COMPUTER NUMERICAL CONTROL OF MACHINE TOOLS

Laboratory for Manufacturing Systems and Automation
Department of Mechanical Engineering and Aeronautics
University of Patras, Greece

Dr. Dimitris Mourtzis

Associate professor

Patras, 2016

Chapter 4:
Tool Changing and Tool Registers

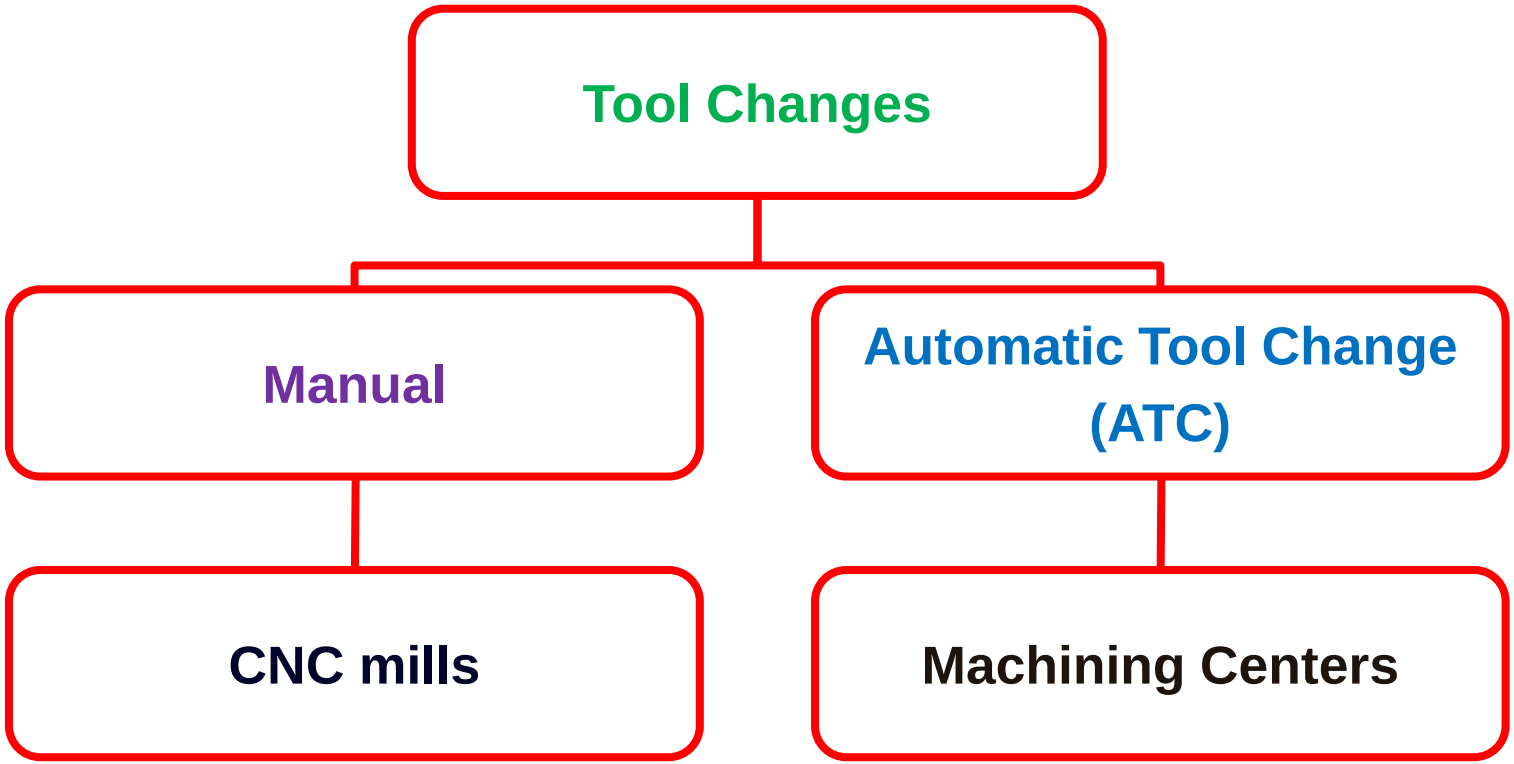
Objectives of Chapter 4

- Explain why the **speed**, **repeatability**, and **accuracy** of tool changing are important factors in numerical control
- Name the two types of **tool changes**
- Explain why **quick-change tooling** is used on NC mills
- Explain how tooling is used in automatic tool change functions
- Name the **five types of automatic tool changers** and briefly describe the operation of each
- Describe the two basic methods of **tool storage**
- Explain what **tool registers** are and what they are used for
- Describe what **tool offset length** is and how it is determined
- Explain **how tool offsets may be entered by the operator** during setup and how the programmer allows for this

Tool Changing and Tool Registers

Tool Changes

There are two types of tool changes:



Tool Changing and Tool Registers

Tool Changes:

It is the tool changing capability that separates the CNC Machining Center from the CNC Milling machines

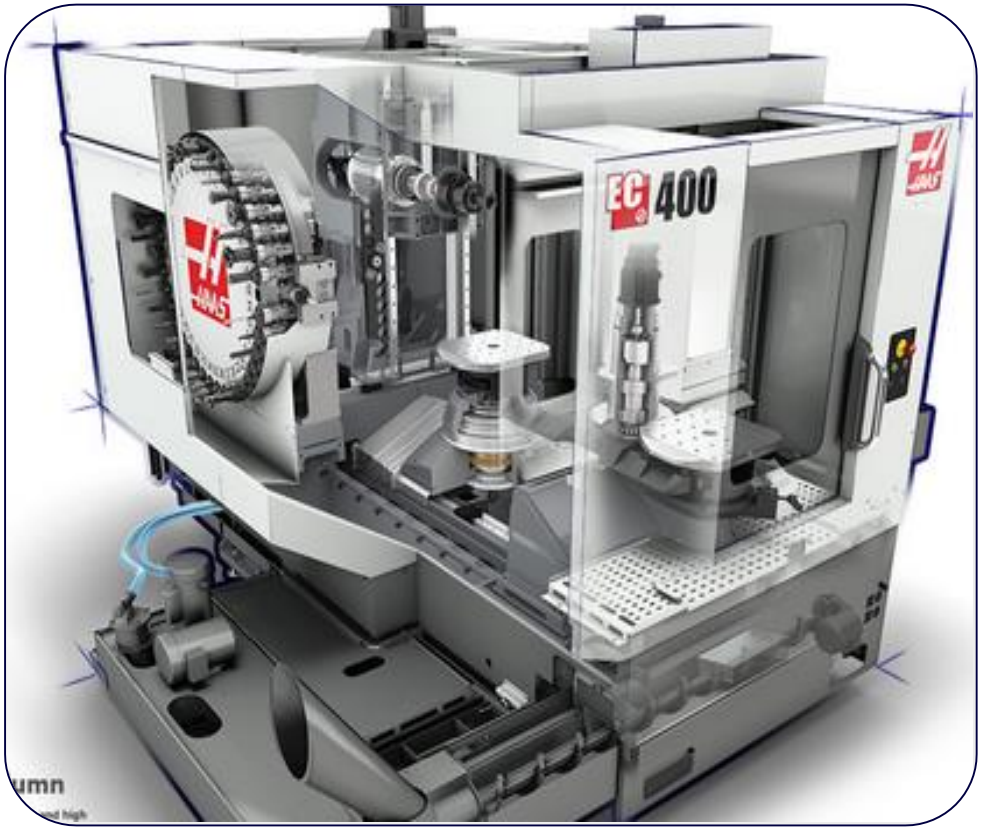
- **Machining Centers** like **milling machines** have the capability to do **numerous machining operations** (drilling, tapping, milling etc)

- This is opposed to a machine capable of a **single function only** such as an **NC drilling machine**

Tool Changing and Tool Registers

FIGURE 4-1:A vertical spindle CNC milling machine
(Photo courtesy of GSM CNC CO.)

Tool Changing and Tool Registers



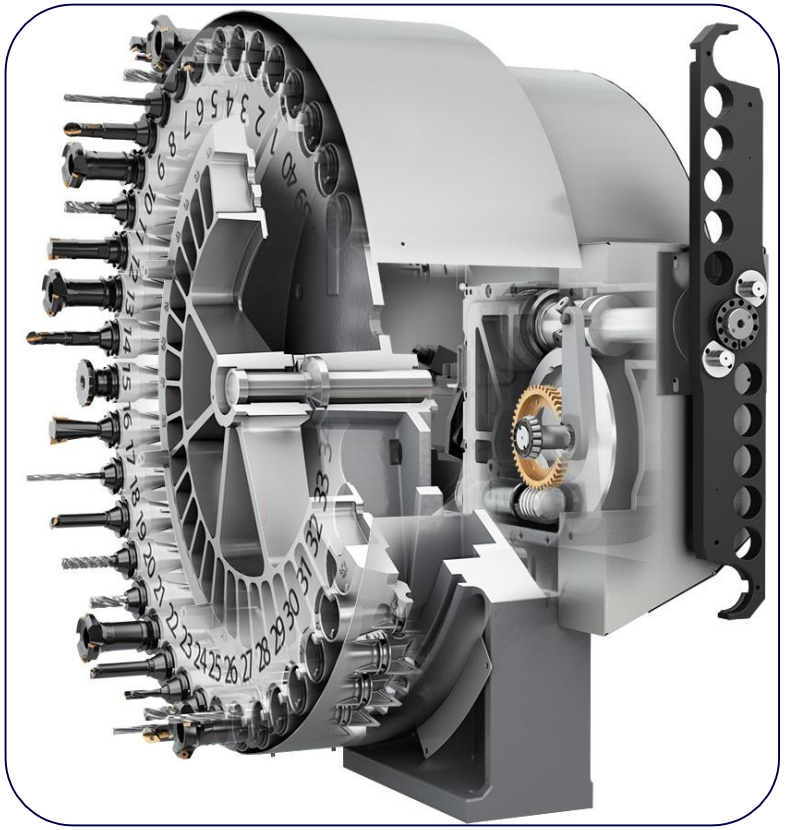


FIGURE 4-2: A Horizontal CNC machining center employing automatic tool change
(Photo courtesy ©Haas Automation, Inc.)

