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

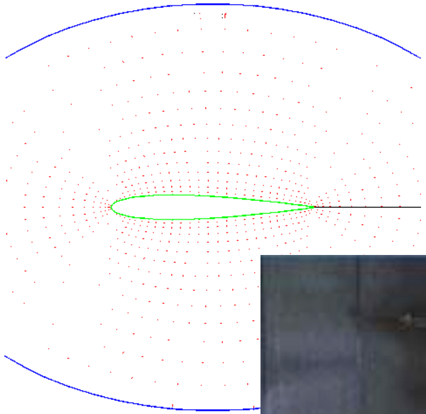
History: http://users.bergen.org/~jdefalco/CNC/history.html

Tutorial:
http://users.bergen.org/~jdefalco/CNC/index.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, McGraw Hill, 1986.
* The CNC Workbook : An Introduction to Computer Numerical Control by Frank Nanfarra, et al.

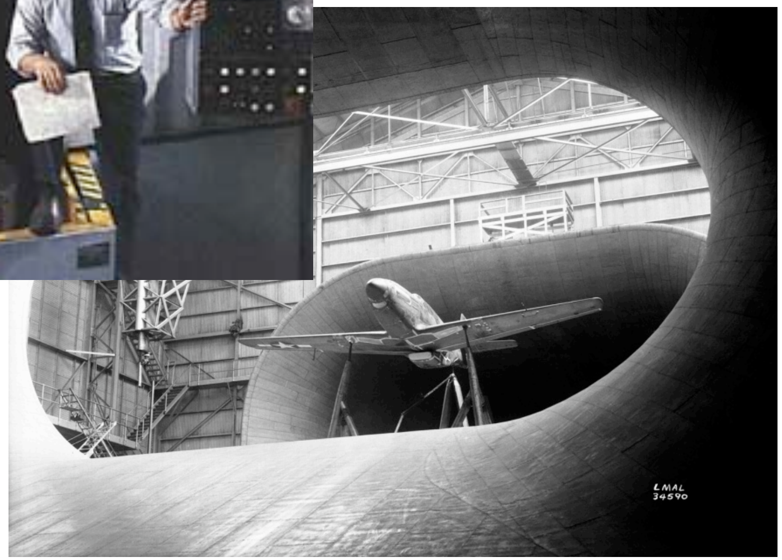
CAD/CAM and CNC



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 accuraccy 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 accuraccy, reliability, and the ability to introduce changes/new designs.
- To augment the workload.
- To reduce prodution costs.
- To reduce waste due to errors and other human factors.
- To carry out complex tasks (e.g. Simlutaneous 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.

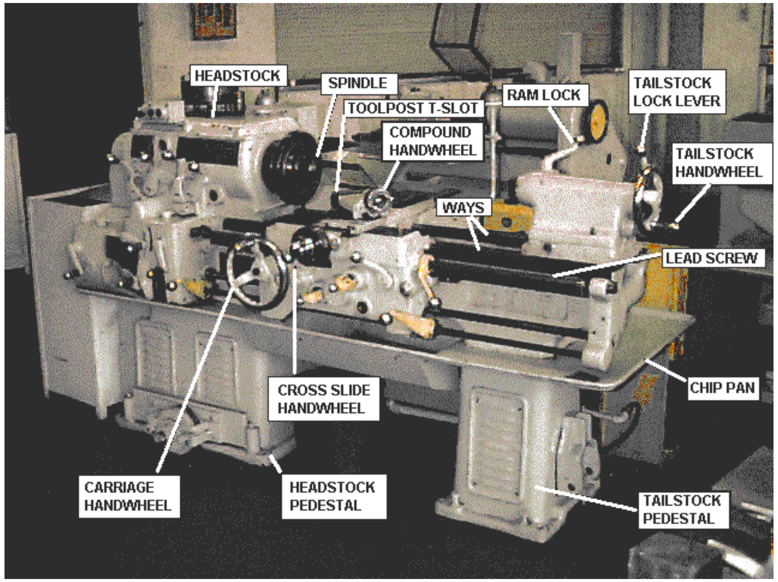
CAD/CAM e CNC

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.

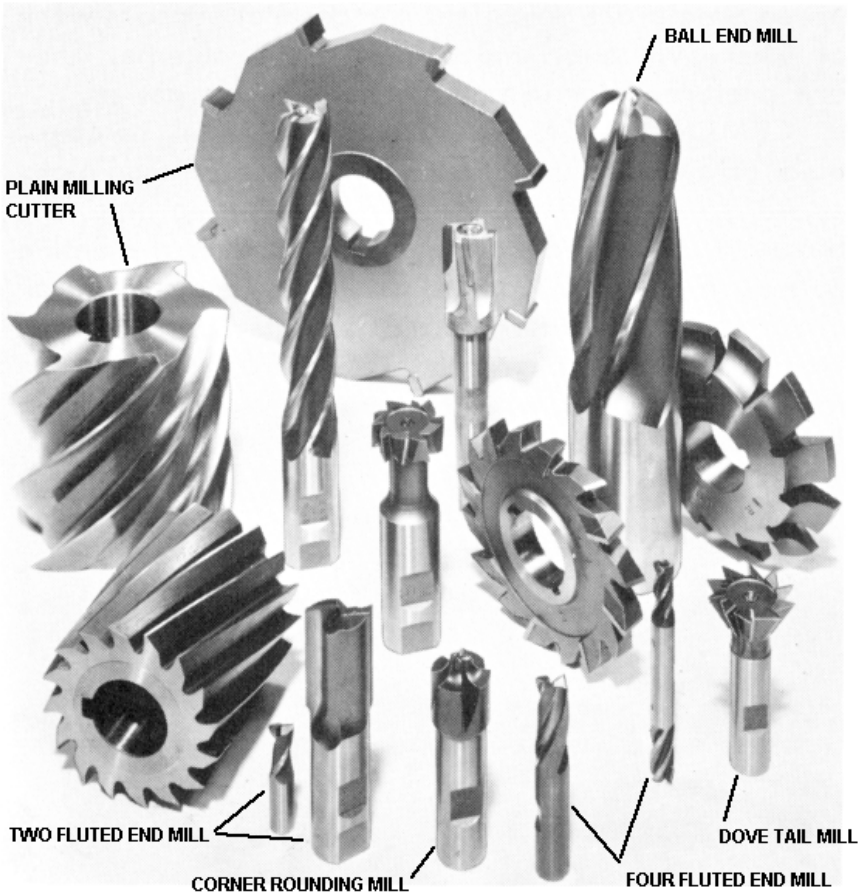
CAD (Computer Aided Design)
Allows the design in a computer environment.

