University of BRISTOL

Department of Mechanical Engineering

VIRTUAL PRODUCT DEVELOPMENT (MENGM6049) – Lecture 6
Design for Machining & CNC Machining
2017-2018

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The Purpose of the Lecture

- What is machining and why is important?
- Type of Machining Processes: Milling & Turning
- CNC Machine Tools
  - Control Unit & Servo Axis control & Basic Length Unit (BLU)
  - How it works.
  - Coordinate System
  - Turning operations
  - External/Internal Counter/Profiling Operations
  - Key Parameters Effect Productivity & Part Quality (cutting speed, feedrate, depth of cut)
- The importance of machining and sustainability.
- Sustainability analysis using virtual machining methodology for environmental impact, such as CO2 emissions and climate change.
- Optimisation of machining parameters to reduce environmental impact and save energy.

Intended Learning Outcomes

After taking the unit the students would be able to:

1. Draw, manipulate and analyse advanced engineering curves including splines and Bezier curves on a Computer Aided Design system.

2. Create a machining process plan for a part and perform virtual machining of the product based on this process plan on a Computer Aided Manufacturing system.

3. Design and optimise a mechanical product from concept to full digital prototype in an integrated Product Lifecycle Management environment.

- To complement the unit, 9 lectures with a series of laboratories (24 hours) are provided to support the unit.

Unit – Supporting Lectures

- Lecture 0 Introduction to coursework/assignment;
- Lecture 1 Introduction to VPD and PLM.
- Lecture 2 CAD Overview & Intro. to Engineering Curve.
- Lecture 3 Reverse Engineering.
- Lecture 4 Curve Analysis.
- Lecture 5 Interrogation of Solids.
- Lecture 6 Design for Machining & CNC Machining.
- Lecture 7 Process Planning for Machining.
- Lecture 8 Virtual Machining.
- Lecture 9 Iterative design, analysis and Optimisation in PLM.

Manufacturing Processes – Machining & The Importance

- There are normally five different manufacturing processes: solidification, bulk deformation, material removal, profiling and sheet forming.
- We only consider machining because most of the engineering components are subjected to some kind of machining during manufacture.
  - **Machining** is the manufacturing process by which parts can be produced to the desired dimensions and surface finish from a blank by gradual removal of the excess material, in the form of chips, with the help of a sharp cutting tool.
  - It is very important to design those parts in such a way that would lead to the increase in efficiency of the machining process, enhancement of the tool life and reduction of the overall cost of machining.

Manufacturing processes and materials

Process	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metals	Thermoplastics	Thermosets	Group
Sand Casting							X		X		X	■	■	Solidification Processes
Investment Casting	X						X	X	X		X	■	■	
Die Casting	■	■	■	■		X			■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		X	
Structural Foam Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Blow Molding (Ext)	■	■	■	■	■	■	■	■	■	■	■		■	
Blow Molding (Inj)	■	■	■	■	■	■	■	■	■	■	■		■	
Rotational Moulding	■	■	■	■	■	■	■	■	■	■	■		■	
Impact Extrusion	■			X				X	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■						X	X	■	X	■	■	■	
Closed Die Forging	■						■			X	X	■	■	
Powder Metal Parts	■						■		X		X	■	■	
Hot Extrusion	■		X	X			X		X	■	■	■	■	
Rotary Swaging	■					X	X		■		■	■	■	
Machining (From Stock)									X	X	X	X	X	Material Removal Processes
ECM					X	X	X	X				■	■	
EDM	X						X	X	X		X	■	■	
Wire EDM	X						X	X	X		X	■	■	Profiling
Sheet Metal (Stamp/bend)	■						X	X	X	X	■	■	■	Sheet Forming Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■		■	
Metal Spinning	■		X					X	X	X	X	■	■	

■ not applicable; □ normal practice; ☒ less common;

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Manufacturing Processes – Machining & The Importance

- Machining is one of the most expensive manufacturing processes.
- Studies have found that the total U.S. expenditures on machining were between $240 to $850 billion dollars in 1998. This was between 3 % and 10 % of the annual U.S. GDP.

References

- R.W. Ivester, M. Kennedy, M. Davies and R. Stevenson, (2000), Assessment of Machining Models: Progress Report, Official contribution of the National Institute of Standards and Technology.
- Ivester, R.; Kennedy, M.; Davies, M.; Stevenson, R.; Thiele, J.; Furness, R.; Athavale, S. Assessment of machining models: Progress report. J. Mach. Sci. Technol. 2000, 4 (3), 511ï 538.
- Ivester, R.; Kennedy, M.; Davies, M.; Stevenson, R.; Thiele, J.; Furness, R.; Athavale, S. Assessment of Machining Models: Progress Report. In Proceedings of the 3rd CIRP International Workshop on Modeling of Machining Operations, Melbourne, Australia, 2000.
- Soons, H.A., Yaniv, S.L., 1995, Precision in machining: research challenges, Gaithersburg, MD: National Institute of Standards and Technology, NISTIR, 5628.

Environmental Impact & Machining Optimisation

- Machining is a major manufacturing operation and it involves a number of sustainability factors, such as CO2 emissions and climate change, that have a big potential for environmental impact and energy consumptions.

- These sustainability factors are:
  - tool life, usage of coolant and lubricant,
  - waste chips and energy consumption.

(I will cover this later at the end of the lecture)

References

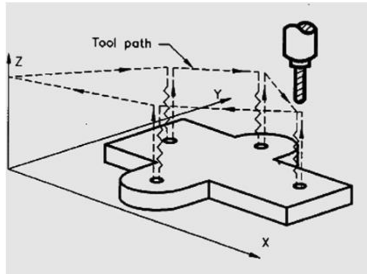
- Alexandru Epureanu, and Virgil Teodor, (2006), On-Line Geometrical Identification of Reconfigurable Machine Tool using Virtual Machining, World Academy of Science, Engineering and Technology 15 2006, pp. 14-18.

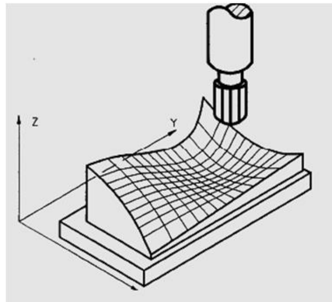
Type of Machining Processes

- Machining processes remove material to form shapes.
- The differences between the various types are the relative motion between cutting tool and workpiece and the type of tool used.
- Typical types can be turning, milling or drilling and they are carried out by machine tools either using manual or automatic (Computer Numerical Control ï CNC) control.
- We only consider CNC machine tools.

CNC Machine Tools Mill , Coordinate System & Motions

Milling is a process of producing flat or complex shapes with the use of a multi-tooth cutting tool. Figure below shows a vertical mill where the machine table is parallel to the ground and is vertical to the cutting tool.

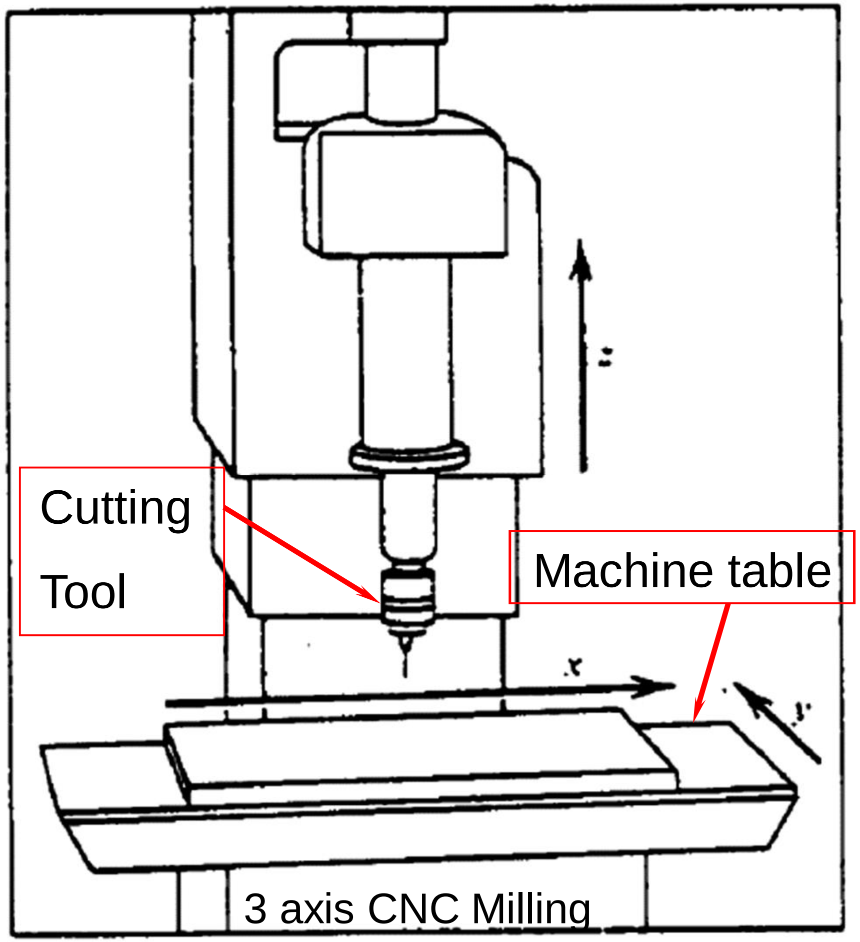




Å Machine table moves in the X and Y direction of feed, perpendicular to the Z axis or the cutting tool.

Å Cutting tool mounted on the Z axis and can move vertically and rotate clockwise or anti-clockwise.