- **Note the pivot insertion tool changer on the side**
- **Tools are stored in a matrix magazine**
- **Safety guards have been removed for clarity**

Tool Changing and Tool Registers

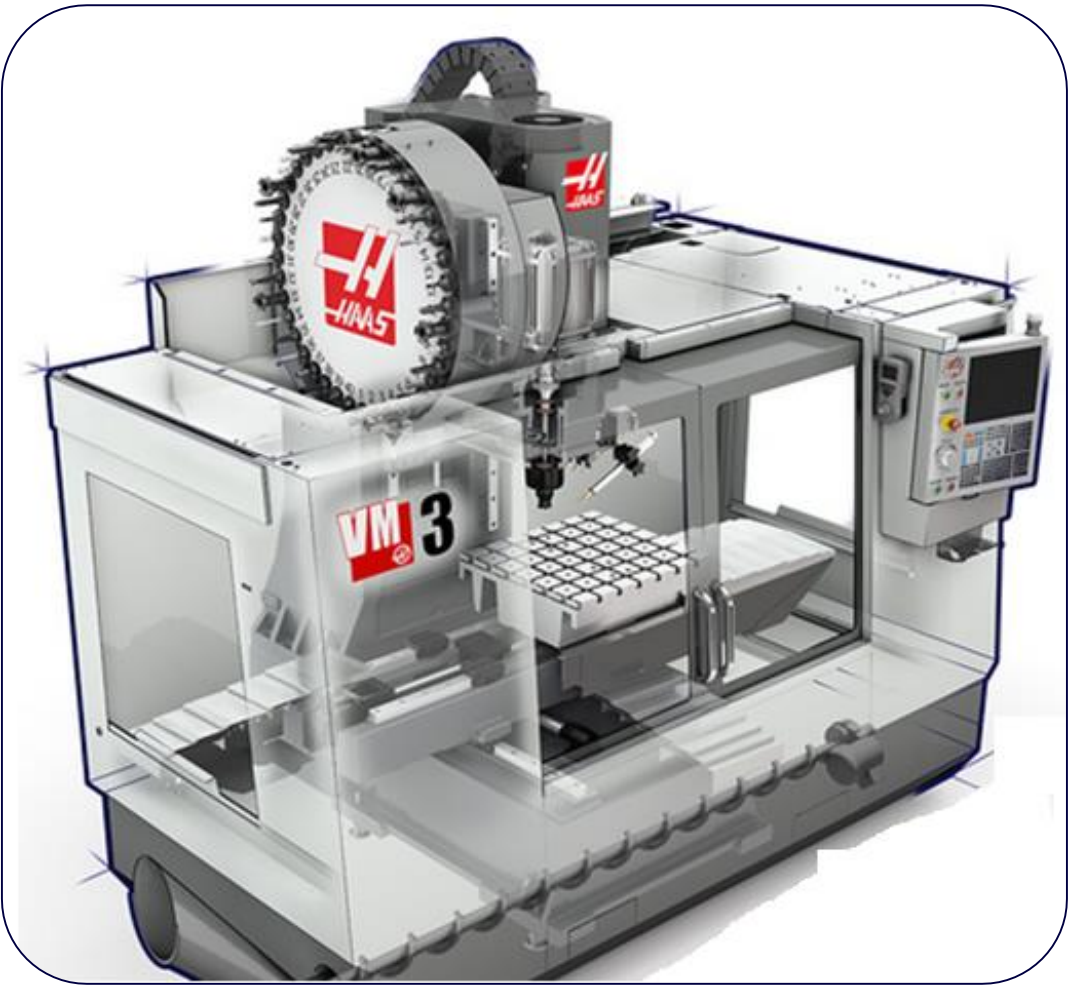
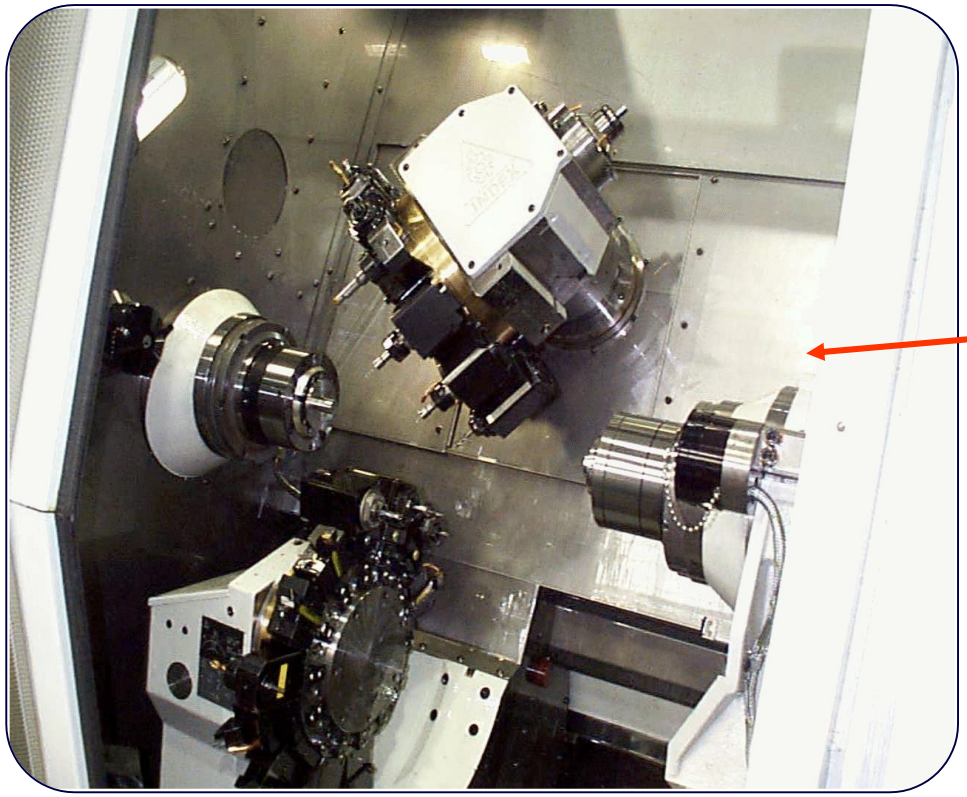


FIGURE 4-3: A Vertical CNC machining center employing automatic tool change

(Photo courtesy ©Haas Automation, Inc.)

Tool Changing and Tool Registers



Special 9-axis control mill/turn lathe and gas turbine fuel nozzle machined

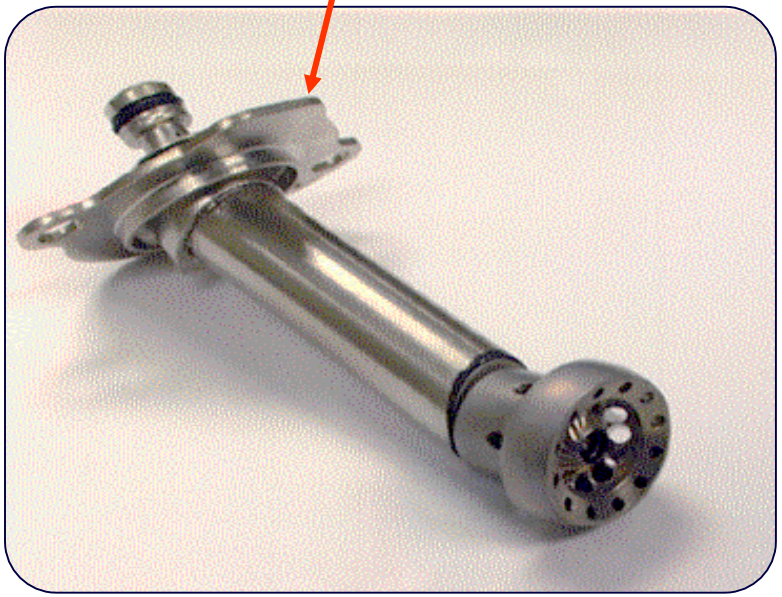


FIGURE 4-4:9-axis control mill/turn lathe 2 spindles, 2 turrets; 28 tool positions,1 milling head,6 tool changer (Photo courtesy of Pratt & Whitney, Canada)

Tool Changing and Tool Registers

Tooling for Manual Tool Change:

What is to be gained by the speed with which a CNC machine can position itself for hole drilling if the tool changes are so lengthy as to cancel the time and accuracy gained by using NC?

Tool changing greatly influences the efficiency of NC so tool changes should take place as quickly and safety as possible

- The **tool must be accurate located in the spindle** to assure proper machining of the workpiece
- **The tool must be located as accurately** as possible in the **same location**
- **The tool must be located in the same relationship to the workpiece** each time is inserted to the spindle

This is known as the **repeatability of a tool** – the ability to locate or repeat its position in the spindle each time it is used

Seams W., "Computer Numerical Control, Concepts & Programming"

Tool Changing and Tool Registers

Tooling for Manual Tool Change

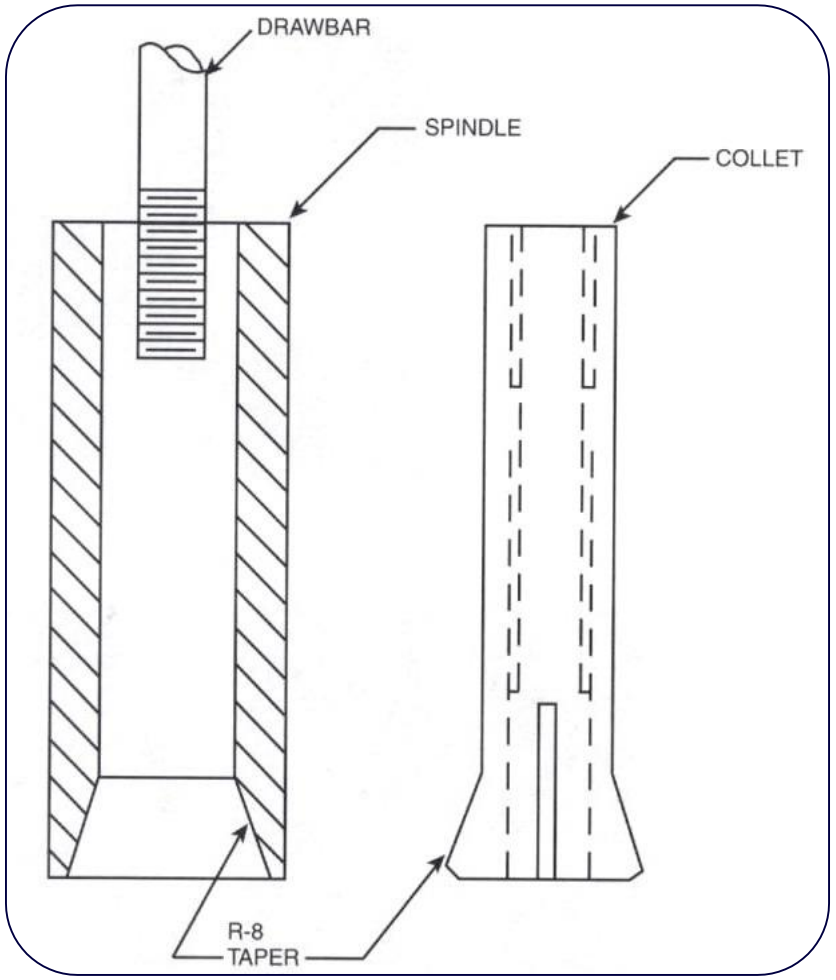


FIGURE 4-5: R-8 spindle and collet

Seams W., "Computer Numerical Control, Concepts & Programming"

- Usually NC mills **(manual tool change)** are supplied with some type of **quick-change tooling system** to accomplish this task
- Most small vertical turret mills are manufactured with an **R-8 spindle taper** that will accept **R-8 collets** (Fig. 4-5)
- Since most vertical turret mills are spin-offs of this design R-8 has become **pseudo-standard** for these machines
- R-8 collets and R-8 tool holders require the use of a **draw-bar**
- For CNC use: a) an automatically tightening draw-bar is supplied with the machine or b) a quick-change tool system is added