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


HEADSTOCK
SPINDLE
TOOLPOST T-SLOT
COMPOUND HANDWHEEL
RAM LOCK
TAILSTOCK LOCK LEVER
TAILSTOCK HANDWHEEL
WAYS
LEAD SCREW
CHIP PAN
CROSS SLIDE HANDWHEEL
CARRIAGE HANDWHEEL
HEADSTOCK PEDESTAL
TAILSTOCK PEDESTAL

CAD/CAM and CNC

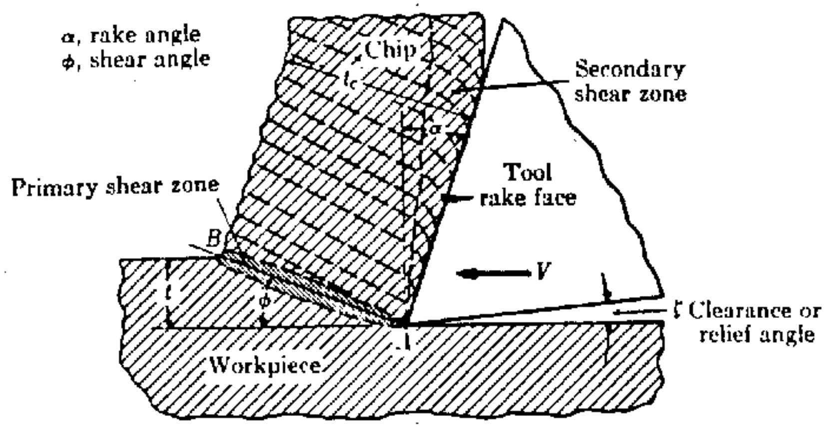
Tools:

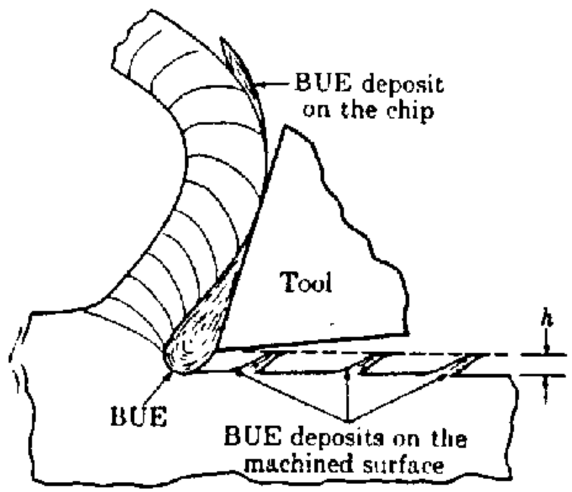


CAD/CAM and CNC

Tools:

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

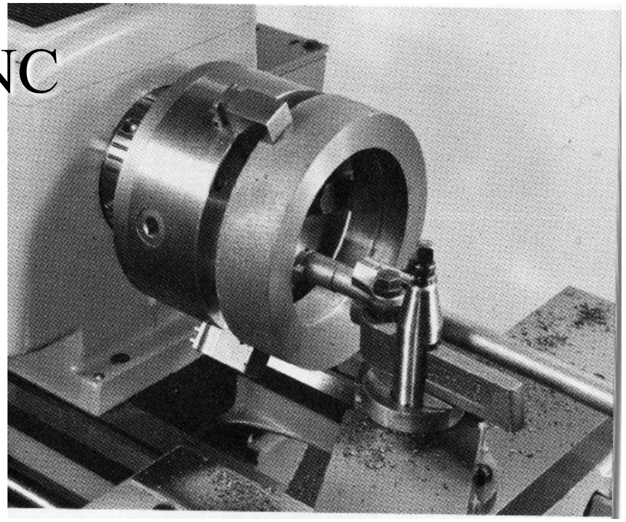


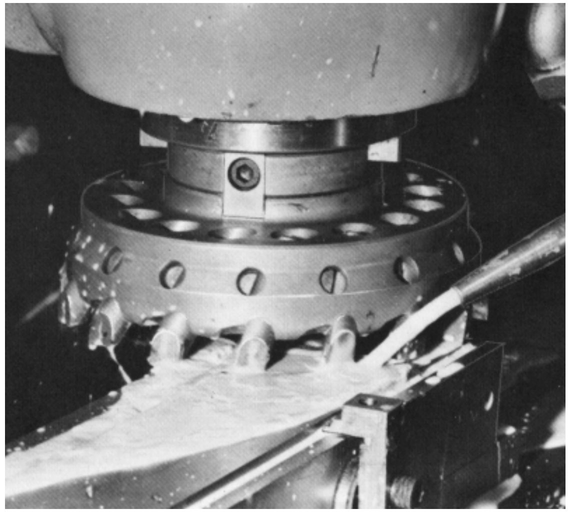


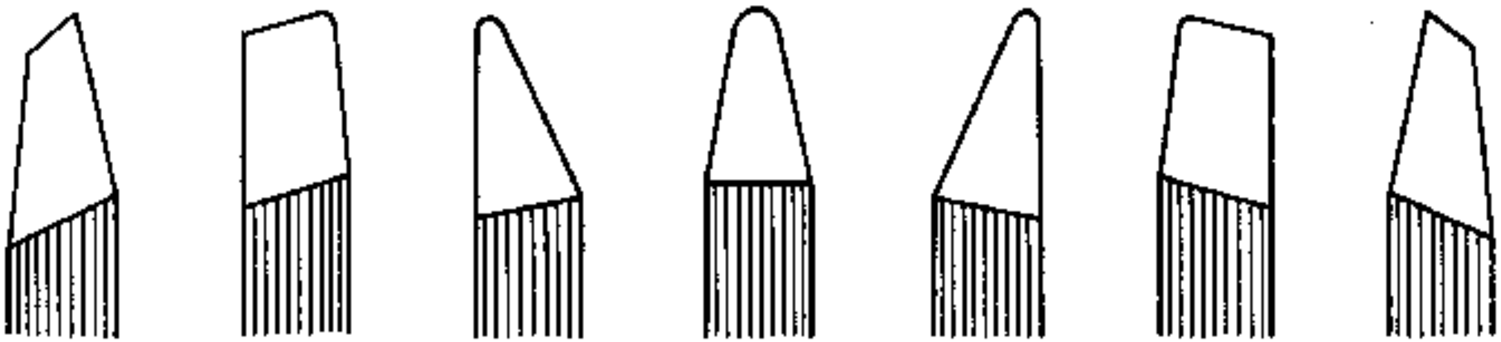
- **Speed of advance**
- **Speed of rotation**
- **Type of tool**

CAD/CAM and CNC

Tools:







Specific tools to perform different operations.

CAD/CAM and CNC

Tools: impact on the quality of finishing (mm)