Å The CNC machine can coordinate all three axes to achieve any combination of motion in one, two or three dimensions at once.



CNC Machine Tools Lathe – Turning, Coordinate System & Motions

Turning is the most important machining process and can produce a wide variety of parts.

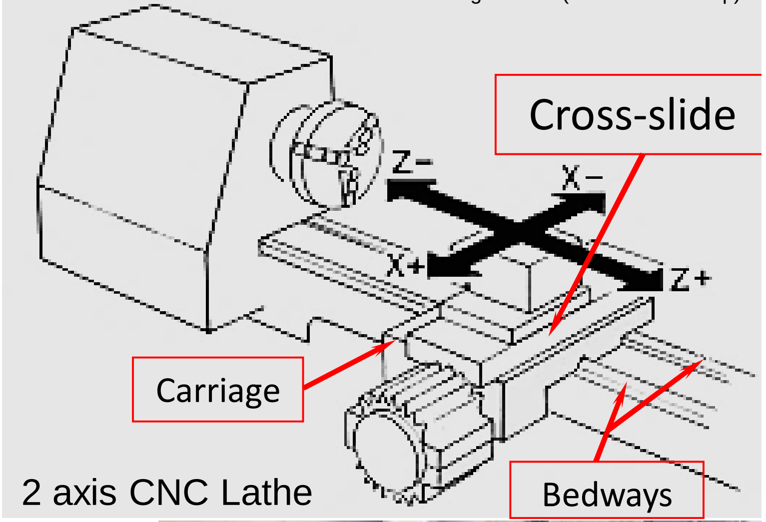
The carriage, or tool-turret-station, travels along the machine's bedways parallel to the workpiece axis, known as the "Z" axis.

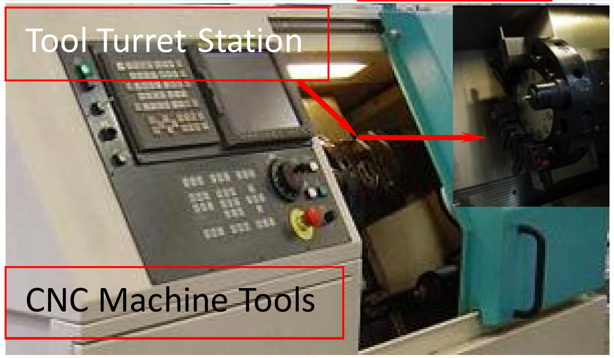
Motion perpendicular to the work is called the "X" axis, provided by the cross-slide mounted on the carriage.

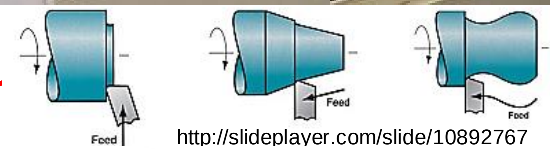
The cutting tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes.

The *primary* motion of cutting in turning is the rotation of the workpiece, and the *secondary* motion of cutting is the feed motion in the Z direction.

The main axes of a lathe or turning center. (Emco Maier Corp)







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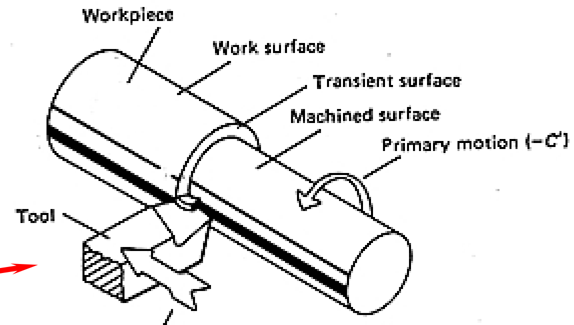


https://personal.egr.uri.edu/vms/ISE%20240/Machining%20Processes-4.pdf

CNC Machine Tools

Å A CNC (computer numerical control) machine consists of three basic components: *Part program*, *Machine Control Unit* and *Machine tool*. It is defined as a machine that is controlled by a set of instructions called ñthe programò

In general CNC machine consists of;

ÅComputer control

ÅServo axis control

ÅTool changers

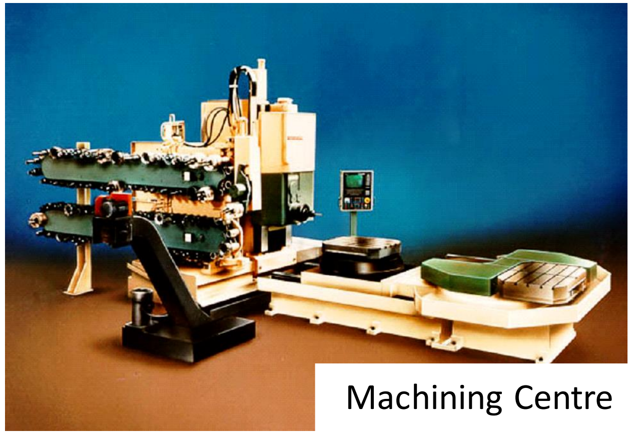
ÅPallet changers

ÅOn-machine programming

ÅData communication

ÅGraphical interface

Turning Centre


Machining Centre

Example of CNC Machines

https://www.youtube.com/watch?v=U6gVVy0xaT4, 20 May 2017, 24 M

Example of Machine Control Unit (MCU)

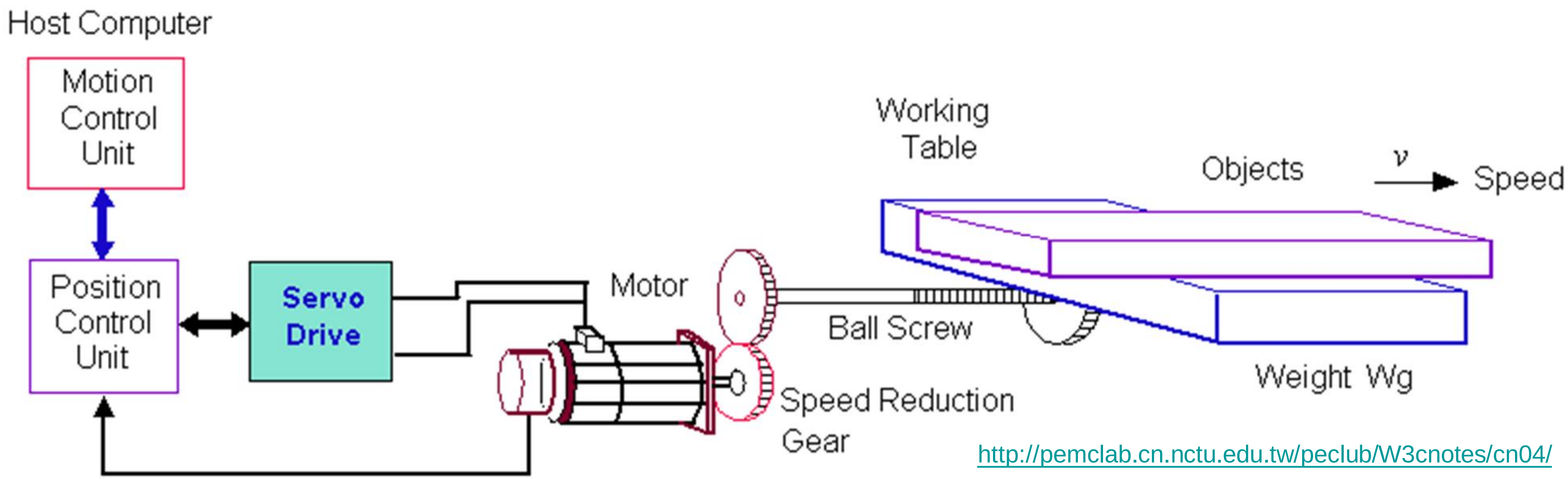
- MCU is a microcomputer that stores the program and executes the commands into actions by the machine tool. The MCU consists of two main units: the data processing unit (DPU) and the control loops unit (CLU).

