automação de Processos Industriais)

CAD/CAM and CNC

http://www.isr.ist.utl.pt/~pjcro/courses/api0809/api0809.html

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Syllabus:

Chap. 4 - GRAFCET (*Sequential Function Chart*) [1 weeks]

... 
Chap. 5 – CAD/CAM and CNC [1 semana]

Methodology CAD/CAM. Types of CNC machines.

Interpolation for trajectory generation.

Integration in Flexible Fabrication Cells.

... 
Chap. 6 – Discrete Event Systems [2 weeks]
Some pointers to CAD/CAM and CNC

History:  http://users.bergen.org/~jdefalco/CNC/history.html

            http://www-me.mit.edu/Lectures/MachineTools/outline.html
            http://www.tarleton.edu/~gmollick/3503/lectures.htm

Editors (CAD):  http://www.cncezpro.com/
                http://www.cadstd.com/
                http://www.turbocad.com
                http://www.deskam.com/
                http://www.cadopia.com/

Bibliography:  * Computer Control of Manufacturing Systems, Yoram Koren,
* The CNC Workbook : An Introduction to Computer
  Numerical Control by Frank Nanfarra, et al.
CAD/CAM and CNC

- Concept
- Tool / Methodology
- Prototype
Brief relevant history

**NC**

1947 – US Air Force needs lead John Parsons to develop a machine able to produce parts describes in 3D.

1949 – Contract with *Parsons Corporation* to implement to proposed method.

1952 – Demonstration at MIT of a working machine tool (NC), able to produce parts resorting to simultaneous interpolation on several axes.

1955 – First NC machine tools reach the market.

1957 - NC starts to be accepted as a solution in industrial applications, with first machines starting to produce.

197x – Profiting from the microprocessor invention appears the CNC.
Evolution in brief

**CAD/CAM and CNC**

- Modification of existing machine tools with motion sensors and automatic advance systems.
- Close-loop control systems for axis control.
- Incorporation of the computational advances in the CNC machines.
- Development of high accuracy interpolation algorithms to trajectory interpolation.
- Resort to CAD systems to design parts and to manage the use of CNC machines.
CAD/CAM e CNC

Objectives:

• To augment the accuracy, reliability, and the ability to introduce changes/new designs.

• To augment the workload.

• To reduce production costs.

• To reduce waste due to errors and other human factors.

• To carry out complex tasks (e.g. Simultaneous 3D interpolation).

• Augment precision of the produced parts.
CAD/CAM and CNC

Advantages:

• To reduce the production/delivery time.

• To reduce costs associated to parts and other auxiliary.

• To reduce storage space.

• To reduce time to start production.

• To reduce machining time.

• To reduce time to market (on the design/redesign and production).
CAD/CAM and CNC

Limitations:

- High initial investment (30,000 to 1,500,000 euros)
- Specialized maintenance required
- Does not eliminates the human errors completely.
- Requires more specialized operators.
- Not so relevant the advantages on the production of small or very small series.
CAD/CAM and CNC

Methodology CAD/CAM

To use technical data from a database in the design and production stages. Information on parts, materials, tools, and machines are integrated.

CAD (Computer Aided Design)
Allows the design in a computer environment.

CAM (Computer Aided Manufacturing)
To manage programs and production stages on a computer.
CAD/CAM and CNC

Tools:
CAD/CAM and CNC

Tools:

Atention to the constraints on the materials used!...

- Speed of advance
- Speed of rotation
- Type of tool
CAD/CAM and CNC

Tools:

Specific tools to perform different operations.
## CAD/CAM and CNC

### Tools: impact on the quality of finishing (mm)

<table>
<thead>
<tr>
<th>Método</th>
<th>50</th>
<th>25</th>
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CAD/CAM and CNC

Evolution of tools performance:
CAD/CAM and CNC

Industrial areas of application:

- Aerospace
- Maquinery
- Electricity (board production)
- Automobiles
- Instrumentation
- Moulds
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Evolution of Numerical Control

- **Numerical Control (NC)**
  - Data on paper ou received in serial port
  - NC machine unable to perform computations
  - Hardware interpolation

- **Direct Numerical Control (DNC)**
  - Central computer control a number of machines DNC ou CNC

- **Computer Numerical control (CNC)**
  - A computer is on the core of each machine tool
  - Computation and interpolation algorithms run on the machine

- **Distributive numerical control**
  - scheduling
  - Quality control
  - Remore monitoring
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Numeric Control

Architecture of a NC system

Open-loop

Close-loop

Reference: +

Controller

DA

DC motor

Gear transmission table

Encoder
CAD/CAM and CNC

Interpolation
Motivation: numerical integration

Area of a function

\[ z(t) = \int_{0}^{t} p(\tau) d\tau \equiv \sum_{i=1}^{k} p_i \Delta t \]