Tool Changing and Tool Registers

FIGURE 4-5b: R8 collets

http://en.wikipedia.org/wiki/Machine_taper#mediaviewer/File:HardingeR8Collets.jpg

Tool Changing and Tool Registers

FIGURE 4-6 A quick change tooling system used for manual tool change

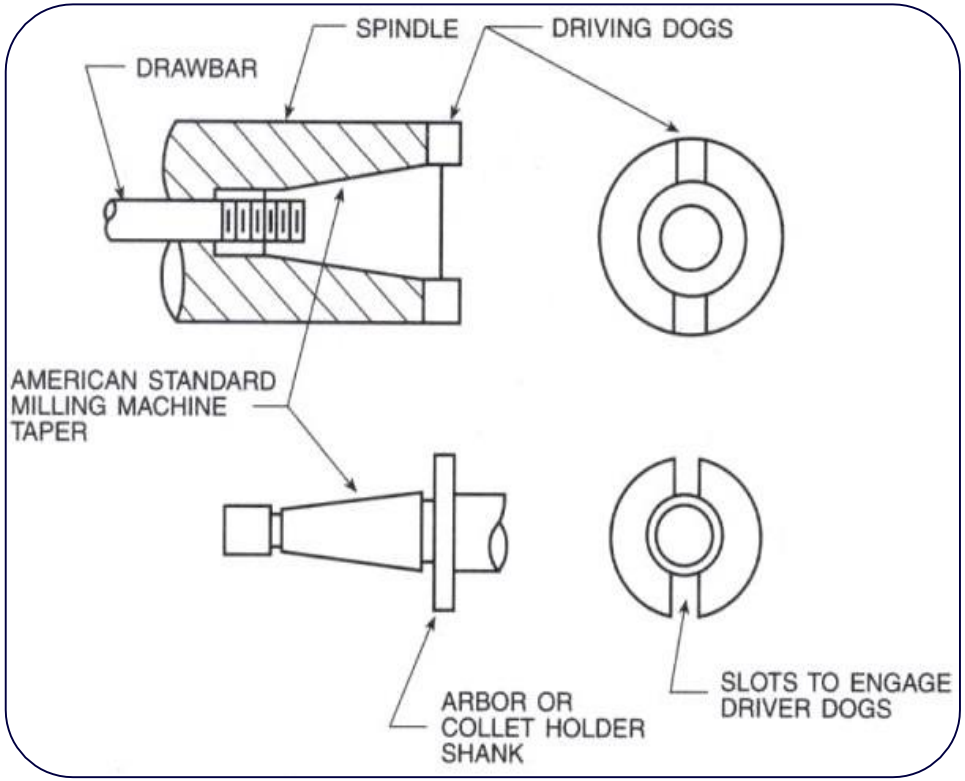
(Photo courtesy of http://www.cncmasters.com/)

Tooling for Manual Tool Change

- The quick-change tooling system consists of:
  - A **quick-release chuck–held** in the machine spindle
  - A **set of tool-holders** that hold the individual tools needed for a particular part program
- The **chuck** is a separate tool-holding system that **stays in the spindle**
- During the tool change the **tool-holder is removed** from the chuck (it is also called the tool-changer) and
- A **toolholder** containing the next required tool is **installed** in the place
- The tools placed in the toolholders are securely held by means of **set screws**
- Many varieties of quick-change tool systems are available on the market (Fig. 4-6)

Tool Changing and Tool Registers

Tooling for Manual Tool Change



- Larger vertical mills and most horizontal mills use another type of spindle taper called the **American Standard Milling Machine Taper** (Fig. 4-7)
- Like the R-8 this taper requires the use of a drawbar
- If no automatic drawbar is supplied with the machine, a quick-change tooling system is added for improving tool changing

FIGURE 4-7 American Standard Milling Machine Taper used on spindle (or collet holder shank)

Seams W., "Computer Numerical Control, Concepts & Programming"

Tool Changing and Tool Registers

American Standard Milling Machine Taper

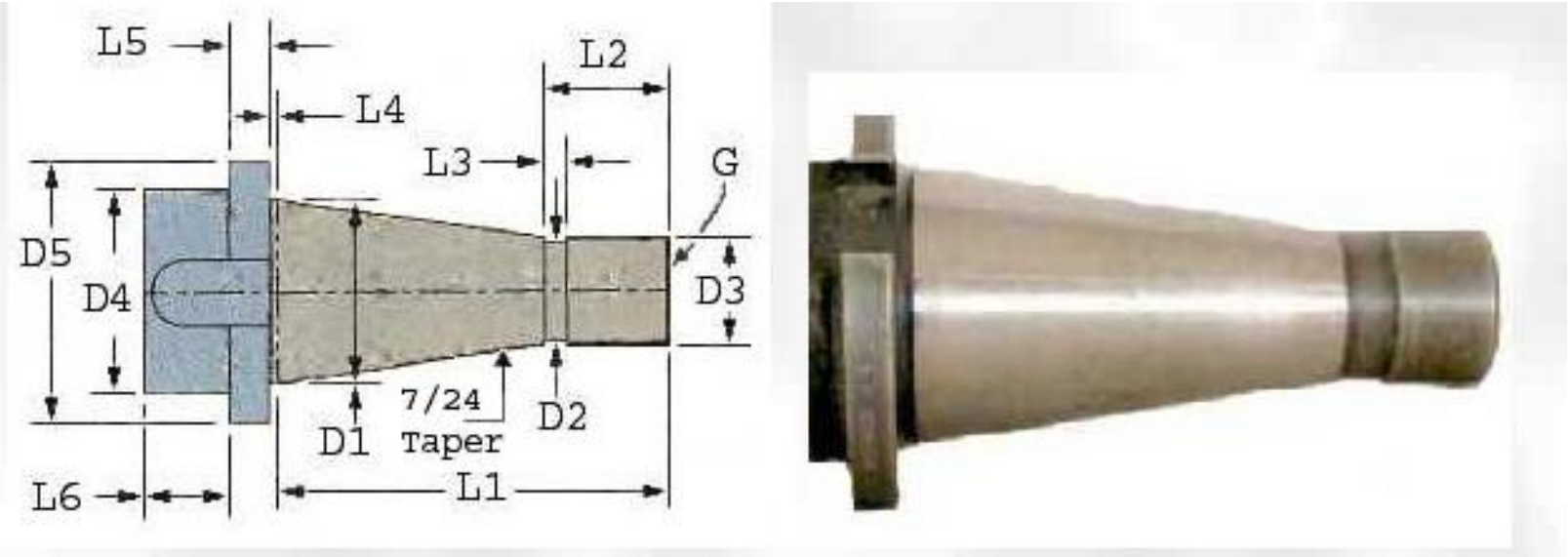


FIGURE 4-7b: American Standard Milling Machine Taper

http://www.tools-n-gizmos.com/specs/Tapers.html

Tool Changing and Tool Registers

Tooling for Automatic Tool Change

- When automatic tool change is used the **requirements for speed and repeatability are even more critical**

- The **machine's tool changer can not** think for itself or correct misalignments or tool setup errors like a human being

- The tool changer will **carry out its tool-changing cycle and nothing else** since that is all it was programmed to do

- Tooling used with a tool changer therefore **MUST**:


Be easy **to center** in the spindle


Be easy for the tool changer **to grab**


Have some means of providing **safe disengagement** of the tool changer from the tool once it is secured in the spindle

Tool Changing and Tool Registers

Automatic Tool Changers (ATC)

- Tools used in **ATC** are **secured in toolholders** designed for that purpose
- These **toolholders** are **installed directly** in the spindle by the tool changer
- Tools and t**oolholders** are shown in Fig. 4-11

FIGURE 4-11 An assortment of tools and toolholders used with CNC machining center
(Photo courtesy of Big Daishowa)

Tooling for Automatic Tool Change

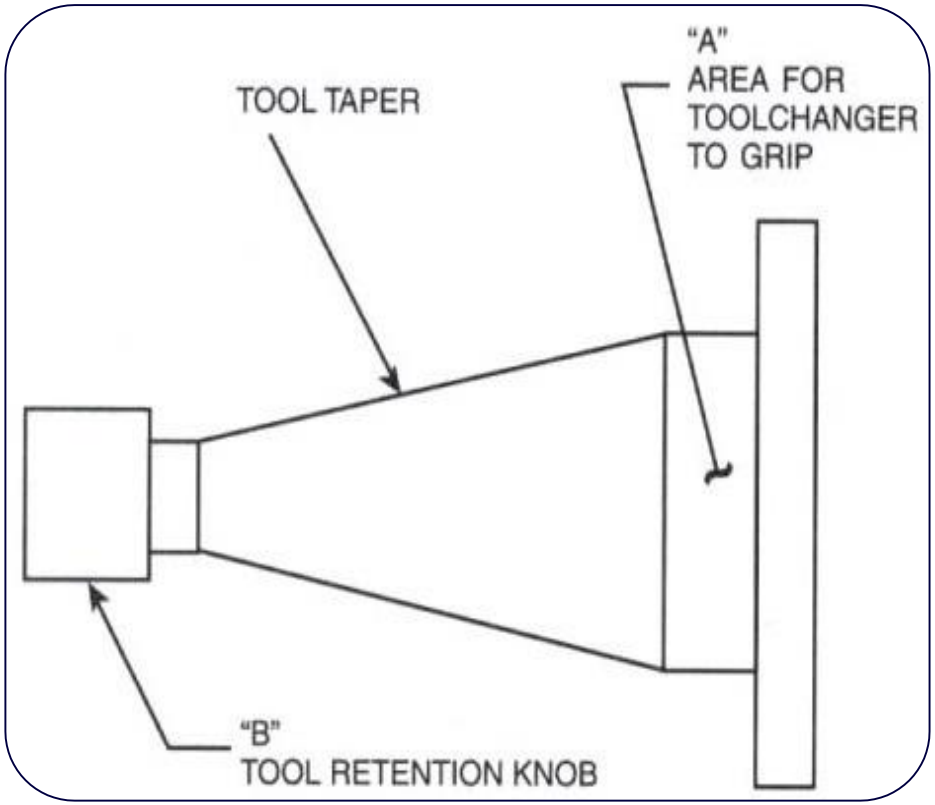


FIGURE 4-8 Typical toolholder used with ATC

Seams W., "Computer Numerical Control, Concepts & Programming"

- **Step 1:** The tool changer grips the tool at **point A**
- **Step 2:** Places the tool in position aligned with the spindle
- **Step 3:** The tool changer insert the tool into the spindle (in some cases spindle descending over the tool)
- **Step 4:** As the tool engages the spindle a split bushing in the spindle will close on the tool retention knob (**Point B**)