GE Fanuc 18-T CNC Controller

Siemens CNC Controller

Typical CNC Servo Axis Control

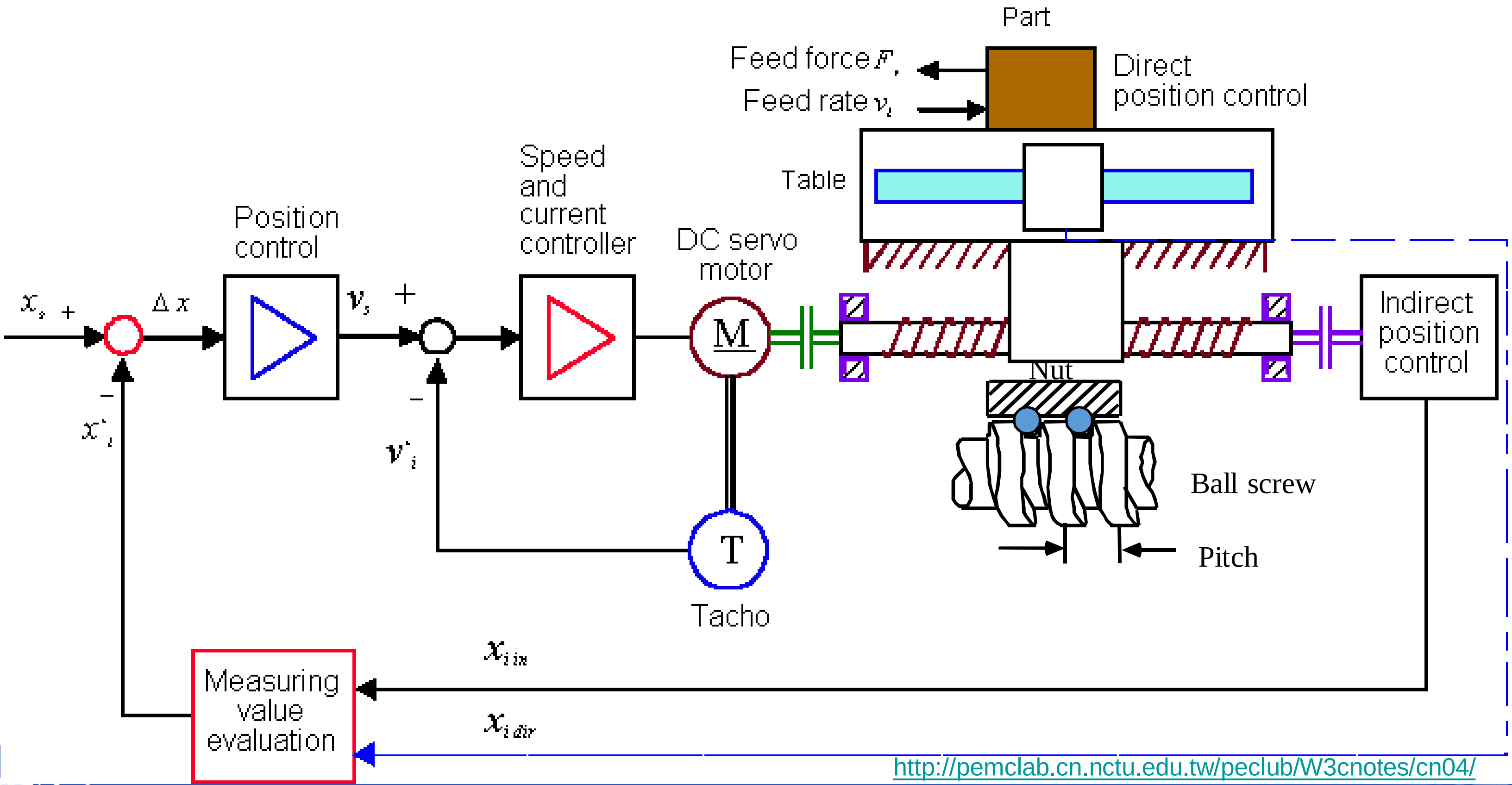
- Modern CNC machines have a servo mechanism with a closed-loop control system capable of accurately determining the position, velocity, and/or acceleration of machine tools axis. A typical motion control system may contain subsystems shown below. The Ball Screw converts the rotational motion of the gear box motor to a linear motion, in this case a table.



http://pemclab.cn.nctu.edu.tw/peclub/W3cnotes/cn04/

Typical Servo Axis Control & BLU (basic length unit)

- The data read into the MCU through the part program defines machine table positions corresponding to the axes of the machine tool. Each axis is equipped with a dc servomotor connected to the table by means of a ball screw, as shown below. The ball screw determines the distance travelled by the table on each revolution of the motor. The CNC resolution is defined as the distance between successive threads of the ball screw called pitch, or BLU (basic-length-unit). BLU is the smallest mechanical step during point-to-point motion.



http://pemclab.cn.nctu.edu.tw/peclub/W3cnotes/cn04/

Machine Control Unit (MCU)

How it works?

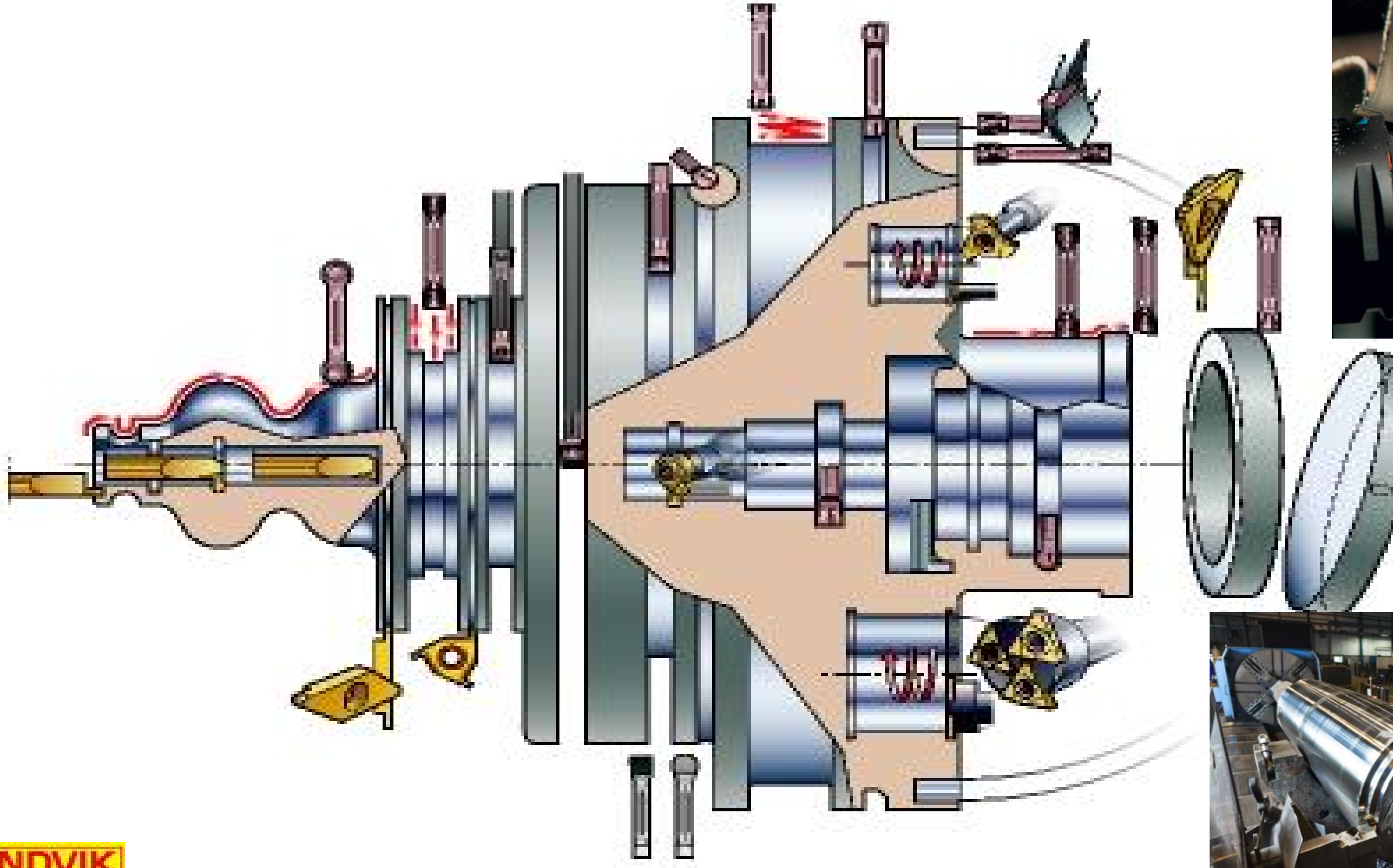
- The DPU (data processing unit) software includes control system software, calculation algorithms, translation software that converts the part program into a usable format for the MCU (control loops unit) and interpolation algorithms to achieve smooth motion of the cutter.

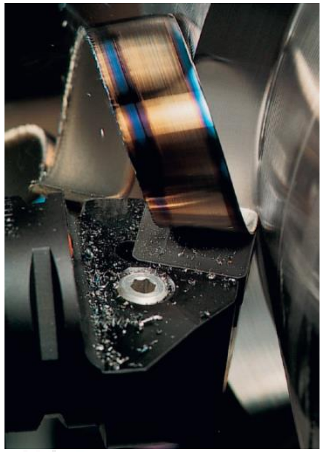
- The DPU processes the data from the part program and provides it to the CLU which operates the drives attached to the machine lead/ball screws and receives feedback signals on the actual position and velocity of each one of the axes. A driver (dc motor) and a feedback device are attached to the lead/ball screw.

- The CLU consists of the circuits for position and velocity control loops, deceleration and backlash take up and function controls, such as spindle on/off. **(Note: this is the most important part of a CNC controller if you are machining free-form or complex shapes, due to not having a constant feedrate).**

CNC Turning Operations – We only considered CNC Lathe

Turning is one of the most common metal cutting operations. The workpiece is rotated about its axis as single-point cutting tools are fed into it, shearing away unwanted material and creating the desired part. Operations can be on both external and internal surfaces to produce an axially-symmetrical contoured part.