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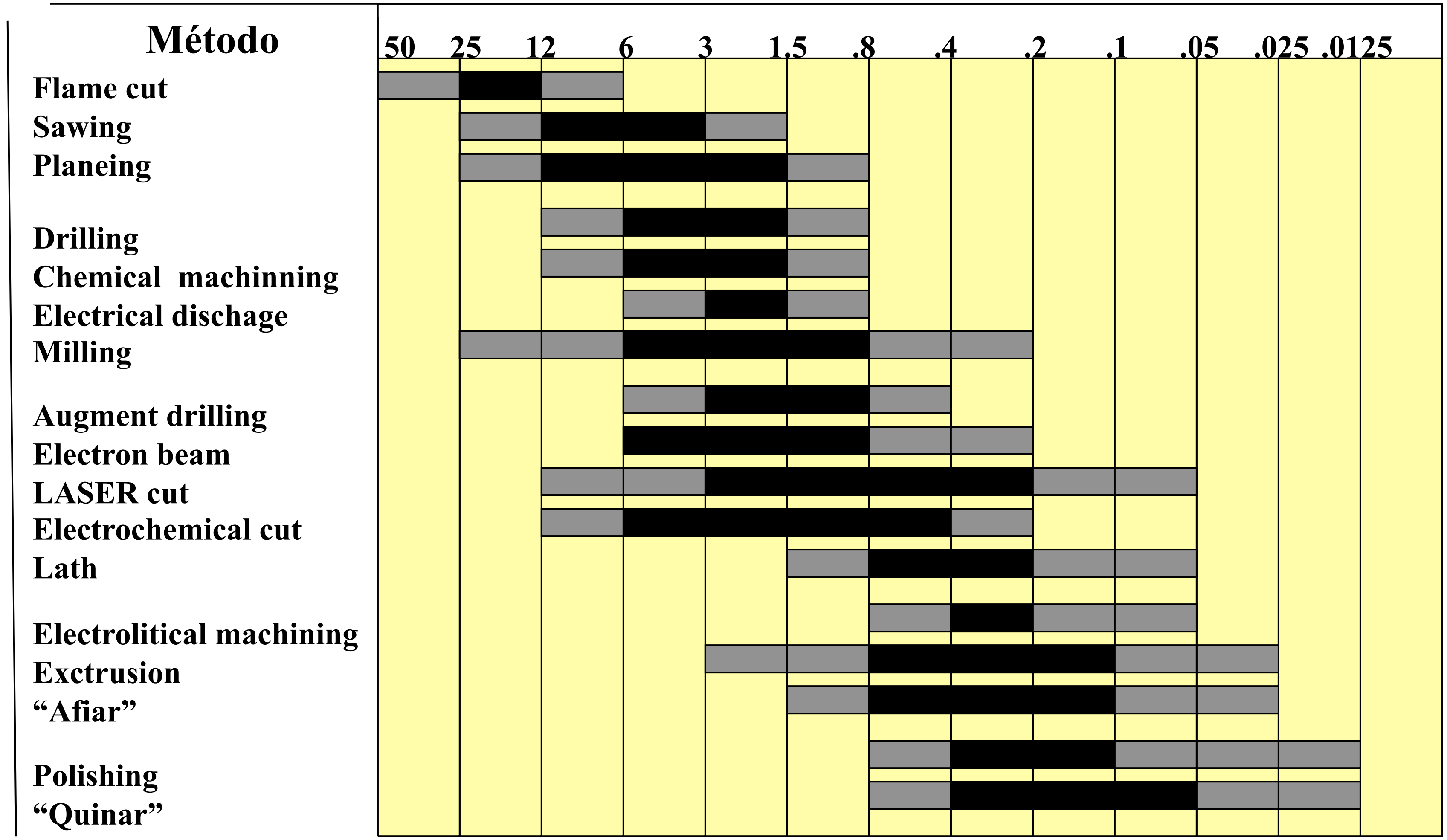
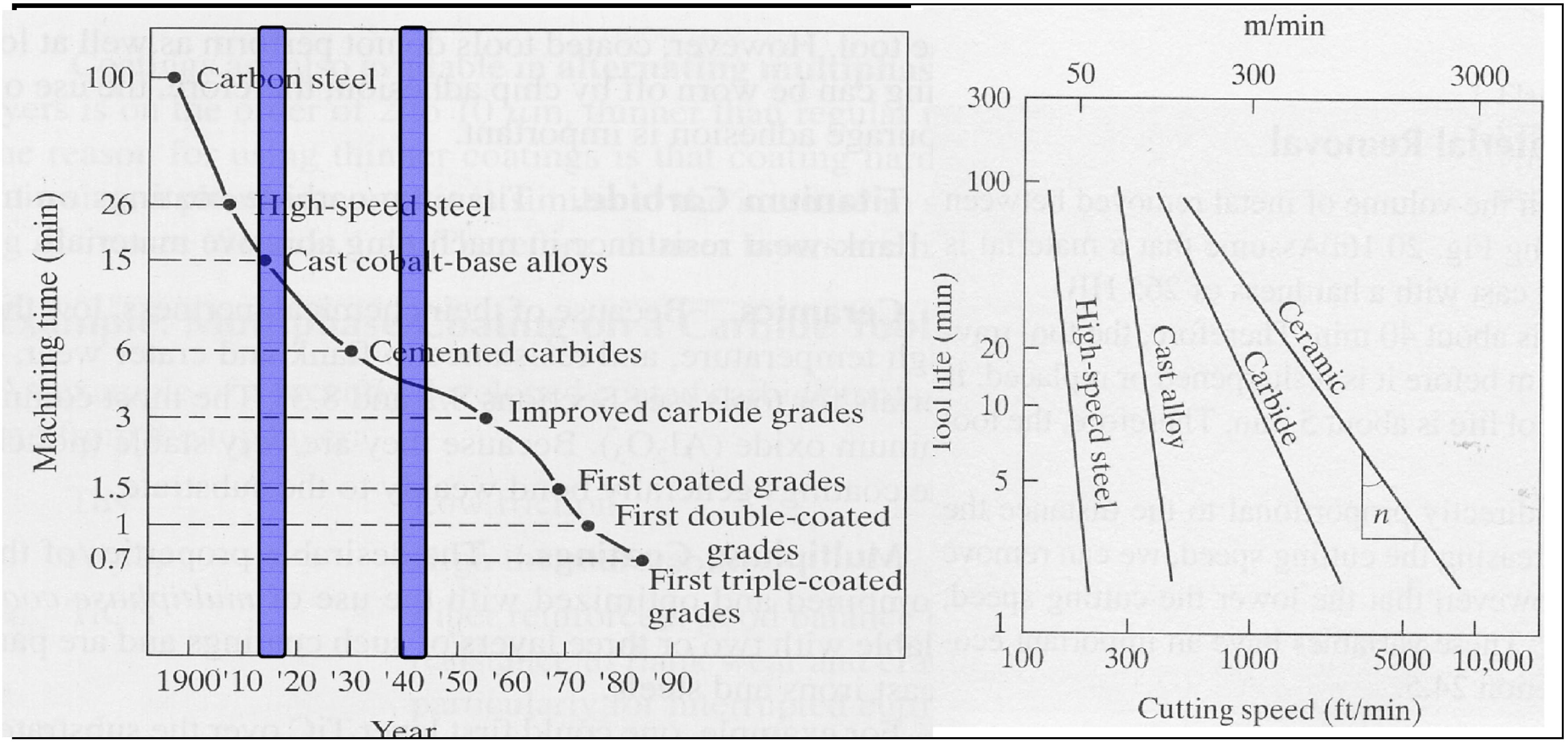


CAD/CAM and CNC

Evolution of tools performance:



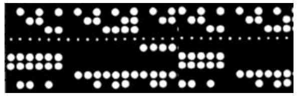
CAD/CAM and CNC

Industrial areas of application:

- **Aerospace**
- **Maquinery**
- **Electricity (board production)**
- **Automobiles**
- **Instrumentation**
- **Moulds**

CAD/CAM and CNC

Evolution of Numerical Control



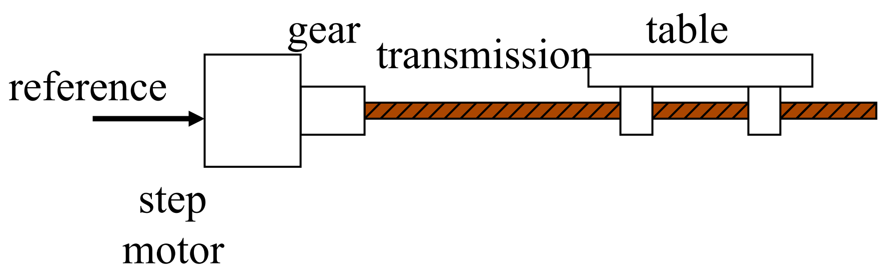
- **Numerical Control (NC)**
  - **Data on paper ou received in serial port**
  - **NC machine unable to perform computations**
  - **Hardware interpolation**
- **Direct Numerical Control (DNC)**
  - **Central computer control a number of machines DNC ou CNC**
- **Computer Numerical control (CNC)**
  - **A computer is on the core of each machine tool**
  - **Computation and interoplation algorithms run on the machine**
- **Distributive numerical control**
  - **scheduling**
  - **Quality control**
  - **Remore monitoring**