Tooling for Automatic Tool Change

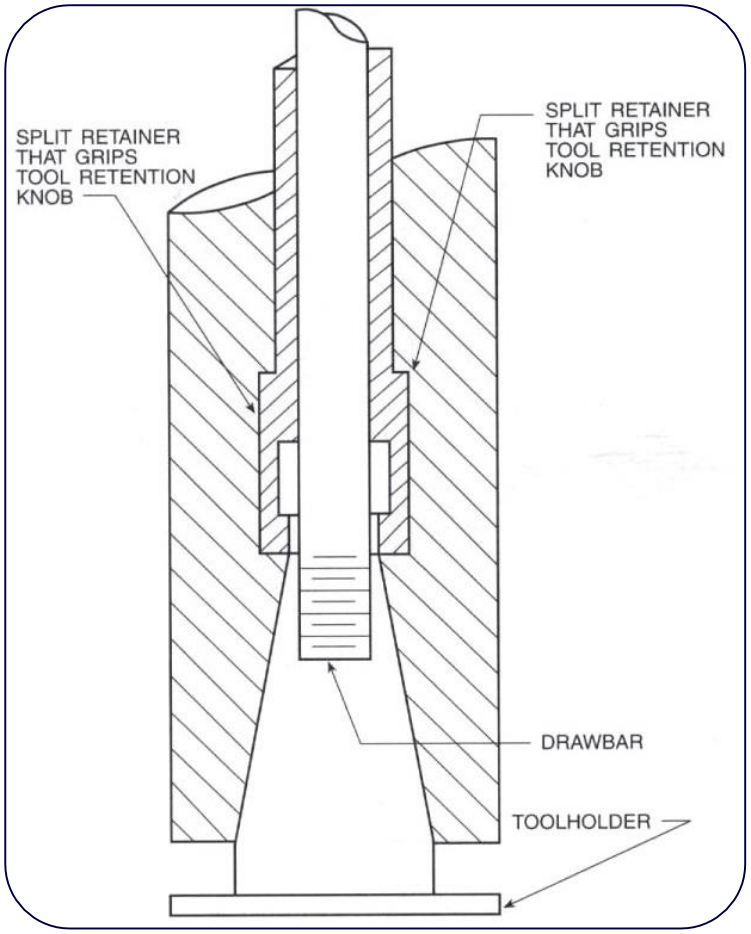
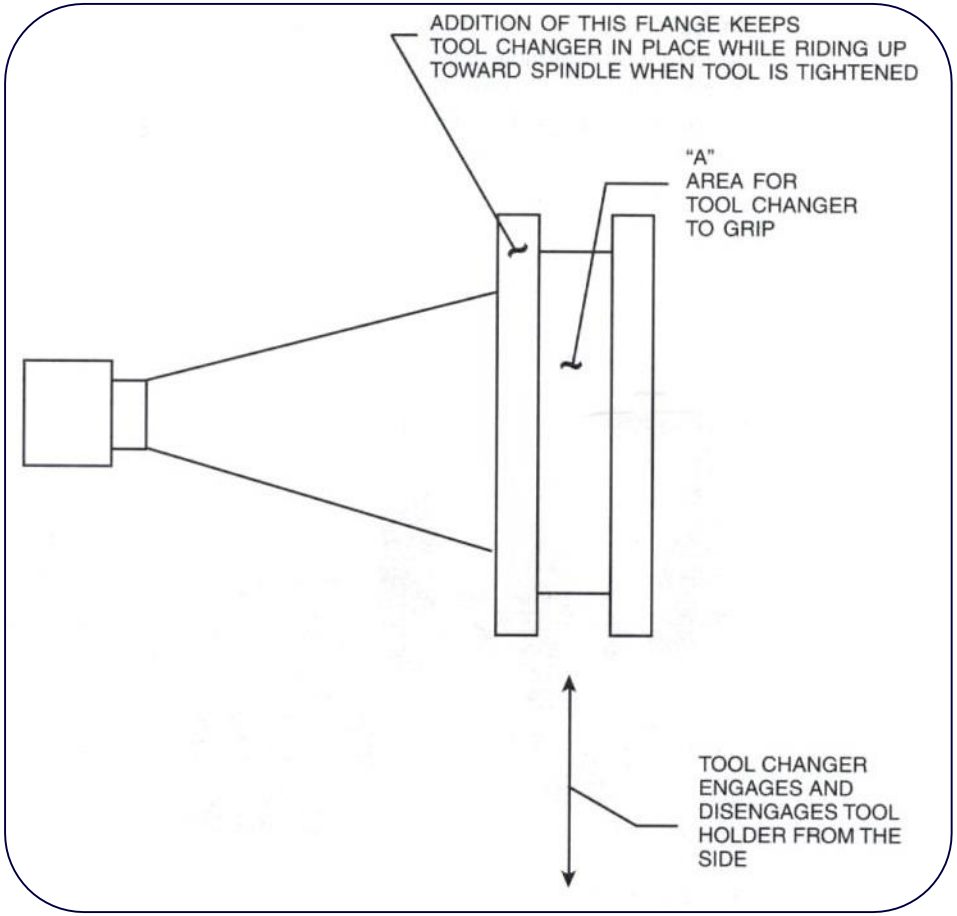


FIGURE 4-9 Split bushing closed over the retention knob to secure the tool as it is draw intro the spindle

Seams W., "Computer Numerical Control, Concepts & Programming"

- **Step 5:** The split bushing holds the tool so that the tool changer can release its grip on the tool
- **Step 6:** The tool is then drawn completely up into the spindle and tightened
- Using this procedure insures:
  - **Proper alignment** of the tool with the spindle
  - **Prevents damage** from occurring to the spindle or tool holder taper

Tooling for Automatic Tool Change



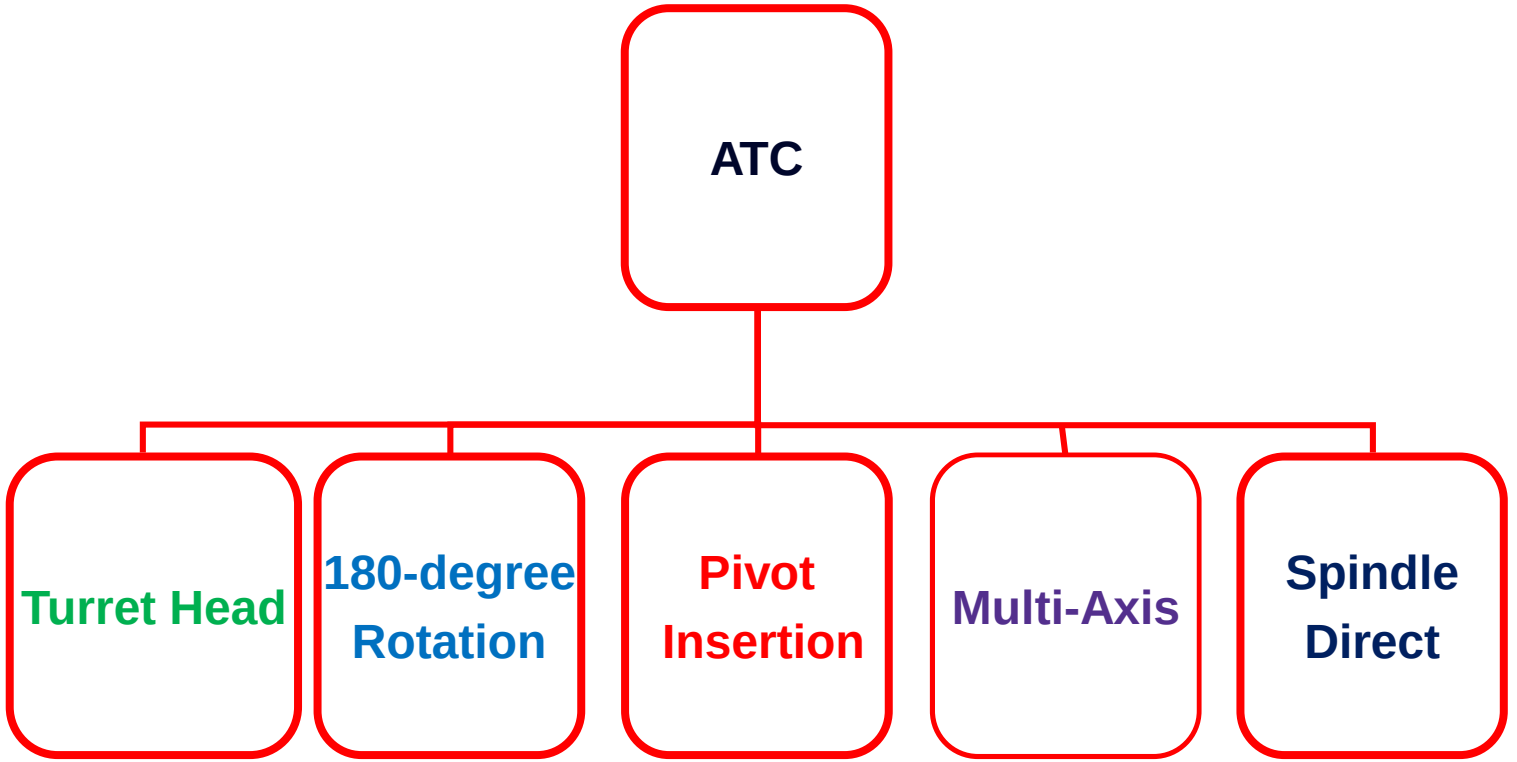
- Another insertion method can be used with a different type of tool holder (Fig. 4-10)
- **Step 1:** Tool changer grips the tool in slot A
- **Step 2:** The tool is inserted into the spindle
- **Step 3:** The tool changer moves towards the spindle as the tool is drawn up into the spindle
- **Step 4:** When the tool is secured in the spindle the tool changer slides off the tool holder from the side

FIGURE 4-10:Tool changer moves in from the side to grip the toolholder in area A while the tool is secured in the spindle

Seams W., "Computer Numerical Control, Concepts & Programming"

Automatic Tool Changers (ATC)

Automatic Tool changers are made in five basic types:



Automatic Tool Changers

Turret Head

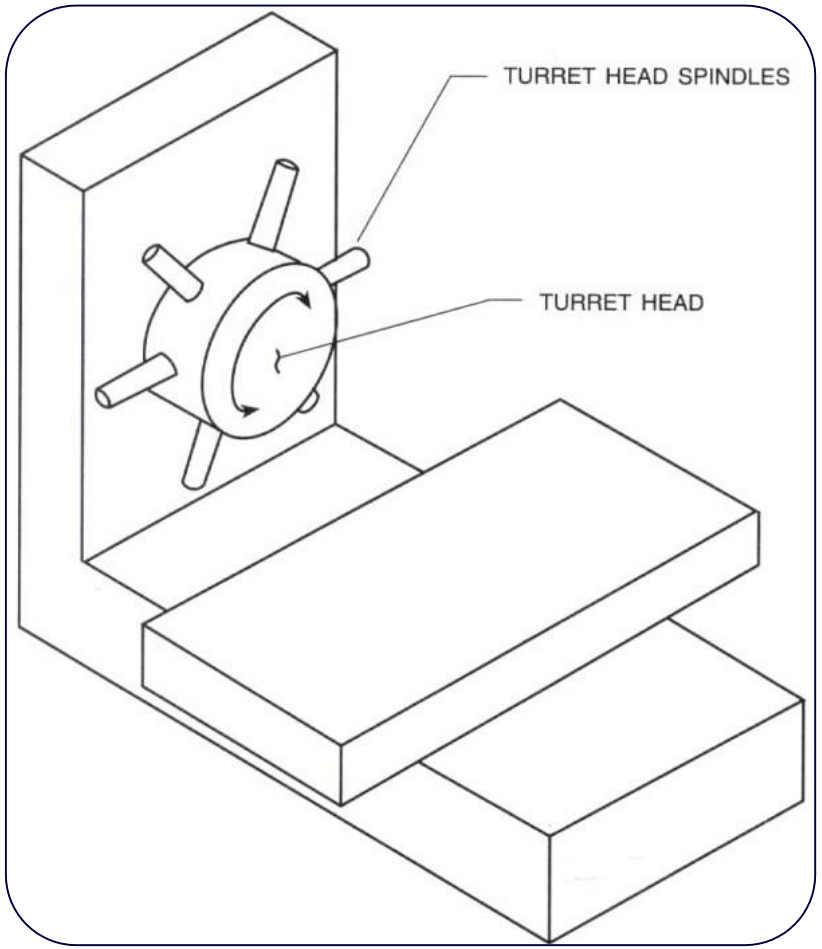


FIGURE 4-12a:Turret head tool changer

- Tool changing accomplished through the use of ***turret head*** is perhaps the ***oldest form*** of ATC
- **Turret Head is a number of spindles** linked to the same milling machine head (Fig. 4-12)
- **The tools are placed in the spindles prior running the program**
- When another tool is needed the ***head moves*** to the desired position
- ***Disadvantage***: The limited number of tool spindles available
- For using more tools than available spindles the operator must remove tools that have already been used and insert those called for later in the program
- ***Problem:*** More machine operator attention
- Turret Head ATC are still in use (drilling)