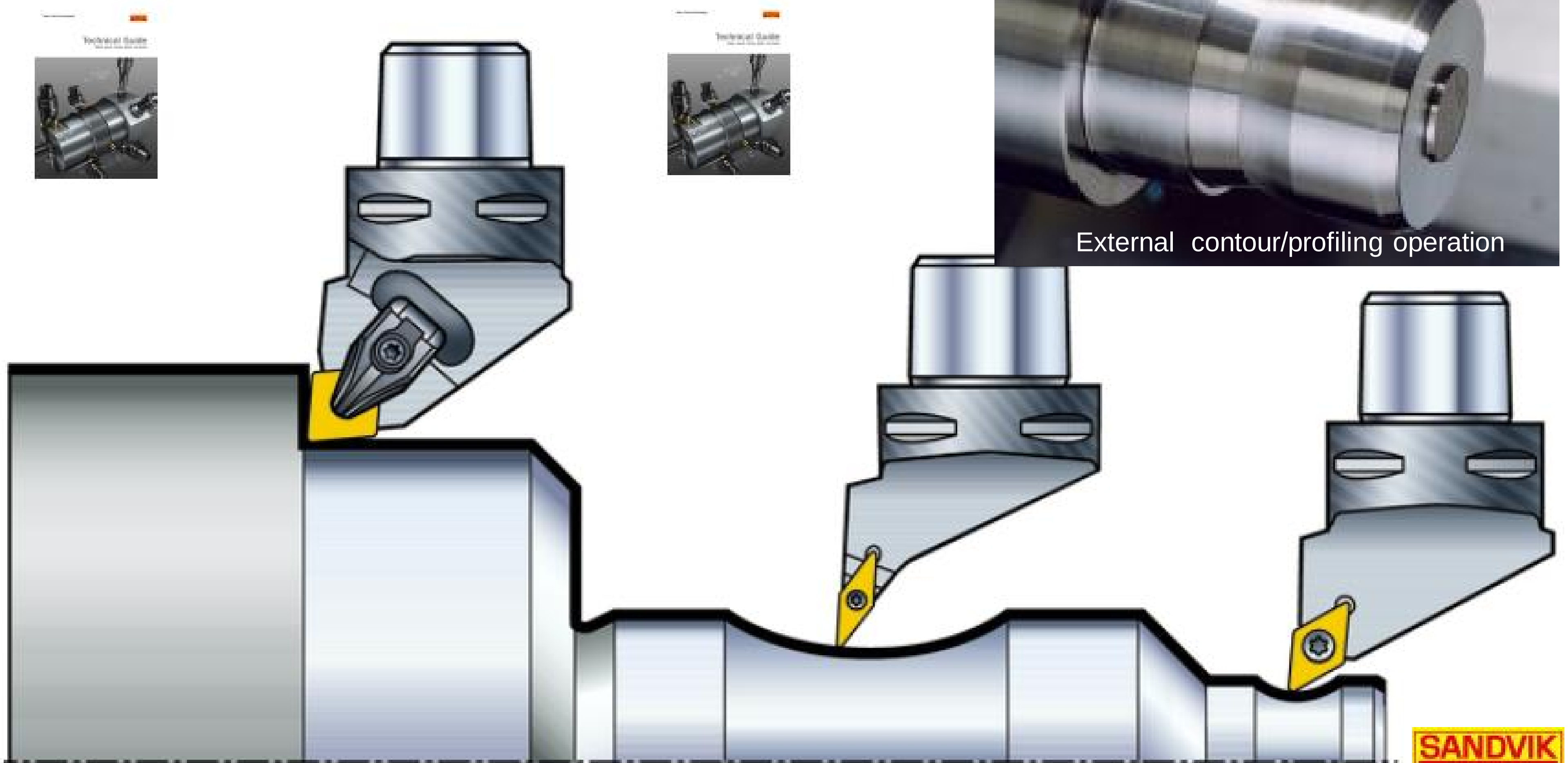
SANDVIK Coromant

http://www.sandvik.coromant.com/en-gb/knowledge/parting_grooving/initial-considerations/pages/default.aspx

CNC External Contour/Profiling in Turning Operations

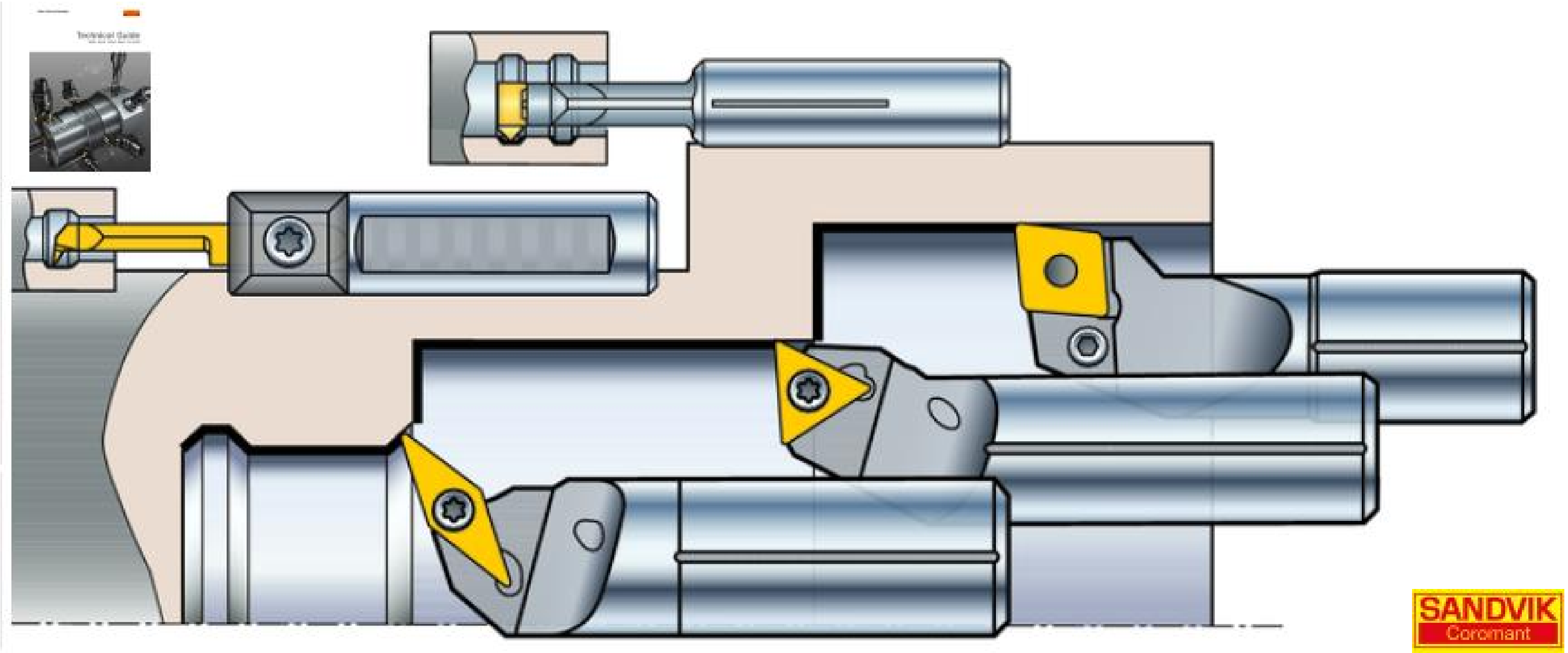
The tool is normally perpendicular to the workpiece and instead of feeding along a straight line parallel to the axis of rotation the tool follows a contour, creating a shape or curve in the turned part.

External contour/profiling operation



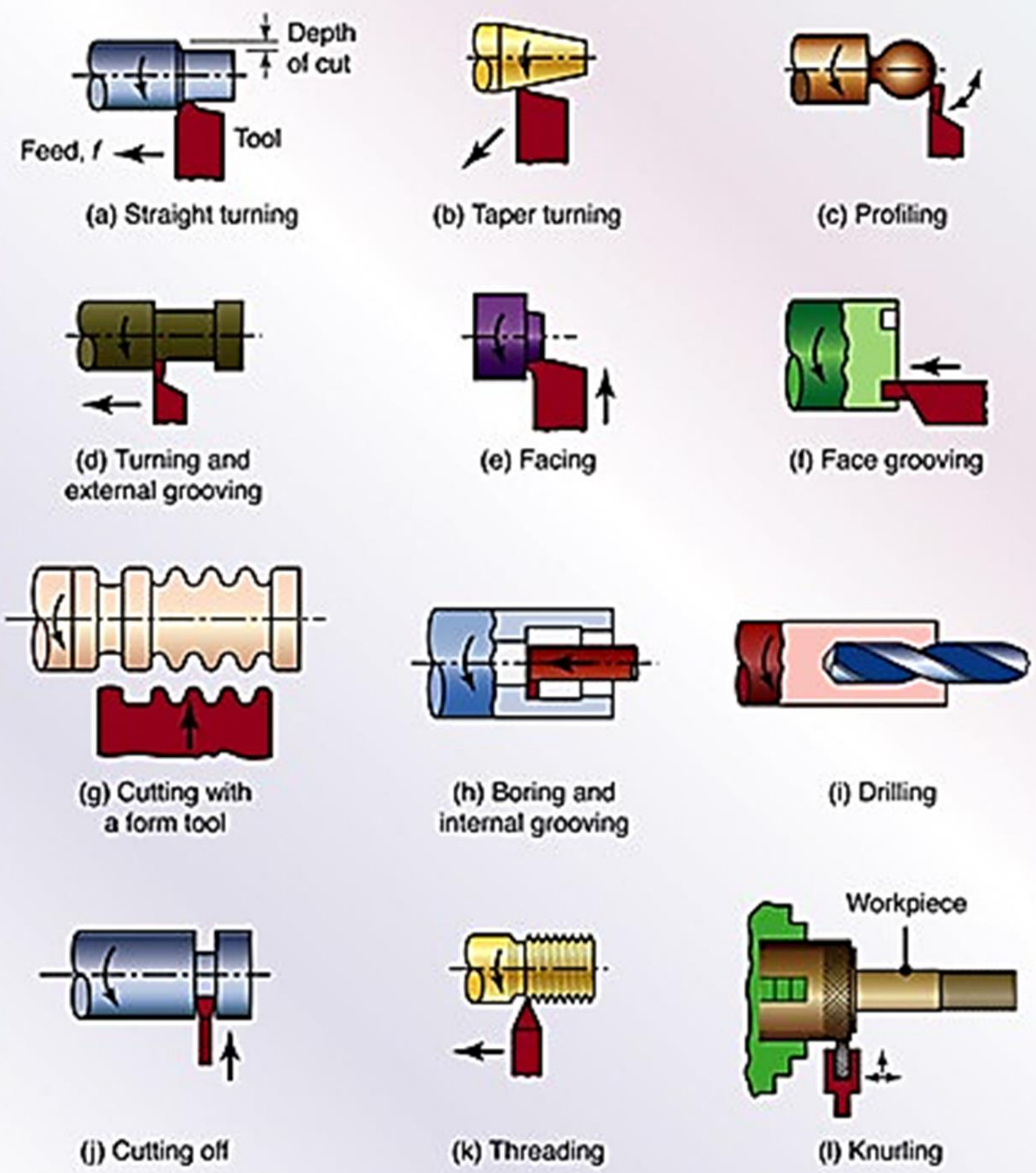
CNC Internal Turning Operations

In an internal operation, the tool is parallel with the axis of rotation:



CNC Turning - Detail of Internal & External Machining

Here are the most common internal and external operations in turning.