CAD/CAM and CNC

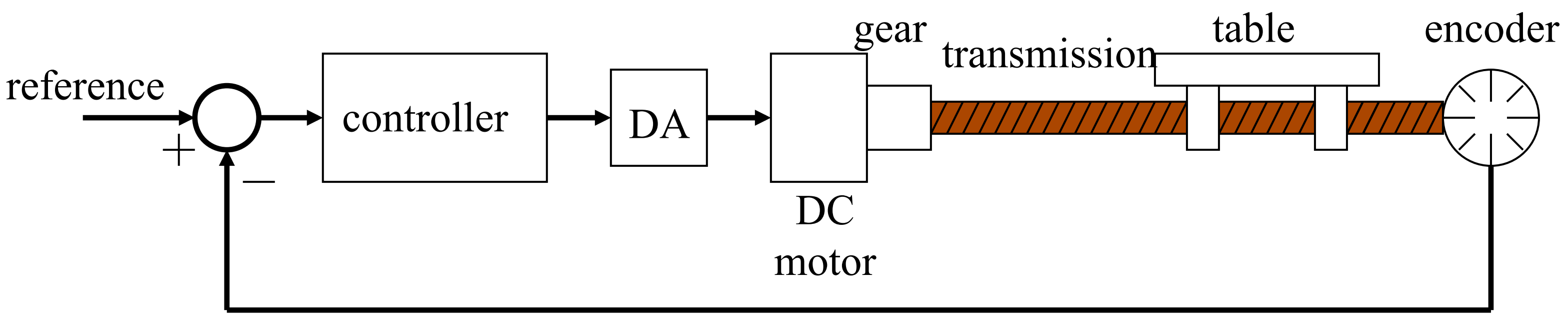
Numeric Control

Architecture of a NC system

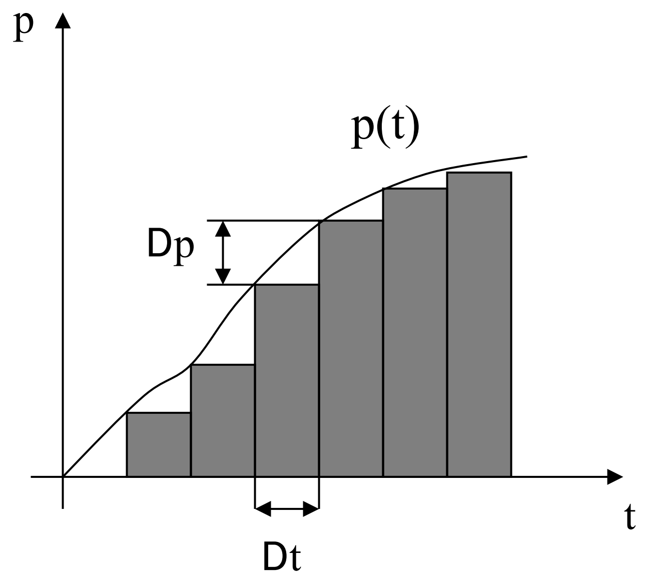
Open-loop



Close-loop



CAD/CAM and CNC



Interpolation
Motivation: numerical integration

Area of a function

$$z(t) = \int_0^t p(\tau) d\tau \cong \sum_{i=1}^{k} p_i \Delta t$$

Introducing z_k, as the value of z at t=kDt

$$z_k = \sum_{i=1}^{k-1} p_i \Delta t + p_k \Delta t = z_{k-1} + \Delta z_k, \qquad \Delta z_k = p_k \Delta t$$

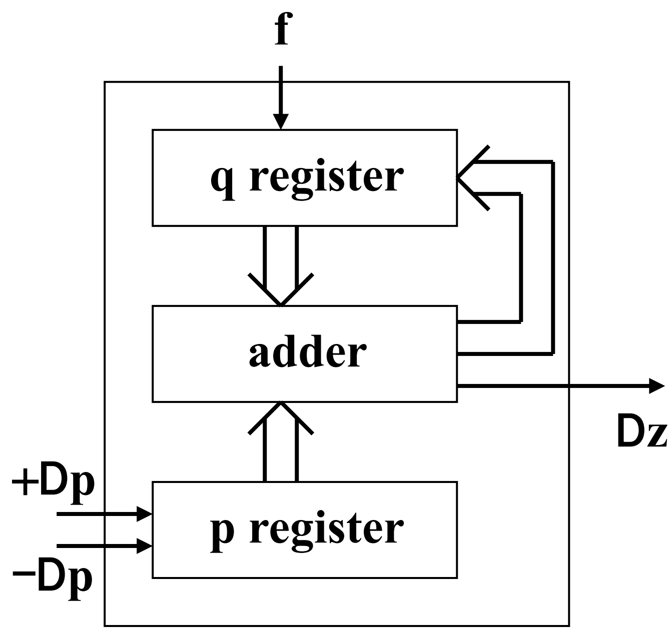
The integrator works at a rythm of f=1/Dt and the function p is given app. by:

$$p_k = p_{k-1} \pm \Delta p_k$$

To be able to implement the integrator in registers with n bits, p must verify $p_k < 2^n$.

CAD/CAM and CNC

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:

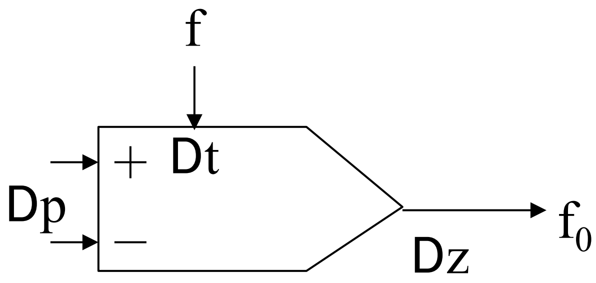
$$\Delta z_k = 2^{-n} p_k$$

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

$$\Delta z_k = C p_k \Delta t$$

CAD/CAM and CNC

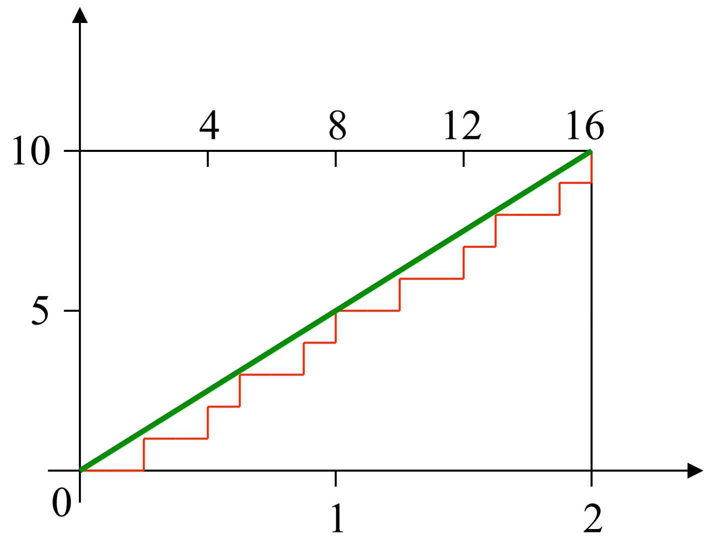
DDA for Linear Interpolation:



Let q=5 and assume 3 bits registers

Passo	q	Dz	S Dz
1	5		0
2	2	1	1
3	7		1
4	4	1	2
5	1	1	3
6	6		3
7	3	1	4
8	0	1	5
9	5		5
		...	

$$f_0 = \left(\frac{\Delta z}{\Delta t}\right)_k = C p_k, \quad \text{where} \quad C = \frac{f}{2^n}$$



CAD/CAM and CNC

Exponential Deacceleration:

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

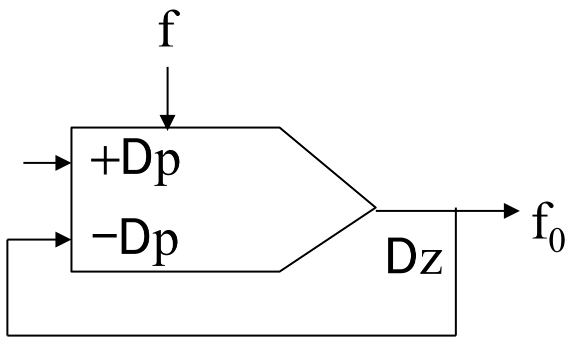
The differential of p(t) is appr.