Automatic Tool Changers

Turret Head Tool Changer

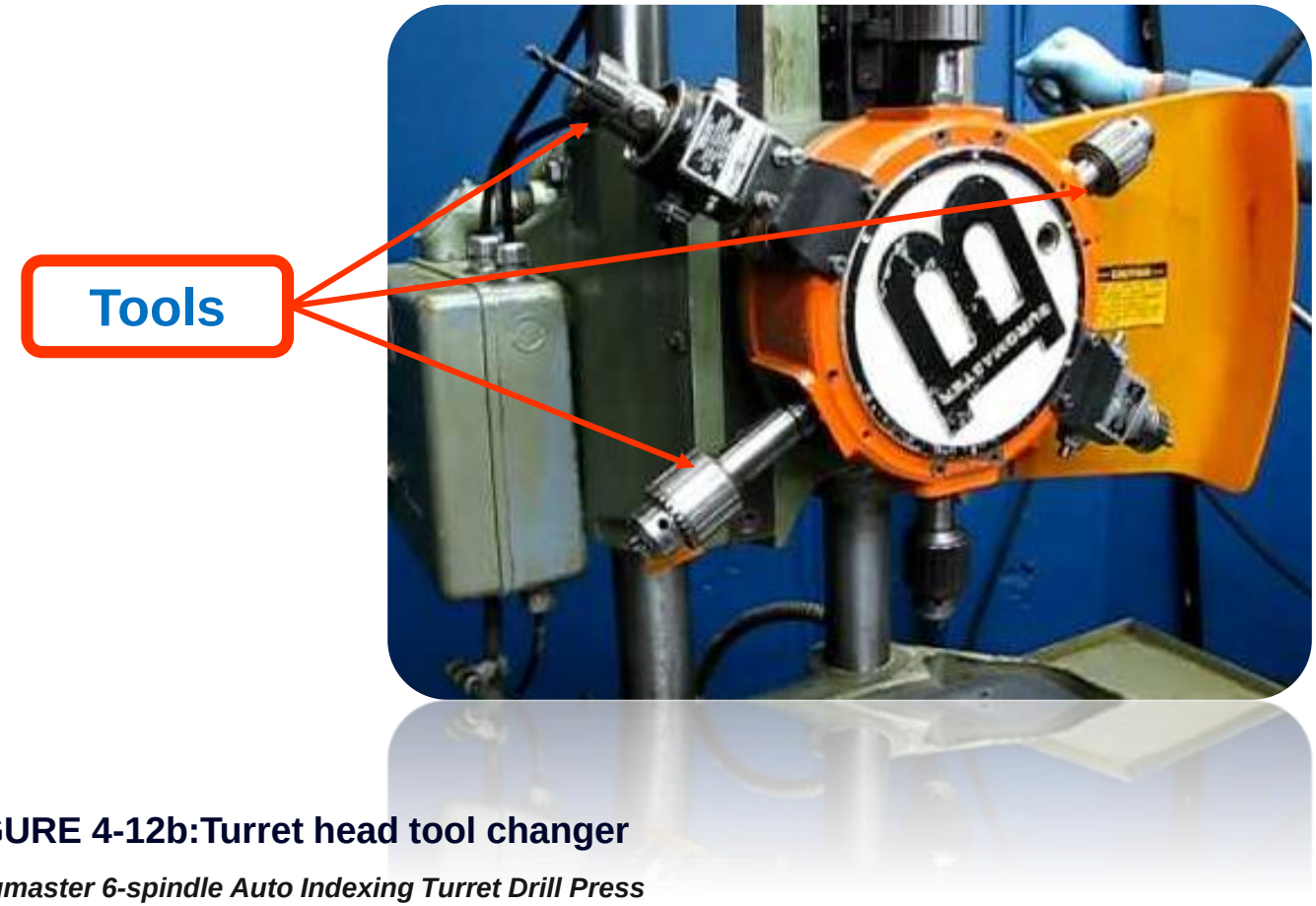


FIGURE 4-12b:Turret head tool changer

Burgmaster 6-spindle Auto Indexing Turret Drill Press

Automatic Tool Changers

180-Degree Rotation

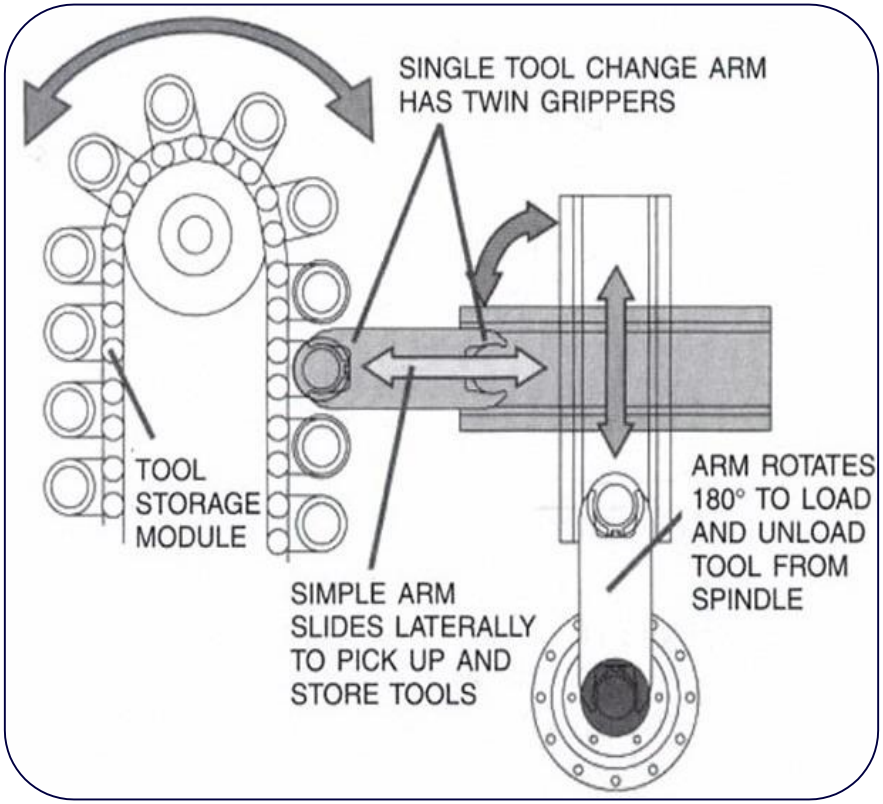


FIGURE 4-13: 180-degree rotation tool changer

(Photo courtesy of Cincinnati Machine)

http://www.directindustry.com/prod/trumpf-machine-tools/automatic-tool-changers-rotary-magazine-high-speed-5691-1586400.html

Automatic Tool Changers

Pivot Insertion

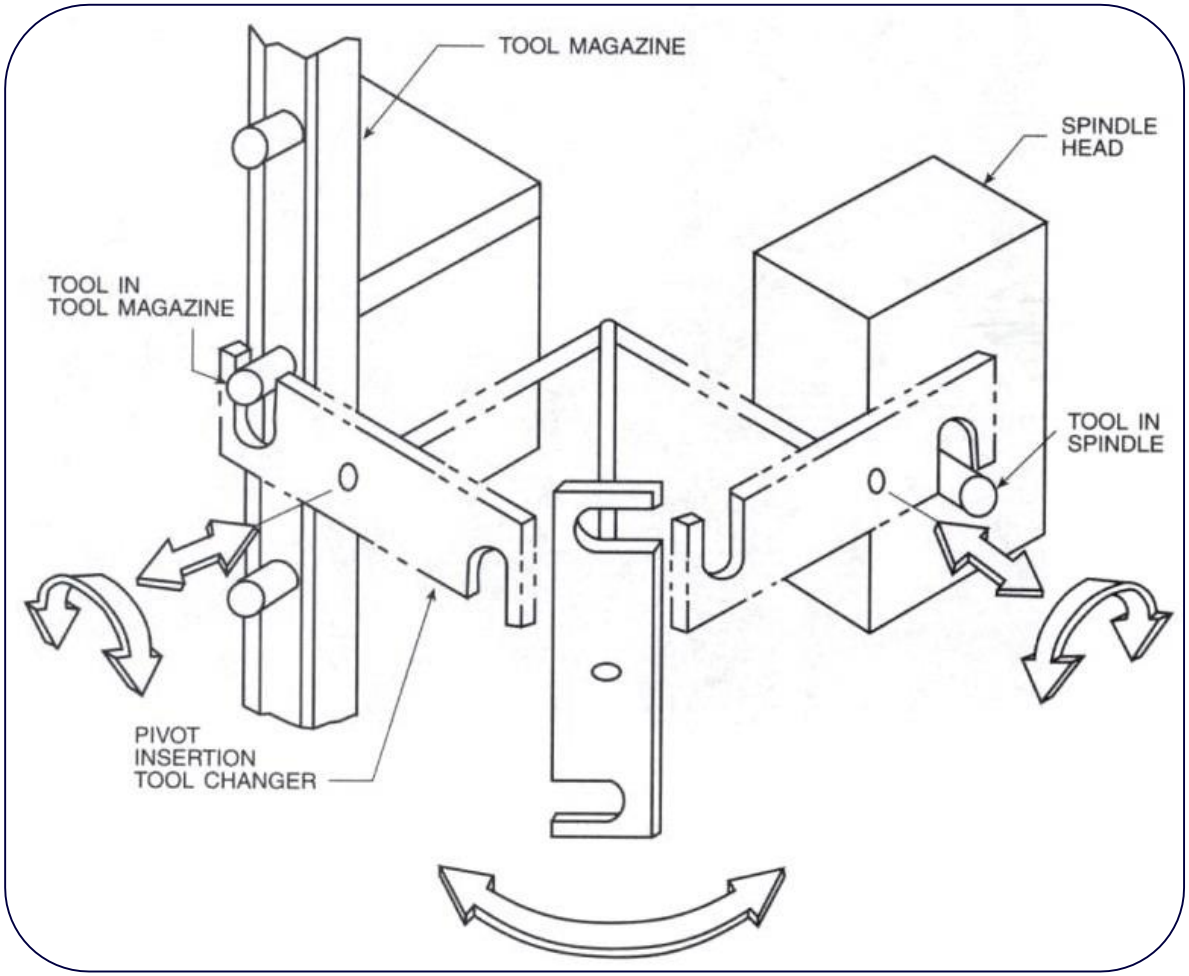


FIGURE 4-14: Pivot insertion tool changer

Seams W., "Computer Numerical Control, Concepts & Programming"