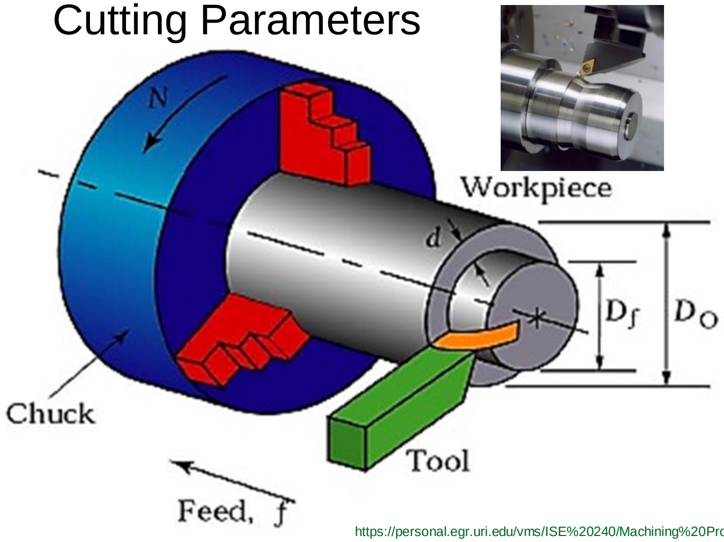


http://slideplayer.com/slide/5783062/

The Key CNC Parameters Effect on Productivity & Part Quality

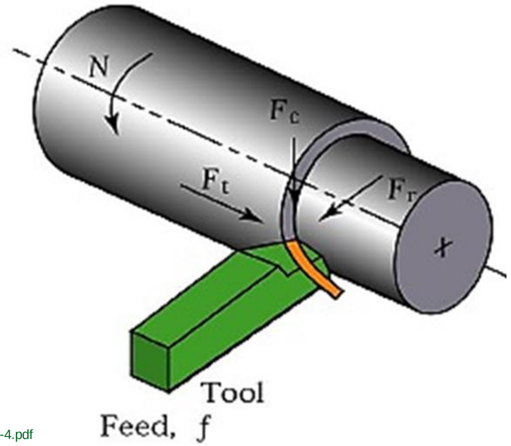
Figures shows basic turning operations: depth of cut (*d*), feedrate (*f*) and spindle rotational speed (*N*) *in rev/min*. These are the three key parameters determining productivity and part quality.

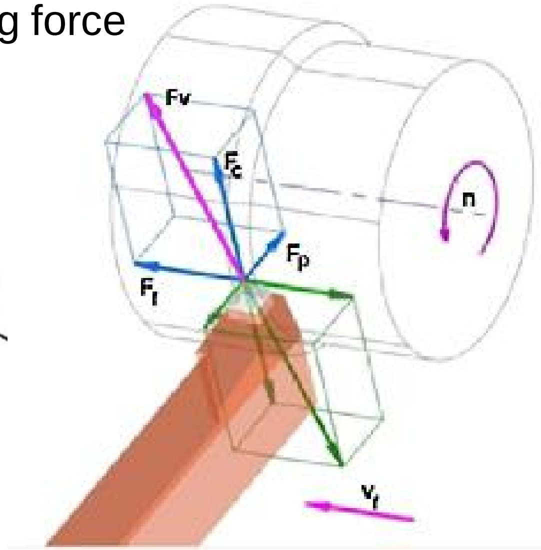
Cutting Parameters



https://personal.egr.uri.edu/vms/ISE%20240/Machining%20Processes-4.pdf

Components of cutting force





http://www.sciencedirect.com/science/article/pii/S2213020915001056

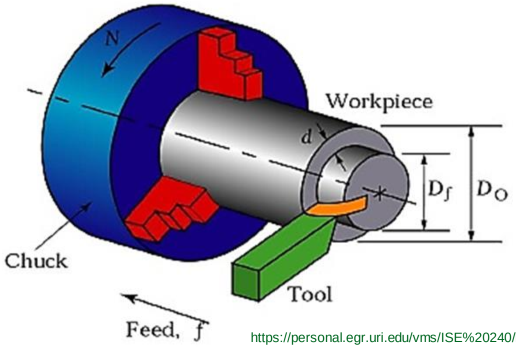
Å**Cutting speed,** *V*c, is the speed of the workpiece as it rotates past the cutting tool.
Å**Feedrate** is the rate at which the tool advances into the workpiece.
Å**Depth of cut** is the amount of material removed as the workpiece revolves on its axis.

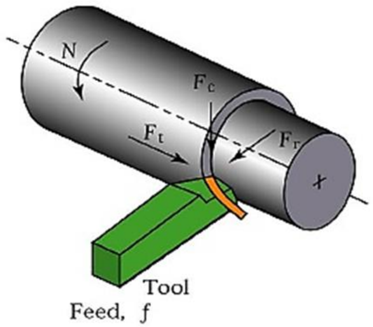
F_x component of cutting force acts perpendicular to the axis of the workpiece expressed as F_p.

F_z component cutting force acts in the direction of feed expressed as F_f .

Å**Other factors** are the type and the geometry of the cutting tool, the angle of the tool to the workpiece, and the overall condition (cutting forces and power of the CNC lathe itself).

Turning Formulae





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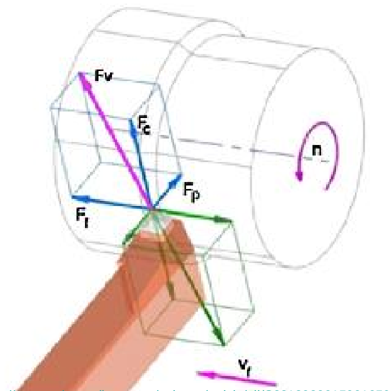

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Cutting speed v_c (m/min)

$$v_c = \frac{D_m \times \pi \times n}{1000}$$

Spindle speed n (rpm)

$$n = \frac{v_c \times 1000}{\pi \times D_m}$$

Metal removal rate Q (cm^3/min)

$$Q = v_c \times a_p \times f_n$$

Net power P_c (kW)

$$P_c = \frac{v_c \times a_p \times f_n \times k_c}{60 \times 10^3}$$

Machining time T_c (min)

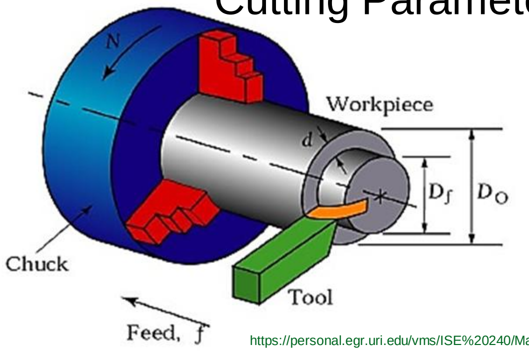
$$T_c = \frac{l_m}{f_n \times n}$$

Symbol	Designation/defination	Unit
D_m	Machined diameter mm (inch)	mm (inch)
f_n	Feed per revolution	mm/r (inch/r)
a_p	Cutting depth	mm (inch)
n	Spindle speed	rpm
P_c	Net power	kW (HP)
Q	Metal removal rate	cm^3/min (inch^3/min)
h_m	Average chip thickness	mm (inch)
h_{ex}	Maximum chip thickness	mm (inch)
T_c	Period of engagement	min
l_m	Machined length	mm (inch)
k_c	Specific cutting force	N/mm^2 (N/inch^2)
KAPR	Entering angle	degree
PSIR	Lead angle	degree

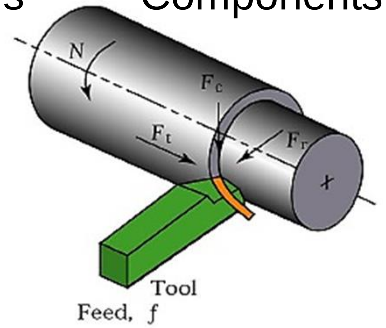
http://www.sandvik.coromant.com/en-gb/knowledge/general_turning/formulas-and-definitions/pages/default.aspx?Country=gb

