Outline – CNC Elements

• CNC Machine Tools
  – Machining Centers
  – Turning Centers
• Elements of Machine Tools
  – Main Structure
  – Transmission Elements
  – Power Generation Systems
  – Measurement Systems
  – Auxillary Systems
  – Control Systems

CNC Machining Center

• A machine tool capable of:
  – Multiple operation and processes in a single set-up utilizing multiple axis,
  – Typically has an automatic mechanism to change tools,
  – Machine motion is programmable,
  – Servo motors drive feed mechanisms for tool axis’s,
  – Positioning feedback is provided by sensors to the control system,

Types of Machining Centers

• Vertical Machining Centers
  – 3-Axis (X, Y, Z)
  – 4-Axis (X, Y, Z, Rotary table)
  – 5-Axis (X, Y, Z, Rotary table, Rotary spindle)
• Horizontal Machining Centers
  – 3-Axis (X, Y, Z)
  – 4-Axis (X, Y, Z, Rotary table)
  – 5-Axis (X, Y, Z, Rotary table, Rotary spindle)

Vertical Machine Centers*

[" Haas Automation.
3-Axis VMC

- Programmable X and Y axes in the plane of the table.
- Z-axis in the spindle’s direction.
- Cost is about $30,000.
- One can machine:
  - One surface of a cube with the cutter-end,
  - Four additional surfaces with the side of the cutter.

5-Axis VMC

3-Axis HMC

- Note the designations of the X, Y, and Z axes.
- Cost is about $90,000.
- Used in mass-production:
  - Easy access to table!
- One can machine:
  - One surface of a cube with the cutter-end,
  - Three additional surfaces with the side of the cutter.

[*] Haas Automation.
4-Axis HMC

- Generally horizontal
  - Table rotates to create the forth axis.
- True four-axis machines start around $100,000.
- One can machine:
  - Four surfaces of a cube with cutter-end
  - Three additional surfaces with the side of the cutter.

5-Axis HMC

- Similar to the 4-axis HMC except the spindle rotates around an axis.
- Cost is about $250,000.
- Used to machine complex parts and molds.
- One can machine:
  - Five sides of a cube with the cutter-end
  - Six sides with the side of the cutter.
- Part can be machined with only one setup:
  - Leads to more accurate part.

HMC vs. VMC

CNC Turning Center*

[*] Spinner WZM
Elements of CNC Machine Tools

- Main Structure
- Transmission Elements
- Power Generation Systems
- Measurement Systems
- Auxillary Systems
- Control Systems

Main Structure

- Stationary Elements
  - Columns, portals, beds, guideways
- Moving Elements
  - Translational: carriages, tables, saddles, etc.
  - Rotational: spindle, chuck, capstan, etc.
- Support Elements
  - Bearings: Ball bearing, journal bearings
  - Couplings

Mechanical Structure of VMC

Mechanical Structure of TC
Transmission Systems

- Ball screw
- Lead Screw
- Rack-and-Pinion
- Worm-and-Rack
- Belt Drives
- Gear Trains

Ball Screw Drives

- Common mechanisms in feed drives.
- High efficiency.
- Capability of backlash-free operation.
- Stroke length is limited up to 4 [m].

Kinematic Relationships for Ball Screw Drive

\[ u = \frac{h_s \theta}{2\pi} \]
\[ T = \frac{h_s F}{2\pi \eta_s} \]
\[ \eta_s = \frac{1}{1 + 0.02 \frac{d_s}{h_s}} \]

Rack-and-Pinion Drive

- Used for a travel span of 3 [m] up to 20 [m].
- Backlash-free versions are also available
  - an extra-preloading pinion is employed.
  - quite expensive!
Preloaded Rack-and-Pinion Mechanism

Kinematic Relationships for Rack-and-Pinion Drives

\[ u = r_0 \theta \]

\[ T = \frac{r_0}{\eta} F \]

Feed Drive

- An arrangement in machine tools to "feed" the workpiece to the cutting tool.
- Sometimes called "axis drive system."

Power Generation Systems

- Actuators (Electromagnetic or Hydraulic)
  - Linear Motors
  - Rotary Motors
- Drive Systems
  - Power Converters
Measurement Systems

- Can be classified in many different ways:
  - Analog or Digital
  - Linear/Translational or Rotational
  - Absolute or Relative
  - Optical, Electromagnetic, etc.
  - Direct vs. indirect measurement

Auxillary Systems

- Tool Loading Systems
  - Tool Turret
  - Tool Magazine and ATC
- Coolant/Lubricant Supply Systems
- Gear Changers (Spindle) and Tool Alignment Systems
- Automatic Clamps and Brakes

Automatic Tool Changers

CNC Control Systems

- Motion Control System
  - Interpolators
  - Axis Position Controllers
- Programmable Logic Controllers
- Electronic Device Interfaces
- Graphical User Interfaces
Open-loop Control

• Stepper motor system is utilized.
  – Current pulses sent from control unit to motor
  – Each pulse results in a finite amount of revolution of the motor.

Closed-loop Control

• Uses position feedback concept.
  – The servo motor has a feedback loop to check the machine’s actual position.
  – Servo-motors have the ability to reverse instantly to adjust for position error
  – Error compensation allows for greater positional accuracy
  – Modern servo-motors (AC or DC) have higher torque ranges vs. stepper motors.

Open-loop Control (Cont’d)

• Control unit “assumes” desired position is achieved.
  – No positioning compensation
  – Most stepper motor develops low torque

• Advantages:
  – Simple
  – Inexpensive
  – Low maintenance costs

Accesories

Tool Setter (TC):

Rotary Table (VMC):
Complex Machined Parts

Optional Axis