Automatic Tool Changers

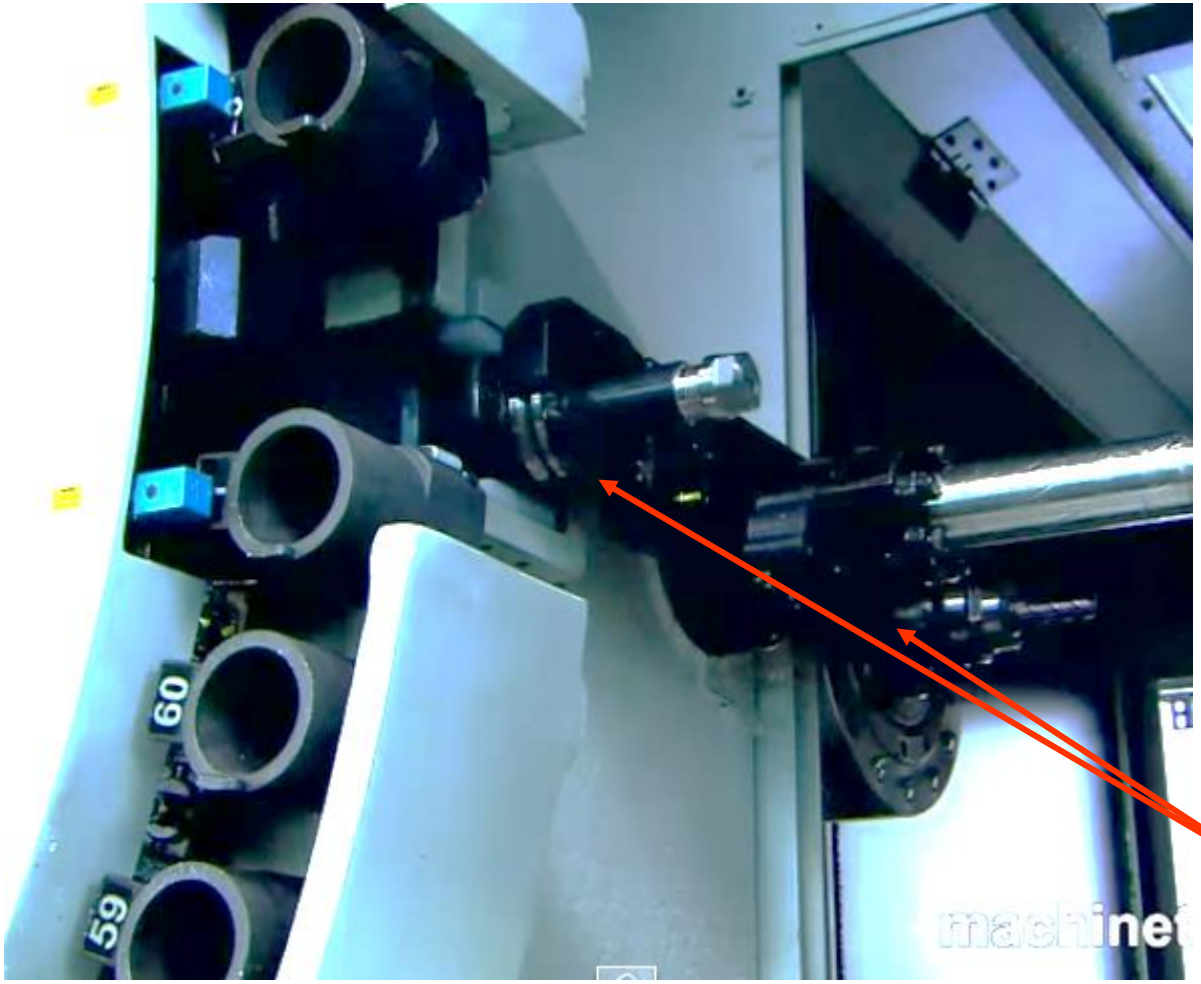


FIGURE 4-15: A pivot insertion tool changer on a horizontal machining center using twin matrix tool storage magazines (Photo courtesy of Cincinnati Machine)

Automatic Tool Changers

Multi - axis

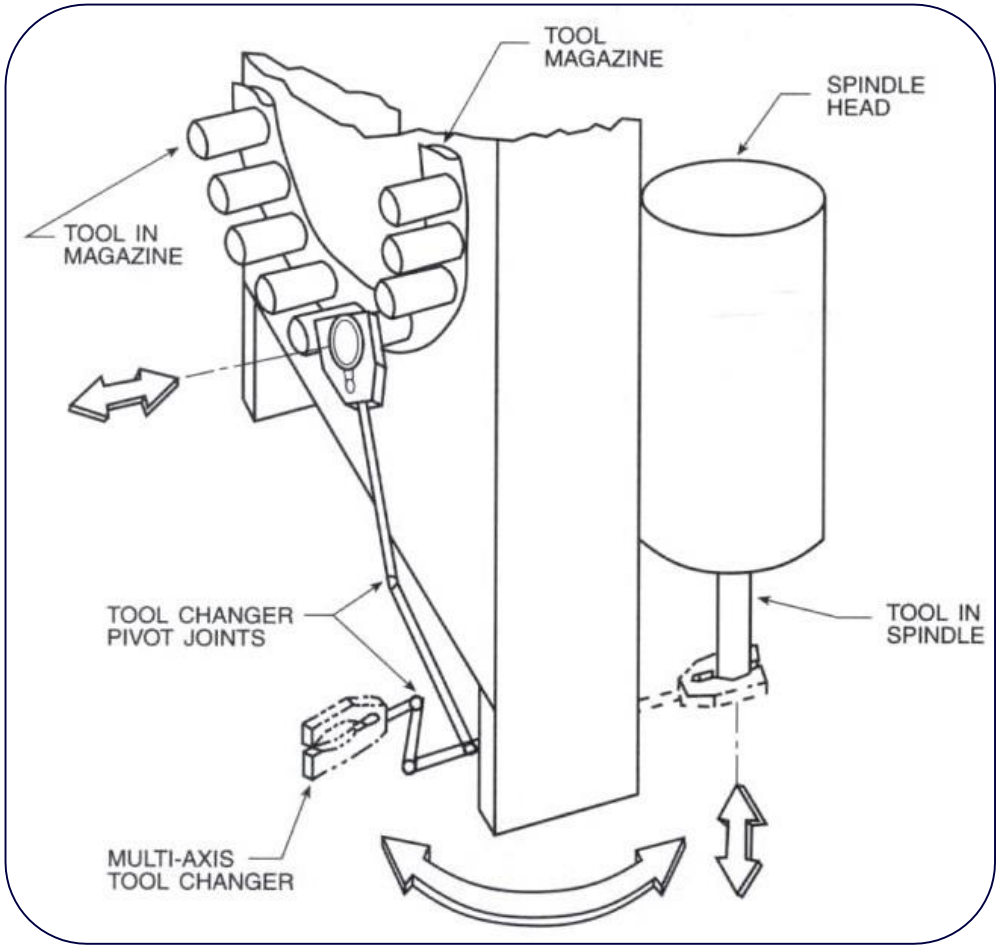
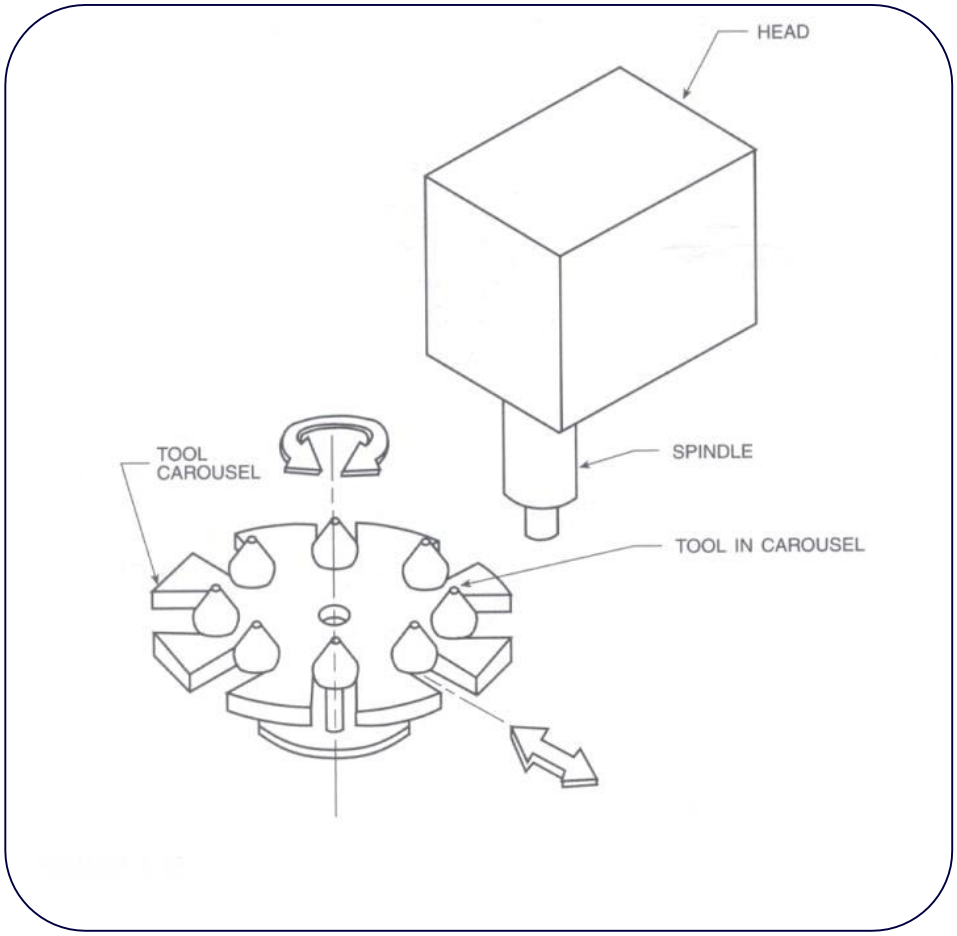


FIGURE 4-17: Multi – axis tool changer

Seams W., "Computer Numerical Control, Concepts & Programming"