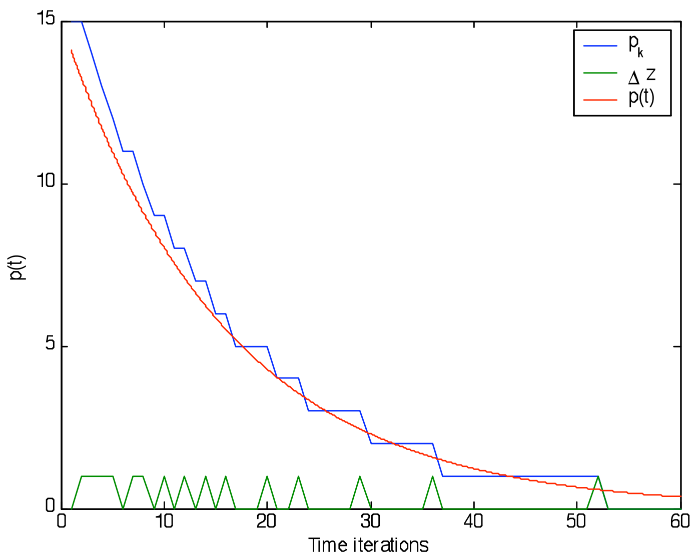
$$-\Delta p = \alpha p_k \Delta t$$

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

Setting C=a,

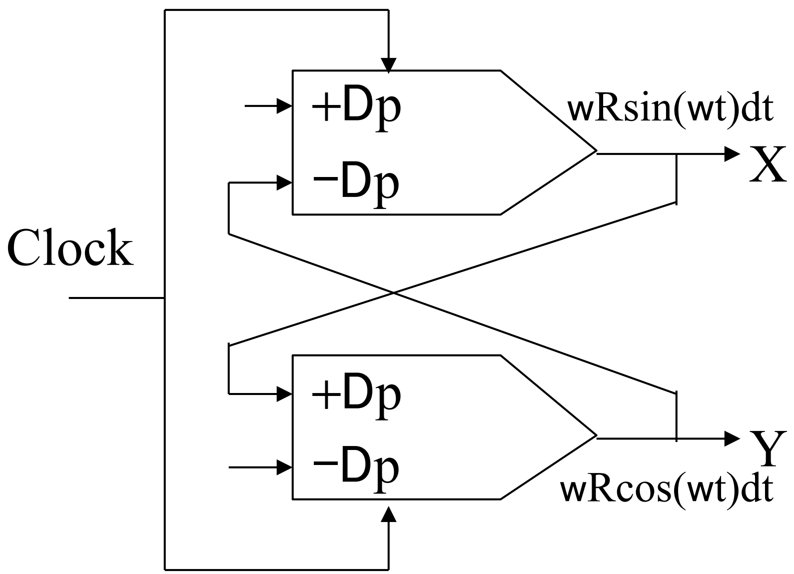
$$-\Delta p = \Delta z$$





CAD/CAM and CNC

Circular Interpolation:



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

$$X=R(1-\cos(\omega t))$$

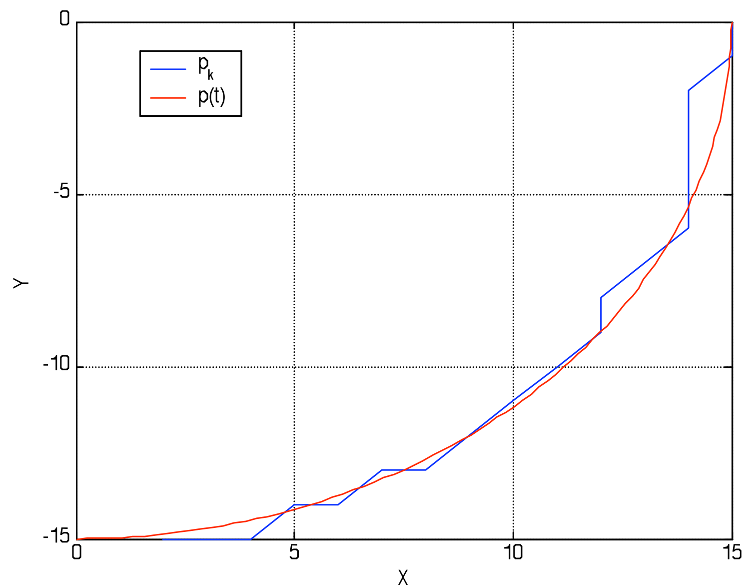
$$Y=\quad R\sin(\omega t)$$

The differential is

$$dX=\omega R\sin(\omega t)dt=d(-R\cos(\omega t))$$

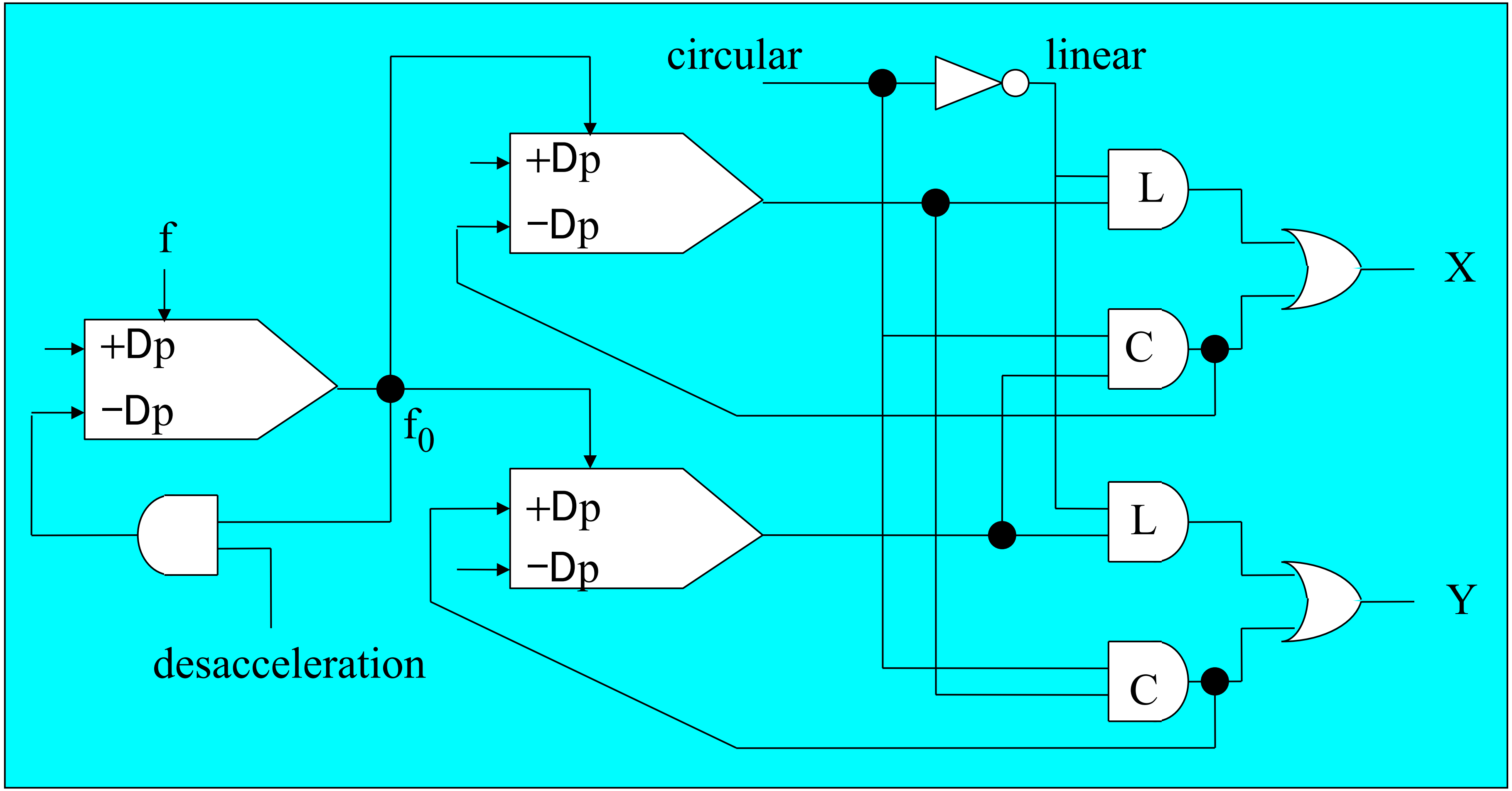
$$dY=\omega R\cos(\omega t)dt=\ d(R\sin(\omega t))$$

Example: Circunference of radius 15, centered at the origin.