Introducing \( z_k \), as the value of \( z \) at \( t=k\Delta t \)

\[ z_k = \sum_{i=1}^{k-1} p_i \Delta t + p_k \Delta t = z_{k-1} + \Delta z_k, \quad \Delta z_k = p_k \Delta t \]

The integrator works at a rhythm of \( f=1/\Delta t \) and the function \( p \) is given app. by:

\[ p_k = p_{k-1} \pm \Delta p_k \]

To be able to implement the integrator in registers with \( n \) bits, \( p \) must verify \( p_k < 2^n \).
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Implementation of a DDA
Digital Differential Analyzer

The p register input is +1, 0 ou –1.

The q register stores the area integration value

\[ q_k = q_{k-1} + p_k. \]

If the q register value exceeds \((2^n-1)\), and overflow occurs and \(Dz=1\):

\[ \Delta z_k = 2^{-n} p_k \]

Defining \(C=f/2^n\), and given that \(f=1/Dt\):

\[ \Delta z_k = Cp_k \Delta t \]
CAD/CAM and CNC

DDA for Linear Interpolation:

Let q=5 and assume 3 bits registers

<table>
<thead>
<tr>
<th>Passo</th>
<th>q</th>
<th>Dz</th>
<th>SDz</th>
</tr>
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<tr>
<td>1</td>
<td>5</td>
<td>0</td>
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<tr>
<td>2</td>
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<td>7</td>
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<td>1</td>
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<td>8</td>
<td>0</td>
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<td>5</td>
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<td>9</td>
<td>5</td>
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<td>5</td>
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</tbody>
</table>

\[ f_0 = \left( \frac{\Delta z}{\Delta t} \right)_k = C p_k, \quad \text{where} \quad C = \frac{f}{2^n} \]
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**Exponential Deacceleration:**

Let \( p(t) = p_0 e^{-\alpha t} \) and \( \frac{\Delta z}{\Delta t} = C p_k = C p_0 e^{-\alpha t} \).

The differential of \( p(t) \) is appr.

\[- \Delta p = \alpha p_k \Delta t\]

Example: \( p(t) = 15e^{-t} \)

Setting \( C = a \),

\[- \Delta p = \Delta z\]
Circular Interpolation:

Let \((X - R)^2 + Y^2 = R^2\) or

\[X = R\left(1 - \cos(\omega t)\right)\]
\[Y = R \sin(\omega t)\]

The differential is

\[dX = \omega R \sin(\omega t) dt = d(-R \cos(\omega t))\]
\[dY = \omega R \cos(\omega t) dt = d(R \sin(\omega t))\]

Example: Circumference of radius 15, centered at the origin.
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Full DDA

- Desacceleration

- Linear

- Circular
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CNC Axes Control

Dynamics of a control loop

\[ T_s \]

\[ \frac{k_2}{k_1} \]

\[ f_{\text{ref}} \]

\[ \frac{1}{s} \]

\[ k_{\text{DA}} \]

\[ \frac{k_1}{1 + \tau s} \]

\[ k_g \]
CAD/CAM and CNC

CNC Programming

Steps to execute a part

A) Read/interpret the technical drawings
CAD/CAM and CNC

CNC Programming

B) Choice of the most adequate machine tool for the several stages of machining

Relevant features:

• The workspace of a machine versus the part to be produced
• The options available on each machine
• The tools available
• The mounting and the part handling
• The operations that each machine can perform
CAD/CAM and CNC

CNC Programming

C) Choice of the most adequate tools

Relevant features:

• The material to be machined and its characteristics
• Standard tools cost less
• The quality of the mounting part is function of the number of parts to produce
• Use the right tool for the job
• Verify if there are backup tools and/or stored available
• Take into account tool aging
### CNC Programming

Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

<table>
<thead>
<tr>
<th>Material</th>
<th>W·s/mm³</th>
<th>hp·min/in.³³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloys</td>
<td>0.4–1.1</td>
<td>0.15–0.4</td>
</tr>
<tr>
<td>Cast irons</td>
<td>1.6–5.5</td>
<td>0.6–2.0</td>
</tr>
<tr>
<td>Copper alloys</td>
<td>1.4–3.3</td>
<td>0.5–1.2</td>
</tr>
<tr>
<td>High-temperature alloys</td>
<td>3.3–8.5</td>
<td>1.2–3.1</td>
</tr>
<tr>
<td>Magnesium alloys</td>
<td>0.4–0.6</td>
<td>0.15–0.2</td>
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<tr>
<td>Nickel alloys</td>
<td>4.9–6.8</td>
<td>1.8–2.5</td>
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<tr>
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<td>3.8–9.6</td>
<td>1.1–3.5</td>
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<tr>
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<td>1.1–1.9</td>
</tr>
<tr>
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<td>2.7–9.3</td>
<td>1.0–3.4</td>
</tr>
</tbody>
</table>
CAD/CAM and CNC