Automatic Tool Changers

Spindle Direct



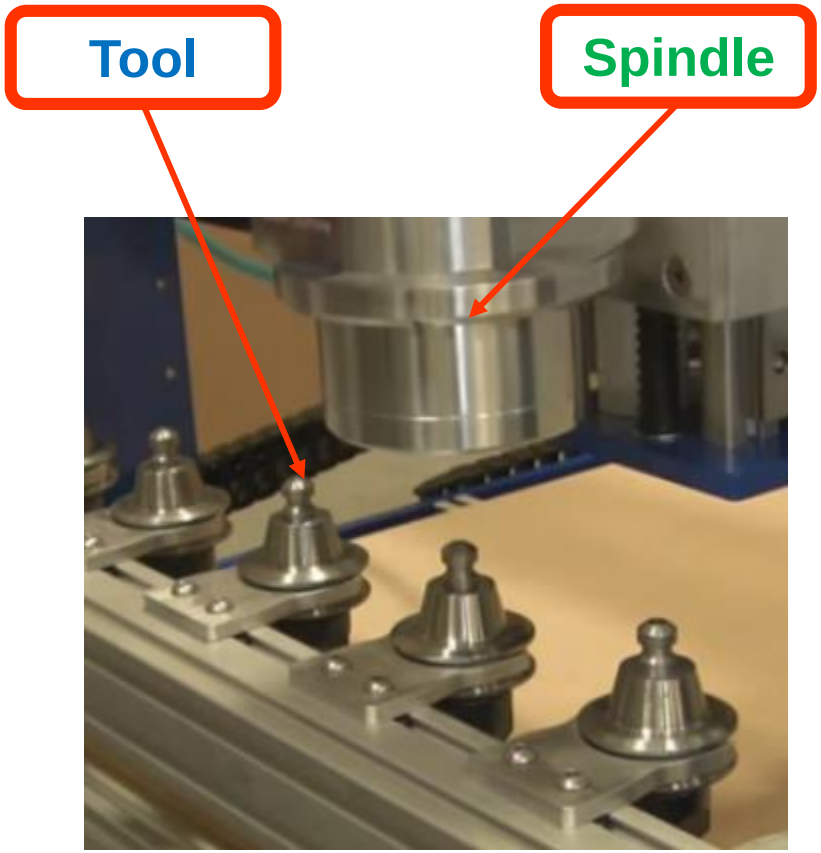


FIGURE 4-18: Spindle Direct Tool Changer

Seams W., "Computer Numerical Control, Concepts & Programming"

Automatic Tool Changers

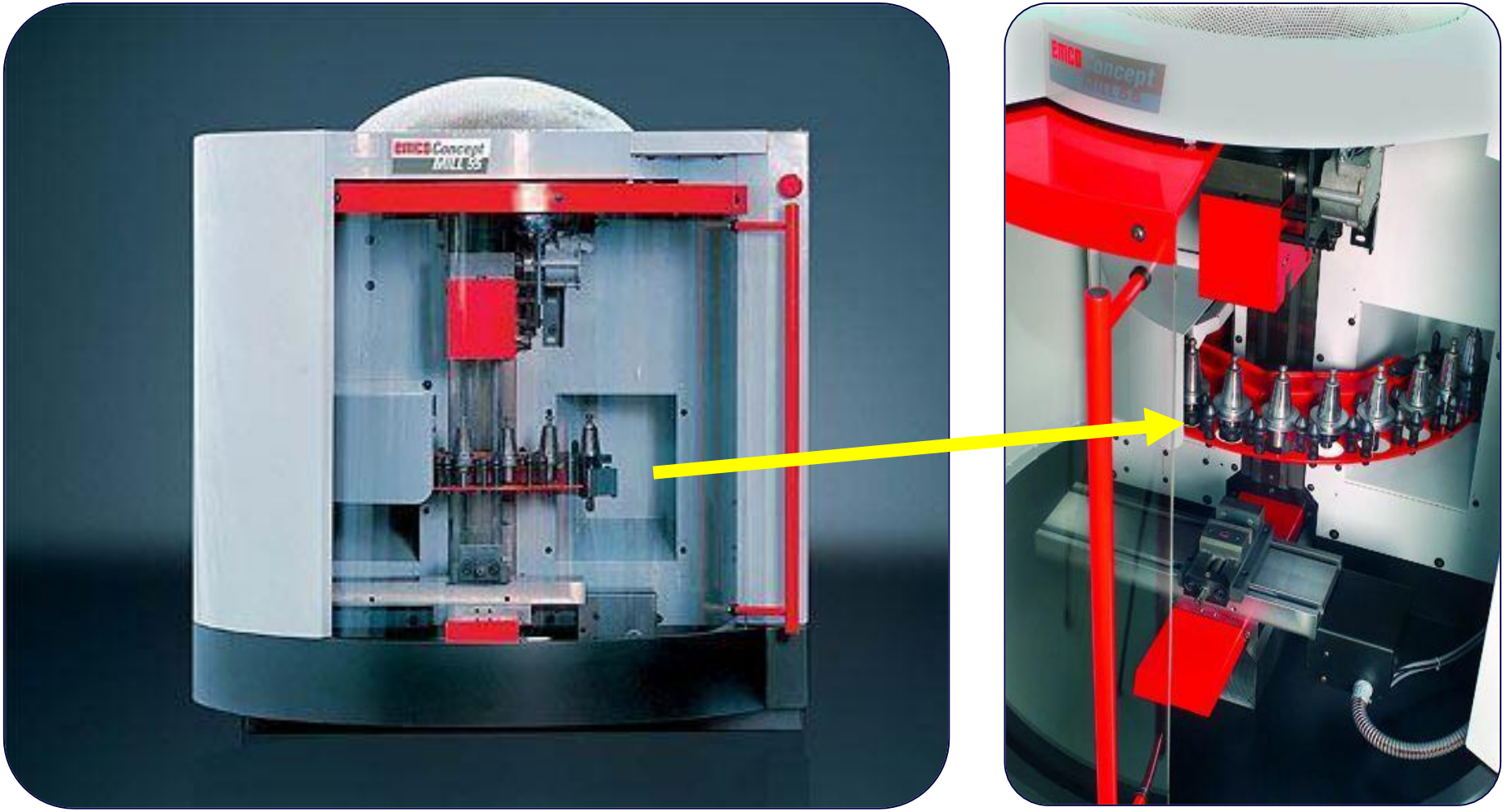


FIGURE 4-19: A vertical spindle machining center. Note the tool changer and carousel tool storage magazine (Photo courtesy of EMCO)

Automatic Tool Changers

FIGURE 4-20: A vertical spindle machining center using carousel tool storage
(Photo courtesy of HURCO)

Tool Length Offset

General

- **Tools used for machining can vary in length**
- When using **3-axis NC machinery** there are **two basic methods to compensate** the different tool lengths:
  - **Pre-measuring the tools**
  - Using **CNC controller's tool length compensation feature**

Preset Tool Method

- Set the tool to a specific length
- The known length is can be then added to the program's Z-axis coordinates
- Setting the tool to a specific length: **Presetting – Preset Tools**
- Tool set-up drawing may be used
- Special tool-setting equipment is used to measure the tools accurately
  - The **cost** of the **equipment** is **high**
  - The **labour** for **tool setting** is **high**
  - The **replacement** of **broken Preset Tools** is **complicated**
  - The **Preset tools** must be set to **specific length** to function properly

Tool Length and Tool Length Offset

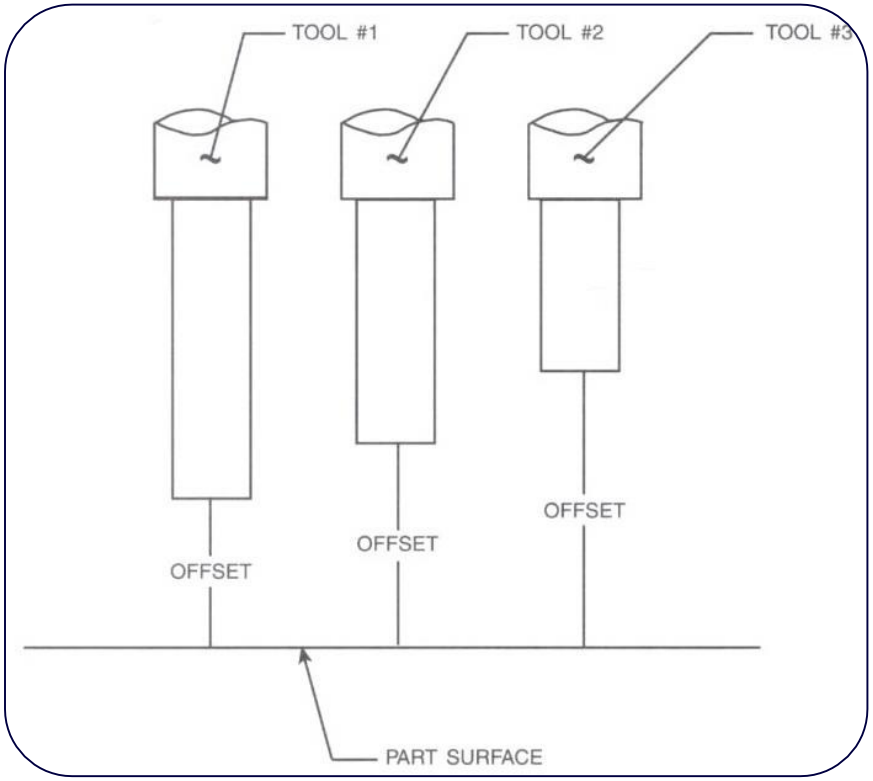


FIGURE 4-21: Tool length offset, difference of gage tool trim method

Seams W., "Computer Numerical Control, Concepts & Programming"

Tool Length Offset

- CNC machinery has revolutionized tool setting by the Programmable Tool Register

Tool Register:

- Is a ***memory spot*** in the computer where the length of the tool may be stored
- When a tool is called up the computer checks the Tool Register to see ***how much offset*** has been programmed for that tool
- Check the ***comments*** for tool offset
- The ***MCU sifts the Z-axis*** by the amount stored in the offset register