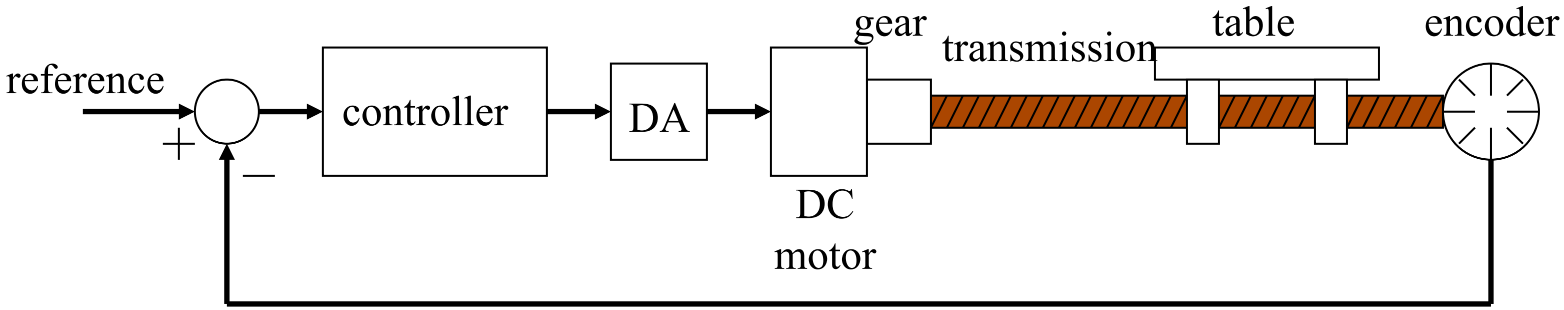
CAD/CAM and CNC

Full DDA

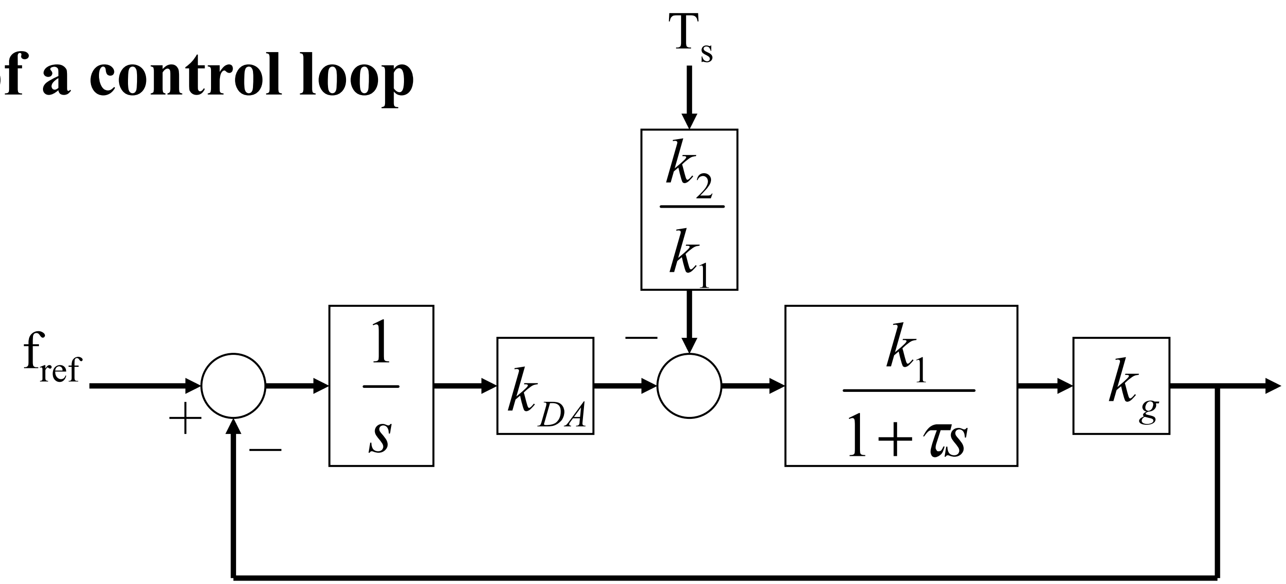


CAD/CAM and CNC

CNC Axes Control



Dynamics of a control loop

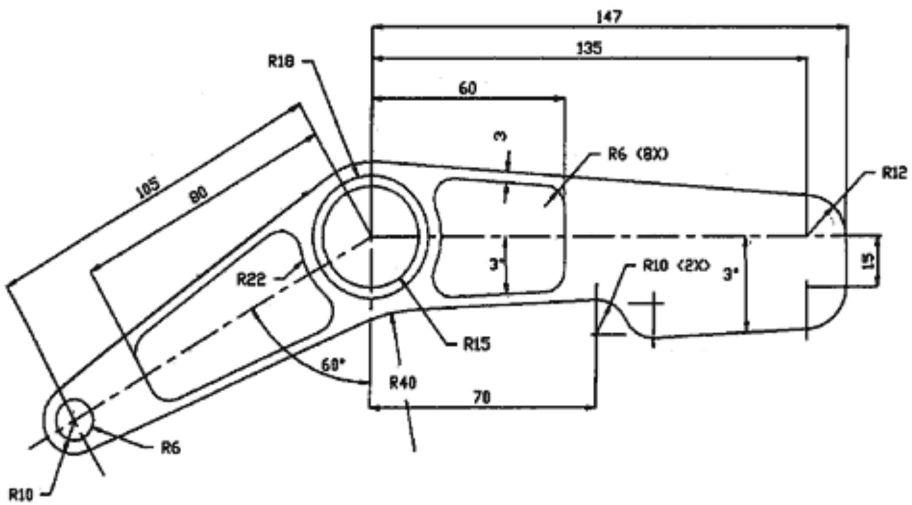


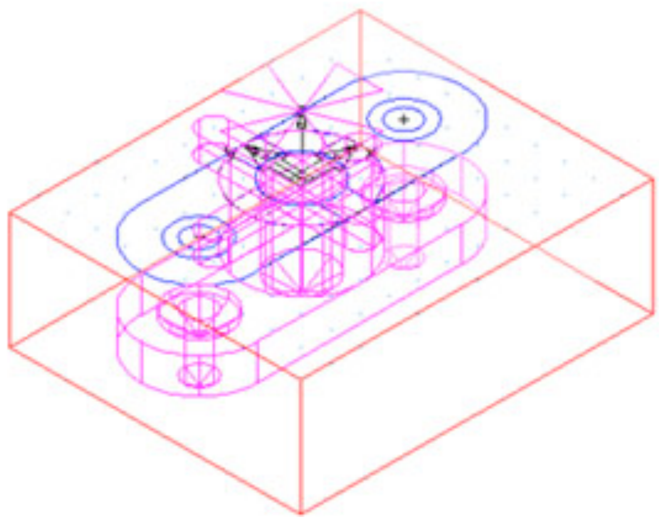
CAD/CAM and CNC

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 machinning

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 machinned and its characteristics**
- **Standard tools cost less**
- **The quality of the mounting part is function of the number od 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**