Turning Cutting Parameters

Cutting Parameters



Components of cutting force



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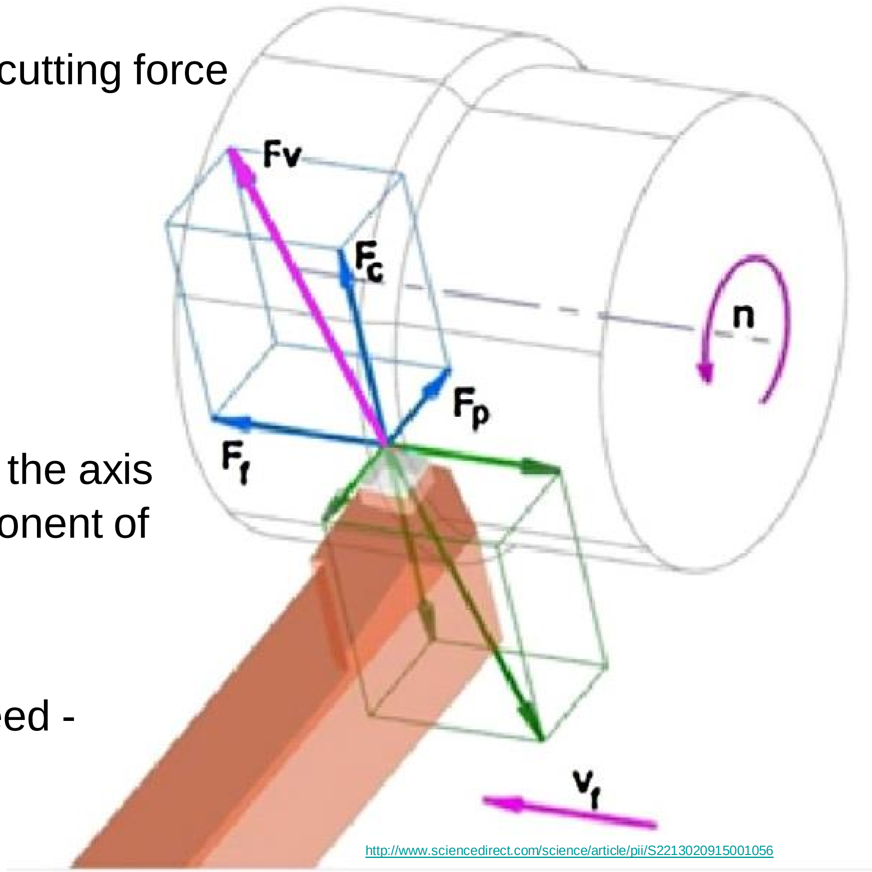

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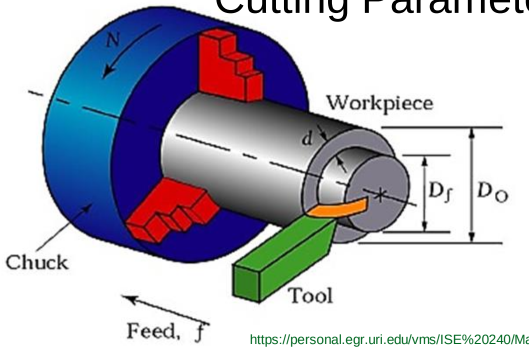
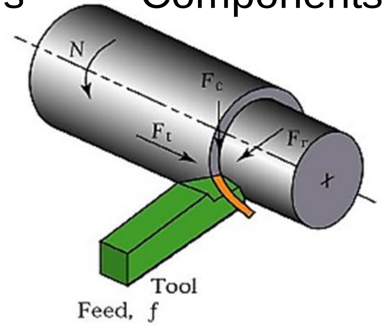
F_x component of cutting force acts perpendicular to the axis of the workpiece - expressing radial (passive) component of cutting force F_p.

F_z component cutting force acts in the direction of feed - expressing feed component of cutting force F_f.

Turning Cutting Parameters

Cutting Parameters Components of cutting force





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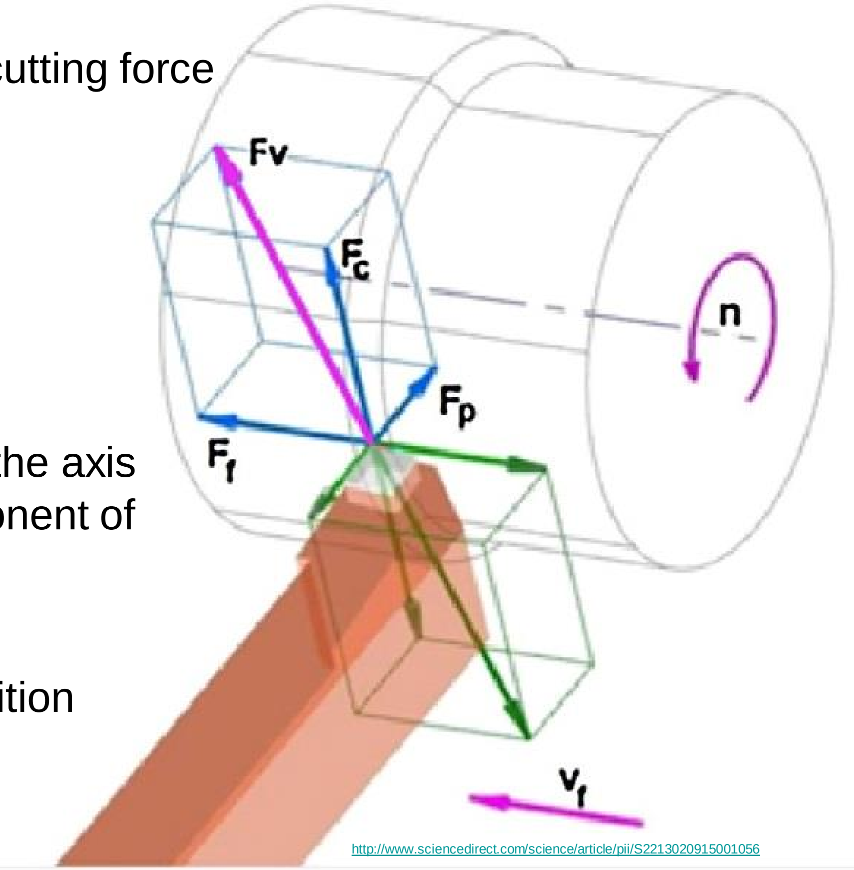

http://www.sciencedirect.com/science/article/pii/S2213020915001056

F_x component of cutting force acts perpendicular to the axis of the workpiece - expressing radial (passive) component of cutting force F_p.

F_p greatly affects dimensional accuracy of machined surfaces, the geometric deviations of shape and position and surface roughness of the machined surface.

F_y component of cutting force acts tangentially expressing cutting component of cutting force F_c.

F_c is the basis for determining the limiting conditions in the choice of cutting parameters. Specifies the required power and the total amount of heat in the cutting zone.

F_z component cutting force acts in the direction of feed - expressing feed component of cutting force F_f.

F_f is used in the dimensioning traverse mechanisms.

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CNC Machine Turning Tools

- Images below show turning operations and the chip formation at the tool tip, insert & tool holder.
- **For productivity and quality of surface finish, selection of cutting tools are very important.** The type and the geometry of the cutting tool, the angle of the tool to the work and the overall condition and power of the CNC lathe itself should be considered.

https://www.youtube.com/watch?v=S68mI0xtrRU, 3.45 M

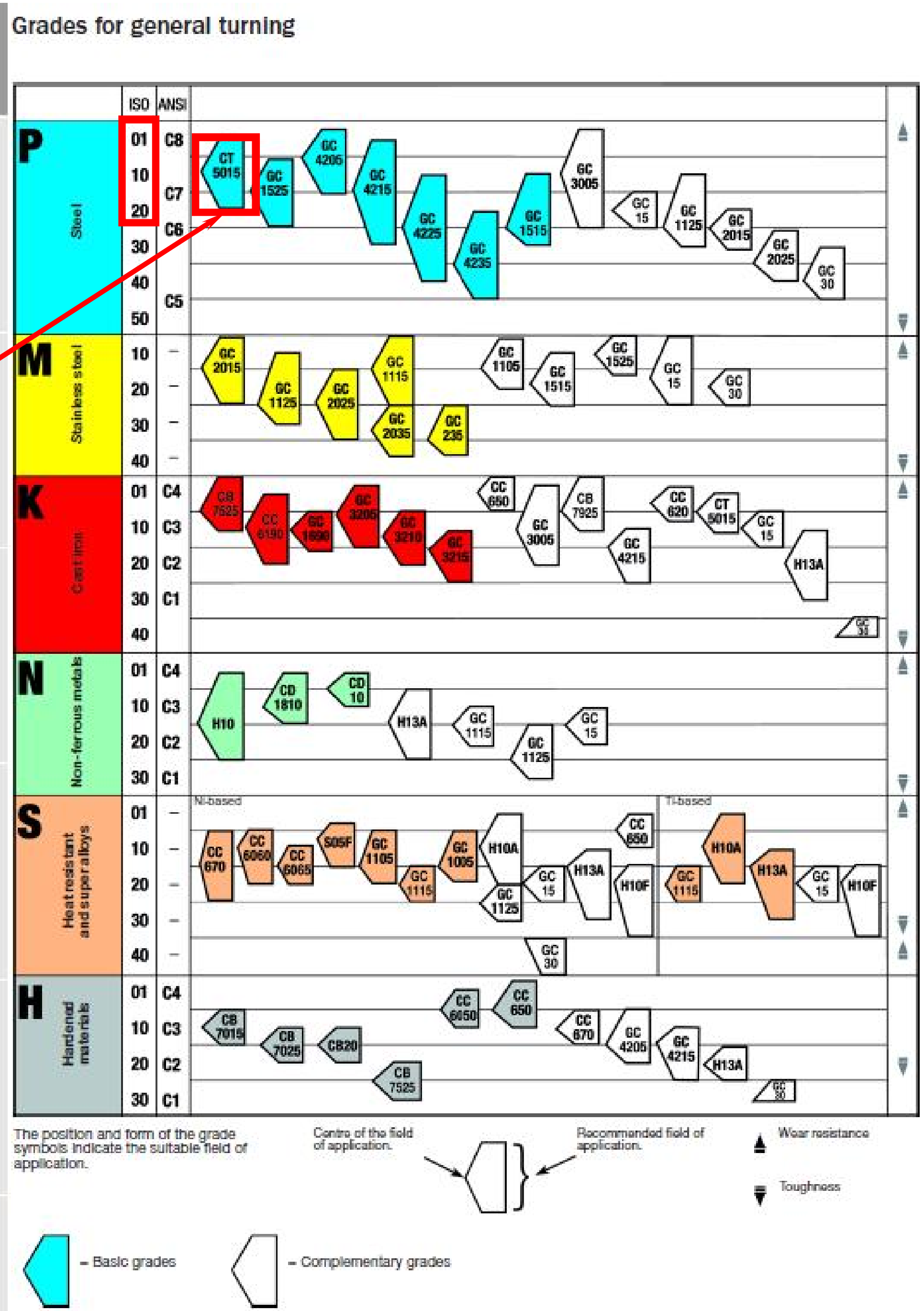
http://www.sandvik.coromant.com/sitecollectiondocuments/downloads/global/catalogues/en-gb/turning/turn_a.pdf