CNC Programming

D) Cutting data

- Spindle Speed – speed of rotation of the cutting tool (rpm)

- Feedrate – linear velocity of advance to machine the part (mm/minute)

- Depth of Cut – depth of machining in z (mm)
CAD/CAM and CNC

CNC Programming

E) Choice of the interpolation plane, in 2D $\frac{1}{2}$ machines
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CNC Programming

F₁) Unit system

imperial – inches (G70) or international milimeters (G71).

F₂) Command mode*

Absolut – relative to world coordinate system (G90)

Relative– mouvement relative to the actual position (G91)

* There are other command modes, e.g. helicoidal.
CAD/CAM and CNC

CNC Programming

G) MANUAL DATA INPUT

<table>
<thead>
<tr>
<th>N</th>
<th>Sequence Number</th>
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<tbody>
<tr>
<td>G</td>
<td>Preparatory Functions</td>
</tr>
<tr>
<td>X</td>
<td>X Axis Command</td>
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<tr>
<td>Y</td>
<td>Y Axis Command</td>
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<tr>
<td>Z</td>
<td>Z Axis Command</td>
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<td>R</td>
<td>Radius from specified center</td>
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<td>A</td>
<td>Angle ccw from +X vector</td>
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<td>I</td>
<td>X axis arc center offset</td>
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<td>J</td>
<td>Y axis arc center offset</td>
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<td>Tool number</td>
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<td>M</td>
<td>Miscellaneous function</td>
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</table>
Example of a CNC program

N30 G0 T1 M6
N35 S2037 M3
N40 G0 G2 X6.32 Y-0.9267 M8
N45 Z1.1
N50 Z0.12
N55 G1 Z0. F91.7
N60 X-2.82
N65 Y0.9467
N70 X6.32
N75 Y2.82
N80 X-2.82
N85 G0 Z1.1
...

Unregistered HyperCam
CAD/CAM and CNC

Preparatory functions (inc.)

G00 – GO

G01 – Linear Interpolation

G02 – Circular Interpolation (CW)

G03 – Circular Interpolation (CCW)
Other preparatory functions

- **G04** - A temporary dwell, or delay in tool motion.
- **G05** - A permanent hold, or stopping of tool motion. It is canceled by the machine operator.
- **G22** - Activation of the stored axis travel limits, which are used to establish a safety boundary.
- **G23** - Deactivation of the stored axis travel limits.
- **G27** - Return to the machine home position via a programmed intermediate point
- **G34** - Thread cutting with an increasing lead.
- **G35** - Thread cutting with a decreasing lead.
- **G40** - Cancellation of any previously programmed tool radius compensation
- **G42** - Application of cutter radius compensation to the right of the workpiece with respect to the direction of tool travel.
- **G43** - Activation of tool length compensation in the same direction of the offset value
- **G71** - Canned cycle for multiple-pass turning on a lathe (foreign-made)
- ...
CAD/CAM and CNC

Miscellaneous functions

- M02 - Program end
- M03 - Start of spindle rotation clockwise
- M04 - Start of spindle rotation counterclockwise
- M07 - Start of mist coolant
- M08 - Start of flood coolant
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Canned Cycles

G81 – Drilling cycle with multiple holes
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Ciclos Especiais or Canned Cycles

G78 – Rectangular pocket cycle, used to clean a square shaped area
CAD/CAM and CNC

Tool change

Note: should be of easy access, when performed manually.
Example of CNC programming

Ver: http://www.ezcam.com/web/tour/tour.htm
CAD/CAM and CNC

Example of CNC programming
CAD/CAM and CNC

Advanced CNC programming languages

• Automatically program tool (APT)
  Developed at MIT in 1954

• Derived from APT:
  ADAPT (IBM)
  IFAPT (France)
  MINIAPT (Germany)

• Compact II

• Autospot

• SPLIT
CAD/CAM and CNC

Machine operation

**Rules of Security**

- Security is essential!
- The eyes must be always protected.
- The tools and parts must be handled and installed properly.
- Avoid the use of large cloths
- Clean the parts with a brush. Never with the hands.
- Be careful with you and the others.
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Machine operation

Verify tolerances and tools offsets for proper operation
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Machine operation

Load program

Follow up machine operation

Verify carefully the produced part.