Methods for Tool Trimming or Offsetting

- Difference of gage tool trim
- Plus direction trim
- Minus direction trim

Tool Length and Tool Length Offset

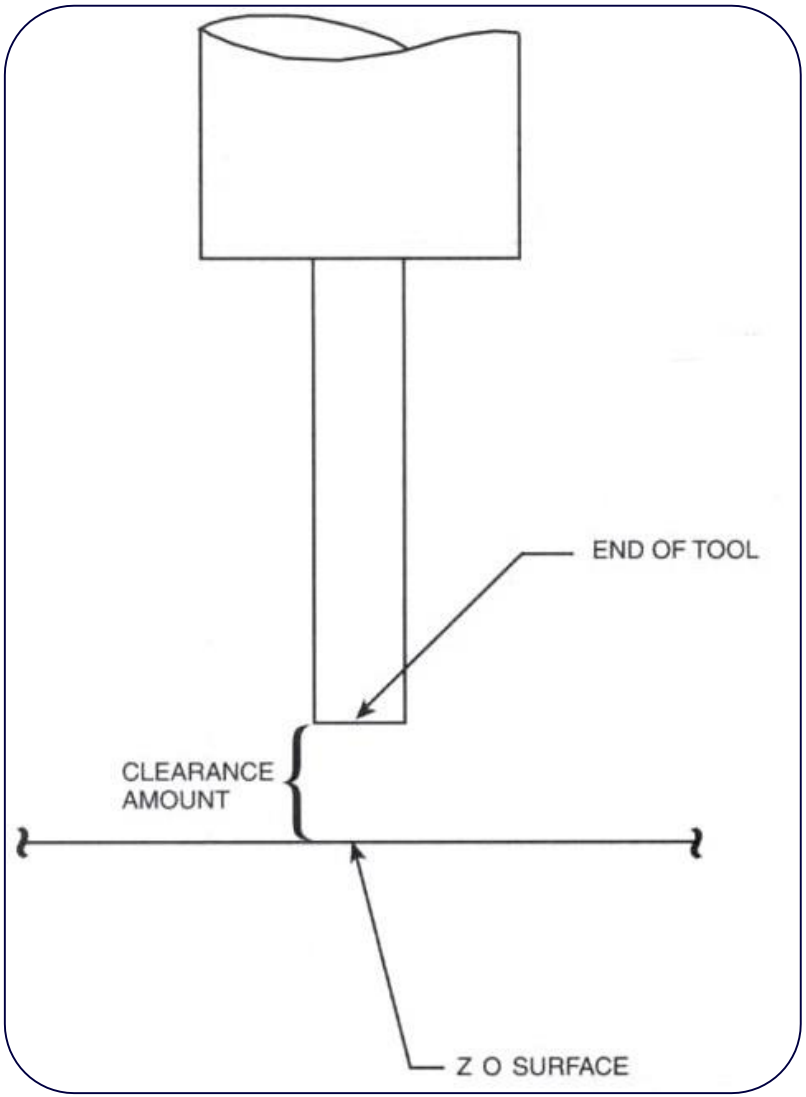


FIGURE 4-22: Tool clearance

Difference of Gage Tool Trim

- It is a variation of the Preset Tool method

Tool Length and Tool Length Offset

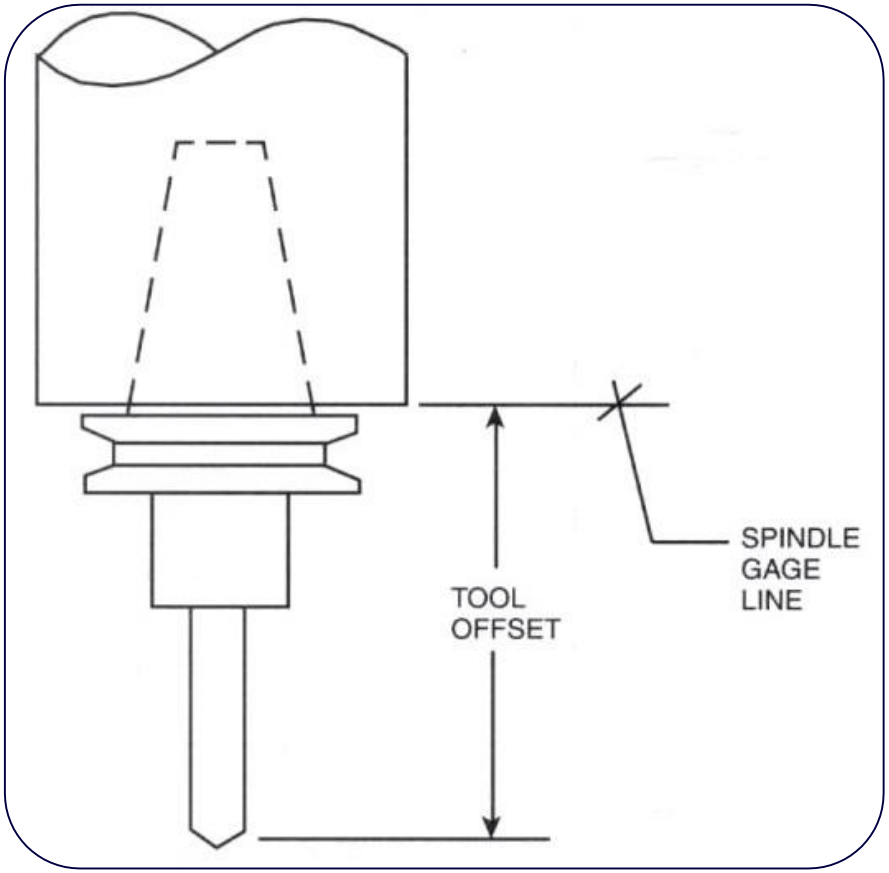


FIGURE 4-23 Tool length offset, plus direction trimming

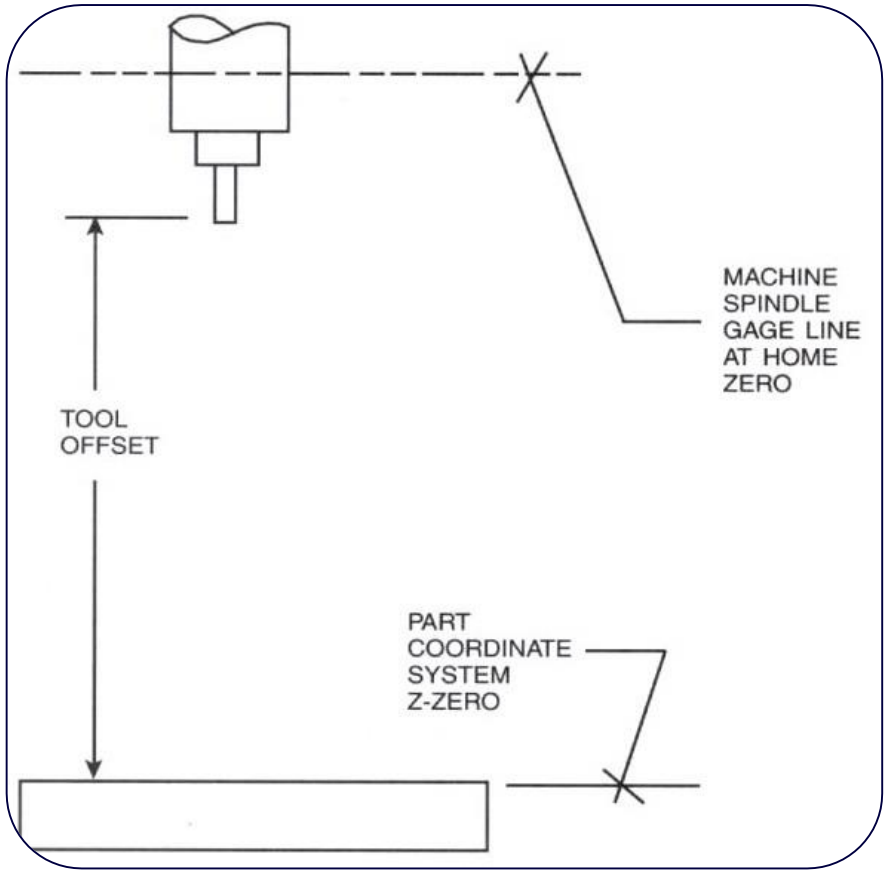


FIGURE 4-24 Tool length offset, minus direction trimming

Seams W., "Computer Numerical Control, Concepts & Programming"

Summary

- The **speed**, **repeatability**, and **accuracy** of a tool change greatly influence the efficiency of numerical control
- There are two types of tool change: **manual** and **automatic**
- Machinery utilizing manual tool change generally incorporates some type of **quick-change tooling system** to facilitate the speed and accuracy of tool changes
- Automatic tool changers are grouped into five categories: **turret head**, **180-degree rotation**, **pivot insertion**, **multi-axis**, and **spindle direct**
- **Tool registers** are places in the computer's memory to program tool offsets

Vocabulary Introduced in this chapter

- 180-degree rotation tool changer
- Automatic tool change (ATC)
- Carousel tool magazine
- Manual tool change
- Matrix tool magazine
- Multi-axis tool changer
- Pivot insertion tool changer
- Preset tools
- Quick-change tooling
- Spindle direct tool changer
- Tool length offset
- Tool offset register
- Turret head
- Tool registers

References

1. Ann Mazakas, Manager of Technical Communications, DP Technology, ‘’The Art of Automation’’, courses materials of ESPTRIT World Conference on CNC
2. Chryssolouris G., «Manufacturing Systems: Theory and Practice», 2nd Edition, 2006, Springer-Verlag
3. http://int.haascnc.com/
4. http://toolkorea.en.ec21.com/
5. http://www.alliedmaxcut.com/
6. http://www.big-daishowa.com/product_page/product_01_chuck.php
7. http://www.bigkaiser.com/
8. http://www.cncmasters.com/
9. http://www.doallind.com/
10. http://www.dptechnology.com/
11. http://www.dptechnology.com/

References

12. http://www.emco-world.com/
13. http://www.emuge.com/technical/pdf/Toolholding/zp10024_gb.pdf
14. http://www.fioramachinery.com.au/
15. http://www.gsm-cnc.com.tw/
16. http://www.hurco.com/
17. http://www.iscar.com/
18. http://www.kennametal.com/
19. http://www.knuth.de/
20. Kalpakjian S., «Manufacturing Engineering and Technology», 2nd Edition, 1992, Addison-Wesley Publishing company
21. Mattson M., “CNC Programming, Principles and Applications”, Delmar, 2002

References

22. Moriwaki T., “Multi-Functional Machine Tool”, CIRP Annals Manufacturing Technology, Vol. 57/2, 2008, pp. 736-749
23. Seams W., “Computer Numerical Control, Concepts & Programming”, 4th Edition, Delmar, 2002
24. Γ. Χρυσολούρης, «Συστήματα Παραγωγής Θεωρία και Πράξη» Μέρος Ι και ΙΙ, Εκπαιδευτικές Σημειώσεις, Πανεπιστήμιο Πατρών, 2001,
25. Γ. Χρυσολούρης, Δ. Μούρτζης, Κ. Τσίρμπας, Σ. Καραγιάννης, “Ορθογωνική Κοπή”, Εκπαιδευτικές Σημειώσεις, Πανεπιστήμιο Πατρών, 2000
26. Γ. Χρυσολούρης, Δ. Μούρτζης, και άλλοι, “Εργαστήρια Μηχανουργικής Τεχνολογίας Ι και ΙΙ”», Εκπαιδευτικές Σημειώσεις για το εργαστήριο του αντιστοίχου μαθήματος, Πανεπιστήμιο Πατρών, 2008 (4η Έκδοση)
27. Δ. Μούρτζης, “Αριθμητικός Έλεγχος Εργαλειομηχανών” Εκπαιδευτικές Σημειώσεις, Πανεπιστήμιο Πατρών, 2011 (3η Έκδοση)
28. Πετρόπουλου Π.Γ., «Μηχανουργική Τεχνολογία – ΙΙ. Τεχνολογία κατεργασιών κοπής των μετάλλων», 1998, Εκδόσεις Ζήτη
29. Σύγχρονες μέθοδοι κατεργασίας υλικών και προγραμματισμός με Ηλεκτρονικό Υπολογιστή (Η/Υ) ,Δ. Μούρτζης ,Κ.Σαλωνίτης