CNC Cutting Tool Selection

- Huge selection of cutting tools from SANDVIC catalogue are available for steel, stainless steel, cast iron, non-ferrous metals, heat-resistant and super alloys and hardened materials.

  - For example CT5015 (HT) ï P10 (P01-20)

An uncoated cermet with excellent resistance to built-up-edge and plastic deformation. Used for finishing low alloy and alloy steel when high surface quality and /or low cutting force is required.



http://www.sandvik.coromant.com/sitecollectiondocuments/downloads/global/catalogues/en-gb/t`urning/turn_a.pdf

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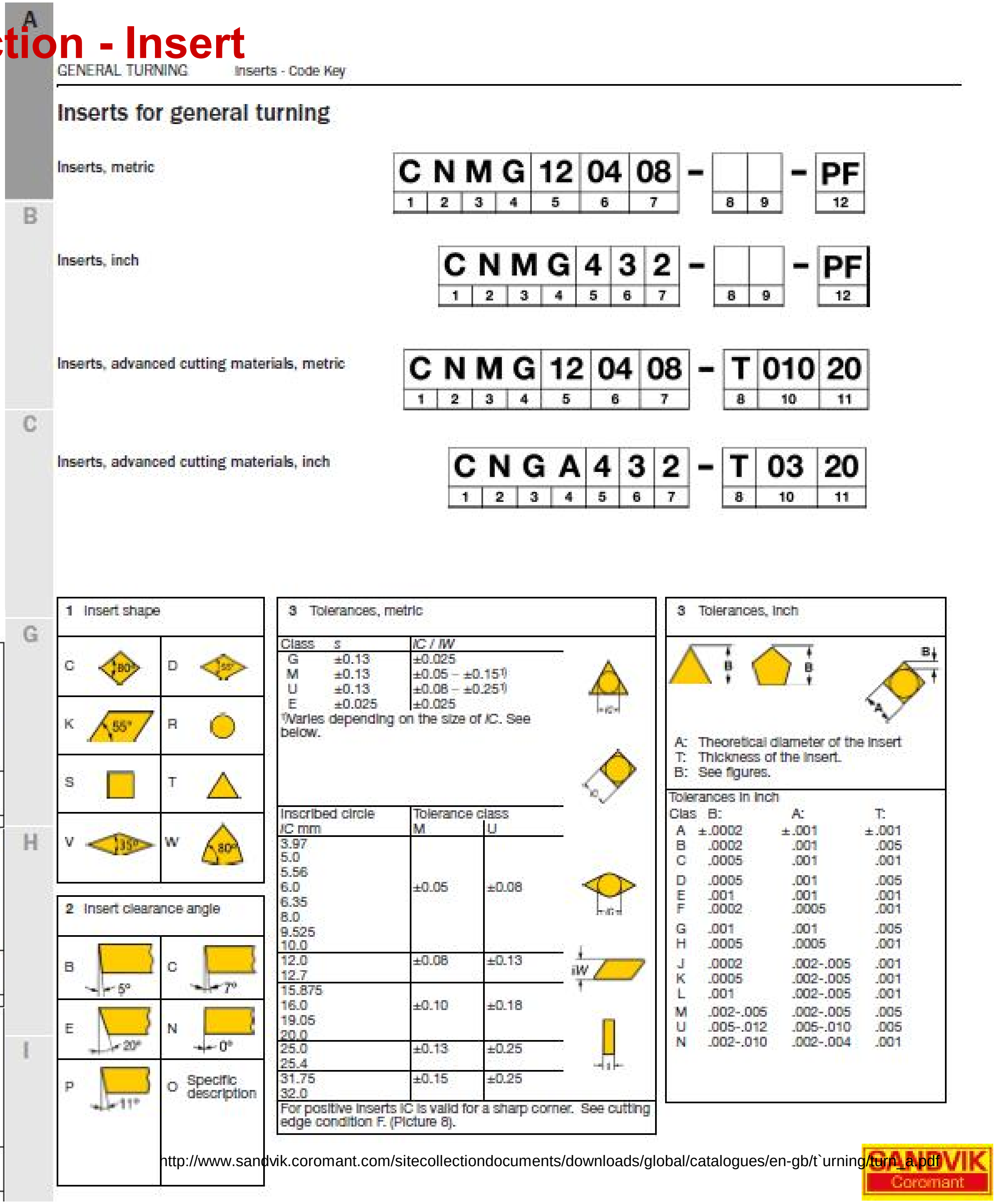
CNC Cutting Tool Selection - Insert

- Huge selection of inserts and tool holders are available. These are from SANDVIK catalogue.



A
GENERAL TURNING   Inserts - Code Key

Inserts for general turning

Inserts, metric: C N M G 12 04 08 – [8] [9] – PF (positions 1 2 3 4 5 6 7 – 8 9 – 12)

Inserts, inch: C N M G 4 3 2 – [8] [9] – PF (positions 1 2 3 4 5 6 7 – 8 9 – 12)

Inserts, advanced cutting materials, metric: C N M G 12 04 08 – T 010 20 (positions 1 2 3 4 5 6 7 – 8 10 11)

Inserts, advanced cutting materials, inch: C N G A 4 3 2 – T 03 20 (positions 1 2 3 4 5 6 7 – 8 10 11)

B C G H I

1 Insert shape

C	80°	D	55°
K	55°	R	
S		T	
V	35°	W	80°

2 Insert clearance angle

B	5°	C	7°
E	20°	N	0°
P	11°	O	Specific description

3 Tolerances, metric

Class	s	IC / IW
G	±0.13	±0.025
M	±0.13	±0.05 – ±0.15[1]
U	±0.13	±0.08 – ±0.25[1]
E	±0.025	±0.025

[1]Varies depending on the size of IC. See below.

Inscribed circle IC mm	Tolerance class M	U
3.97, 5.0, 5.56, 6.0, 6.35, 8.0, 9.525, 10.0	±0.05	±0.08
12.0, 12.7	±0.08	±0.13
15.875, 16.0, 19.05, 20.0	±0.10	±0.18
25.0, 25.4	±0.13	±0.25
31.75, 32.0	±0.15	±0.25

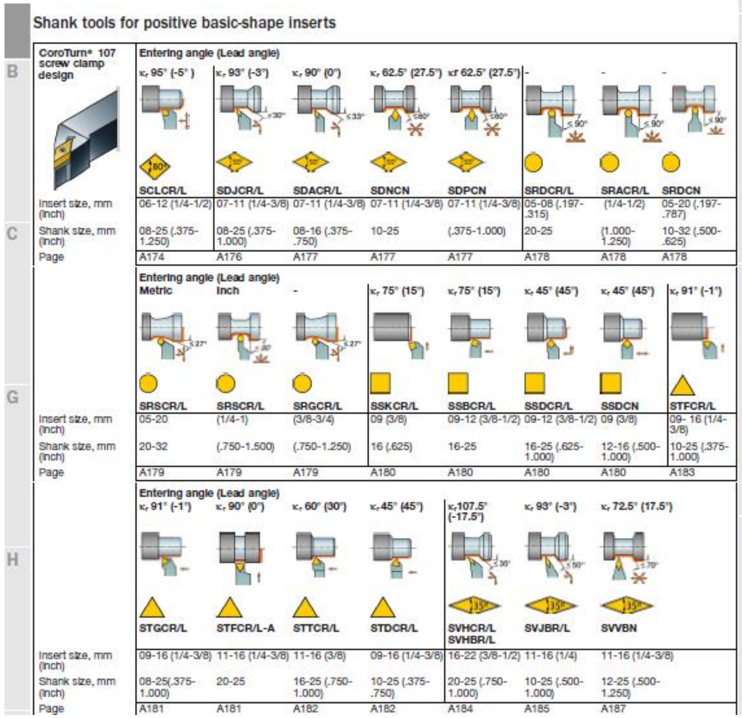
For positive inserts IC is valid for a sharp corner. See cutting edge condition F. (Picture 8).