CAD/CAM and CNC

CNC Programming

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

Material	Specific energy $W \cdot s/mm^3$	Specific energy $hp \cdot min/in.^3$
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4

CAD/CAM and CNC

CNC Programming

D) Cutting data

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

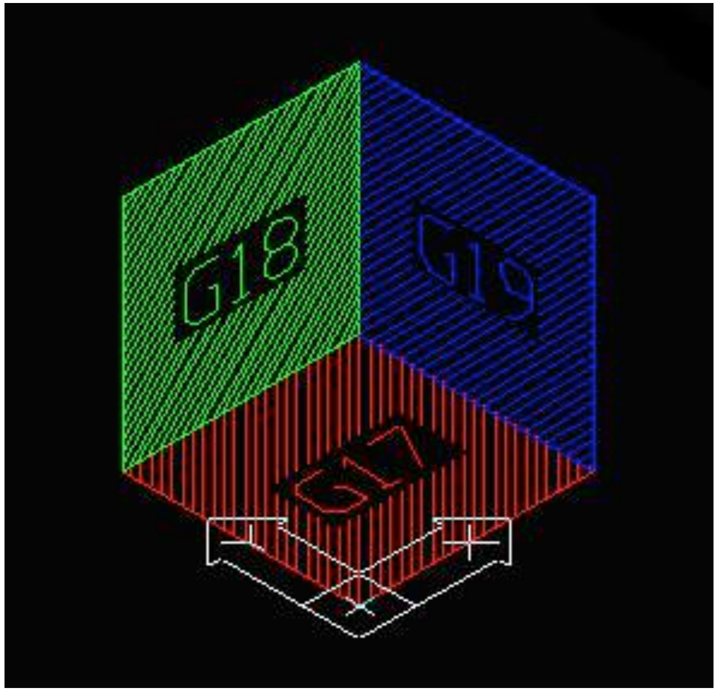
- **Feedrate – linear velocity of advance to machine the part (mm/ minute)**

- **Depth of Cut –deth of machinning in z (mm)**

CAD/CAM and CNC

CNC Programming

E) Choice of the interpolation plane, in 2D ½ machines



CAD/CAM and CNC

CNC Programming

F_1) Unit system

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

F_2) 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

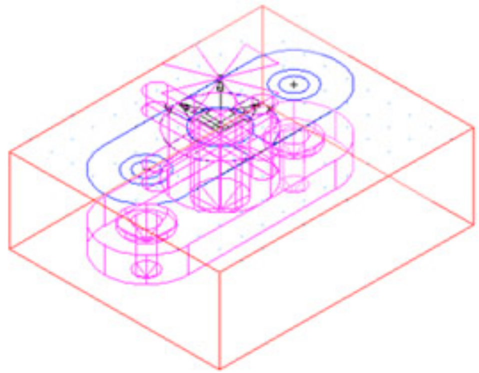
G) MANUAL DATA INPUT

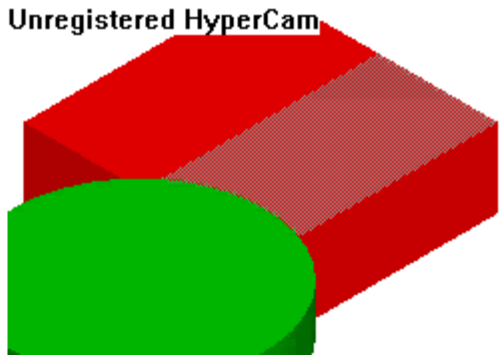
N	Sequence Number
G	Preparatory Functions
X	X Axis Command
Y	Y Axis Command
Z	Z Axis Command
R	Radius from specified center
A	Angle ccw from +X vector
I	X axis arc center offset
J	Y axis arc center offset
K	Z axis arc center offset
F	Feedrate
S	Spindle speed
T	Tool number
M	Miscellaneous function