3 Tolerances, inch

A: Theoretical diameter of the insert
T: Thickness of the insert.
B: See figures.

Tolerances in inch

Clas	B:	A:	T:
A	±.0002	±.001	±.001
B	.0002	.001	.005
C	.0005	.001	.001
D	.0005	.001	.005
E	.001	.001	.001
F	.0002	.0005	.001
G	.001	.001	.005
H	.0005	.0005	.001
J	.0002	.002-.005	.001
K	.0005	.002-.005	.001
L	.001	.002-.005	.001
M	.002-.005	.002-.005	.005
U	.005-.012	.005-.010	.005
N	.002-.010	.002-.004	.001



Shank tools for positive basic-shape inserts

CoroTurn® 107 screw clamp design

Entering angle (Lead angle)	κr 95° (-5°)	κr 93° (-3°)	κr 90° (0°)	κr 62.5° (27.5°)	κr 62.5° (27.5°)	-	-	-
	SCLCR/L	SDJCR/L	SDACR/L	SDNCN	SDPCN	SRDCR/L	SRACR/L	SRDCN
Insert size, mm (inch)	06-12 (1/4-1/2)	07-11 (1/4-3/8)	07-11 (1/4-3/8)	07-11 (1/4-3/8)	07-11 (1/4-3/8)	05-08 (.197-.315)	(1/4-1/2)	05-20 (.197-.787)
Shank size, mm (inch)	08-25 (.375-1.250)	08-25 (.375-1.000)	08-16 (.375-.750)	10-25	(.375-1.000)	20-25	(1.000-1.250)	10-32 (.500-.625)
Page	A174	A176	A177	A177	A177	A178	A178	A178

Entering angle (Lead angle)	Metric	Inch	-	κr 75° (15°)	κr 75° (15°)	κr 45° (45°)	κr 45° (45°)	κr 91° (-1°)
	SRSCR/L	SRSCR/L	SRGCR/L	SSKCR/L	SSBCR/L	SSDCR/L	SSDCN	STFCR/L
Insert size, mm (inch)	05-20	(1/4-1)	(3/8-3/4)	09 (3/8)	09-12 (3/8-1/2)	09-12 (3/8-1/2)	09 (3/8)	09-16 (1/4-3/8)
Shank size, mm (inch)	20-32	(.750-1.500)	(.750-1.250)	16 (.625)	16-25	16-25 (.625-1.000)	12-16 (.500-1.000)	10-25 (.375-1.000)
Page	A179	A179	A179	A180	A180	A180	A180	A183

Entering angle (Lead angle)	κr 91° (-1°)	κr 90° (0°)	κr 60° (30°)	κr 45° (45°)	κr 107.5° (-17.5°)	κr 93° (-3°)	κr 72.5° (17.5°)
	STGCR/L	STFCR/L-A	STTCR/L	STDCR/L	SVHCR/L SVHBR/L	SVJBR/L	SVVBN
Insert size, mm (inch)	09-16 (1/4-3/8)	11-16 (1/4-3/8)	11-16 (3/8)	09-16 (1/4-3/8)	16-22 (3/8-1/2)	11-16 (1/4)	11-16 (1/4-3/8)
Shank size, mm (inch)	08-25(.375-1.000)	20-25	16-25 (.750-1.000)	10-25 (.375-.750)	20-25 (.750-1.000)	10-25 (.500-1.000)	12-25 (.500-1.250)
Page	A181	A181	A182	A182	A184	A185	A187

http://www.sandvik.coromant.com/sitecollectiondocuments/downloads/global/catalogues/en-gb/turning/turn_a.pdf

SANDVIK Coromant

Recap: Virtual Workpiece and Cutting Tools (step 9)

- Normally virtual models of the workpiece and cutting tools have to be developed based on the features, shape and size of the part design and stored in the workpiece and toolset database.
- Therefore, availability & applications of the cutting tools should be considered when designing the part.

References

- Yingxue Yao, Hang Zhao, Jianguang Li and Zhejun Yuan, (2006), Modeling of virtual workpiece with machining errors representation in turning, Journal of Materials Processing Technology 172, 437ï 444.
- http://www.sandvik.coromant.com/sandvik/8200/Coromant/Internet/IN01028.nsf/GenerateTopFrameset?ReadForm&menu=&view=http%3A//www.sandvik.coromant.com/sandvik/8200/coromant/internet/in01030.nsf/NAUnique/C1256AB1003B5597C1257443004C909F%3FOpenDocument&banner=/sandvik/8200/Coromant/Internet/IN01028.nsf/LookupAdm/BannerForm%3FOpenDocument [accessed Jan. 6, 2011].
- For cutting tool coding and classification, refer to Technical Data last section of Modern Metal cutting - A Practical Handbook, A B Sandvik Coromant, (1994).

Recap: Machining Optimisation & Environmental Impact

- **Machining** is a **major manufacturing operation** and it involves a number of **sustainability factors** that have a **big potential** for **environmental impact** and **energy consumptions.**

- These **sustainability factors** include **tool life**, **usage of coolant** and **lubricant**, **waste chips** and **energy consumption**. Therefore *the analyses of machining systems and optimization of these input factors (controls and constraints) and outputs (objective functions) has significant implications for sustainable manufacturing*.

References

- Tool monitoring and adaptive control software; https://www.youtube.com/watch?v=OckbBuMPT24 [accessed Nov. 24, 2017], 2.42M

Sustainability and Virtual Machining Methodology

Adaptive Machining

Initial input data
- Spindle Speed
- Feed Rate
- Depth of Cut

→ Control Units → Driving Units (Servo) → Machining (Machine Tool) →

Sensors
- Tool wear
- Tool deflection
- Torque (Cutting Resistance)
- Vibration
- Cutting Temperature
- Accuracy
- Surface Roughness

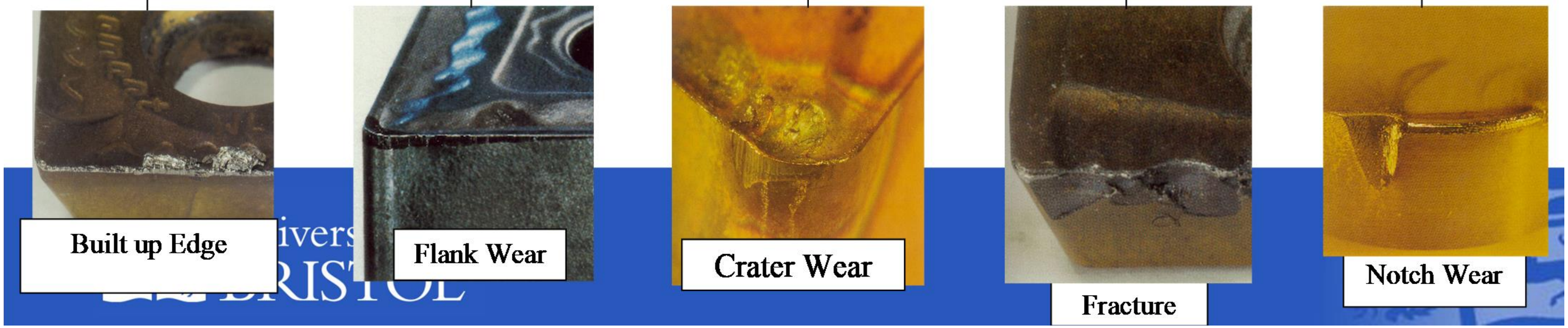
AC Machinability Program

Optimisation Analysis by Computer

Goal Function	*Constraints*
Production Rate	> Allowable Machining Conditions
Production Cost	> Allowable Machine Power
Profit Rate	> Allowable Tool Deflection
Accuracy	> Allowable Surface Roughness
Machining Power	> Allowable Chatter
	> Allowable Errors

Corrected Machining Conditions
- Spindle Speed
- Feed Rate
- Depth of Cut

Conditions of Tool Insert



Recap: Sustainability and Virtual Machining

- Machining is one of the most expensive manufacturing processes. Studies have found that total U.S. expenditures on machining were between $240 to $850 billion dollars in 1998. This was between 3 % and 10 % of the annual U.S. GDP
- A virtual machining methodology can be analysed for environmental impact such as CO2 emissions and climate change with the following objectives:
- Feed rate optimization to maintain constant cutting force
- Optimised NC Program
- Models of Virtual Workpiece and Cutting Tools
- Machining errors and sources of variability

References

- Alexandru Epureanu, and Virgil Teodor, (2006), On-Line Geometrical Identification of Reconfigurable Machine Tool using Virtual Machining, World Academy of Science, Engineering and Technology 15 2006, pp. 14-18.

Recap: Assignment – Videos from Wheel Set Machining

Å https://www.youtube.com/watch?v=ZePkpfXWusw, 5.0 M

Å https://www.youtube.com/watch?v=uRqeKL5VsjI, 2.42 M

Å https://www.youtube.com/watch?v=2clkuzK_Aqs , 2.46M

Learning Outcomes from Machining

- **In general, you will learn and practice the following important principles:**

- Set up the job where the workpiece, stock and machines, (with their machine coordinate system (MCS)) are defined.

- Identify the operational sequences required to produce a spinning top's features.

- Identify cutting tools and order of use, corresponding to the sequence of operations.

- Analyse the machining operations and relationship between the part geometry, cutting tool and machining strategy, to highlight inherent design problems with your spinning top design and possible solutions using dynamic visualization of virtual machining.

- Create the tool-path coordinates and CL DATA file.

- Create a CNC program using a post-processor.

- Shop-floor machining.

Design for Machining _ CNC Machining

Any questions?