CAD/CAM and CNC

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
...
```

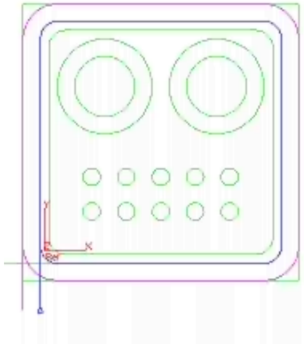




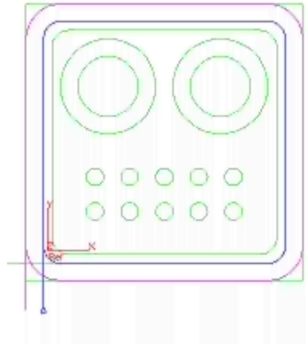
CAD/CAM and CNC

Preparatory functions (inc.)

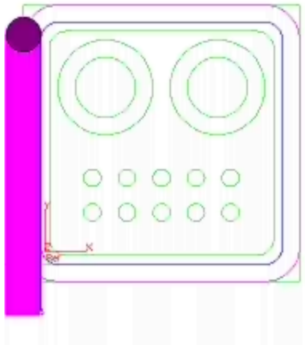
G00 – GO



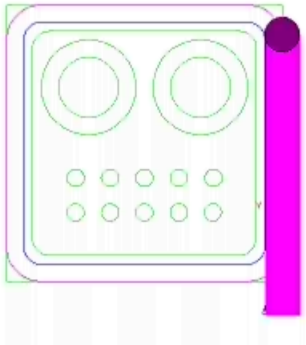
G01 – Linear Interpolation



G02 – Circular Interpolation (CW)



G03 – Circular Interpolation (CCW)



CAD/CAM and CNC

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

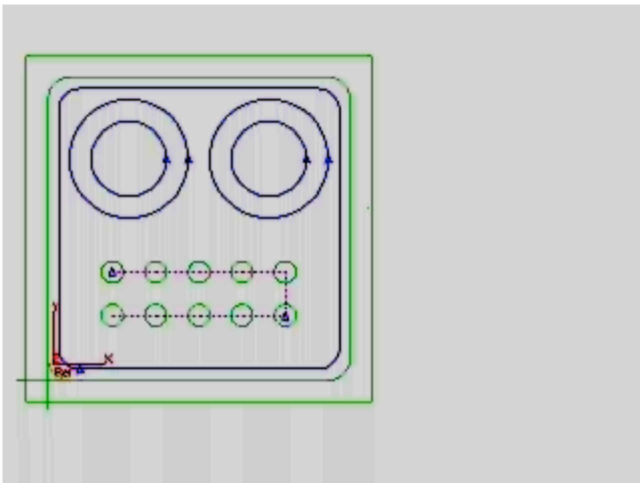
Miscelaneous functions

- 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

CAD/CAM and CNC

Canned Cycles

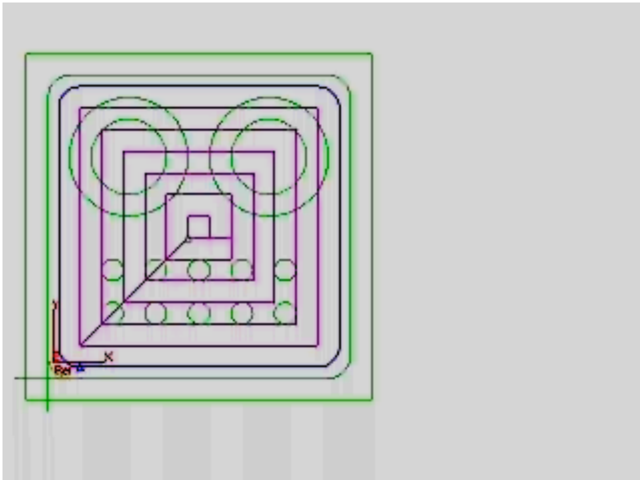
G81 – Drilling cycle with multiple holes



CAD/CAM and CNC

Ciclos Especiais or Canned Cycles

G78 – Rectangular pocket cycle, used to clean a square shaped area



CAD/CAM and CNC

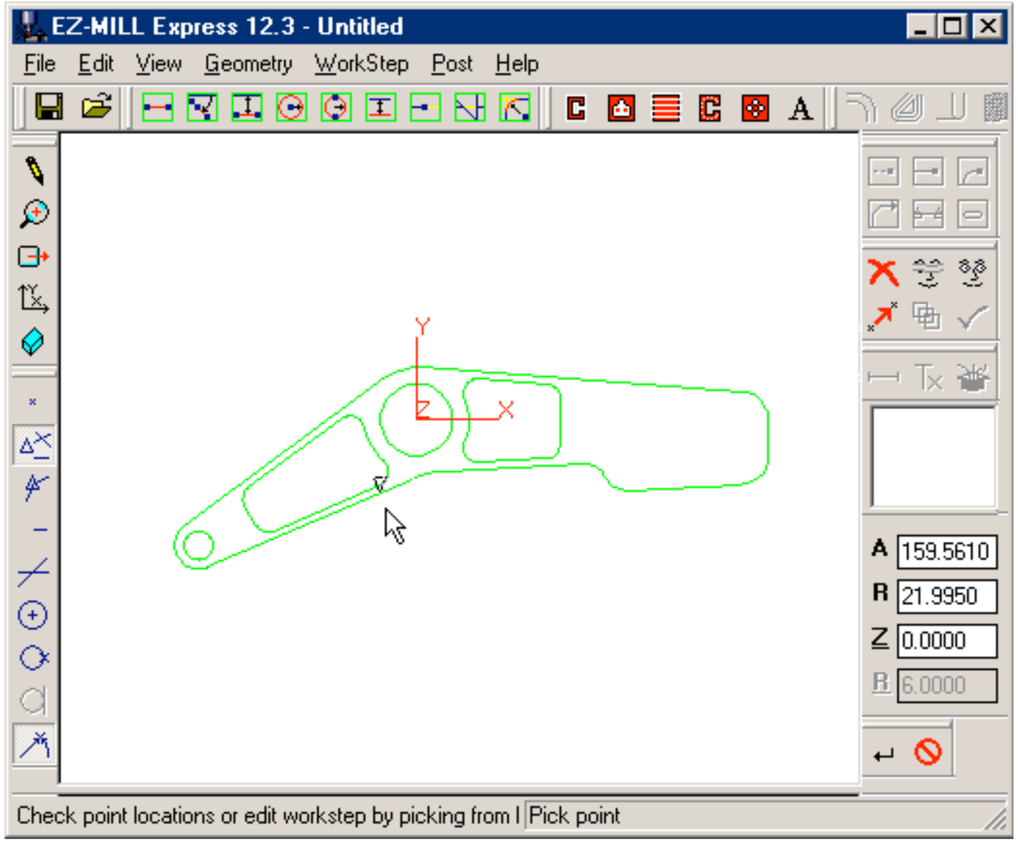
Tool change

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

CAD/CAM and CNC

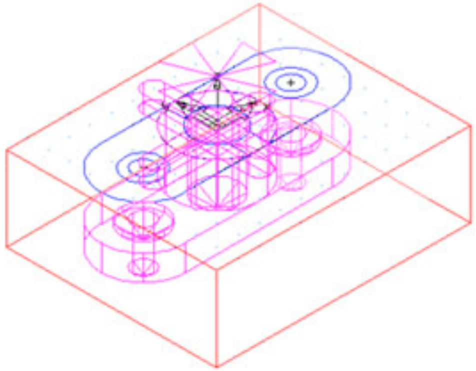
Example of CNC programming

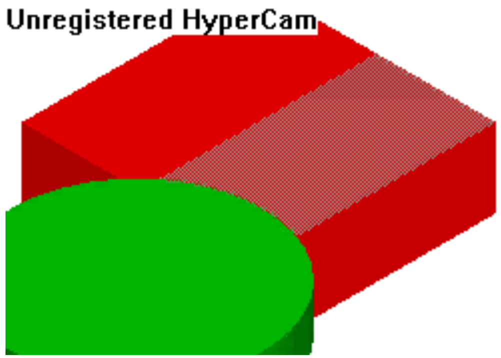
Ver: http://www.ezcam.com/web/tour/tour.htm



CAD/CAM and CNC

Example of CNC programming





CAD/CAM and CNC

Advanced CNC programming languages

- Automatically program tool (APT)
  Desveloped at MIT in 1954

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

- Compact II

- Autospot

- SPLIT

CAD/CAM and CNC

Machine operation

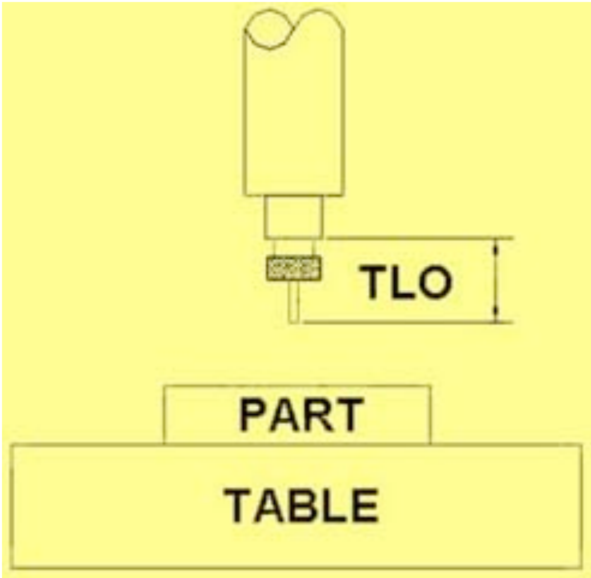
Rules of Security

- 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
- Cleand the parts with a brush. Never with the hands.
- Be careful with you and the others.

CAD/CAM and CNC

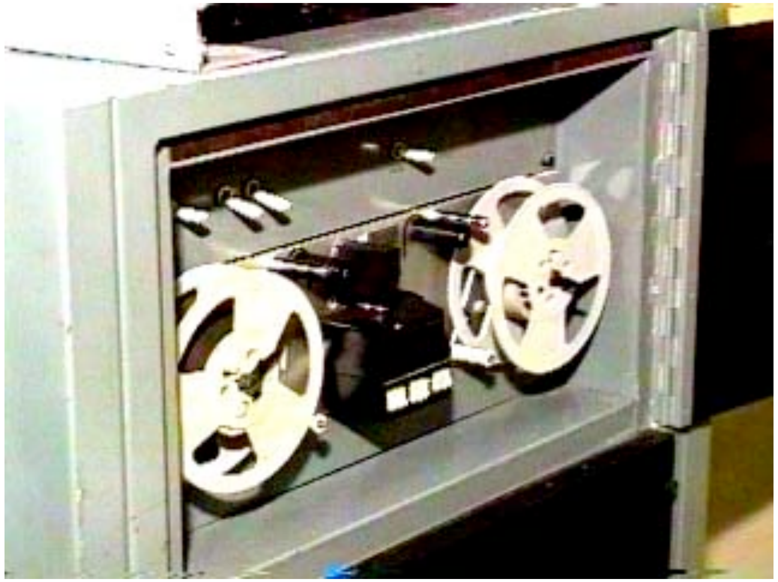
Machine operation

Verify tolerances and tools offsets for proper operation



CAD/CAM and CNC

Machine operation



Load program

Follow up machine operation

Verify carefully the produced part.