Numerical Control (NC) and The A(4) Level of Automation

Chapter 40
40.1 Introduction

• Numeric Control (NC) and Computer Numeric Control (CNC) are means by which machine centers are used to produce repeatable machining process.

• Two types are used:
  – Fixed Automation using mechanical cam
  – Flexible Automation using G Code

• The control programs use either
  – Closed loop control using feedback
  – Or Open loop control
FIGURE 26-1 Early NC machine tools were controlled by paper tape. Soon onboard computers were added, followed by tool changers and pallet changers.
FIGURE 26-2 Open-loop NC versus three position control schemes for NC and CNC machine to
Example of G Code

**FIGURE 26-3** The tool paths necessary to rough and finish turn a part in a CNC lathe are computer generated using G codes.
History of NC

• Machine Centers have been in development over the last 60 years, with significant support from the USAF
• NC has impacted tool design, requiring tools with greater strength and higher temperature resistance
• New NC coding software has removed the earlier need for highly trained programmers, broadening the use of NC to most manufacturing facilities
• Today, a majority of the machines use Distributed Numeric Control, eliminating the need for paper tapes and large onboard processors
FIGURE 26-4 Horizontal machining center with four-axis control (X, Y, Z, R table) receives inputs to the control panel from many sources.
Flexible Manufacturing Systems (FMS)

• FMS enables products to take random paths through the machines

• The system used automated conveyors and NC machines to move parts through a shop, accounting for the variability of machine time for different parts.

• As a part reaches a machine, the appropriate code and tools are used for the part, the central system schedules the parts/machines based on production rate needs.
FIGURE 26-5 An example of a sophisticated FMS developed for machining aircraft parts. A wire-guided cart called an AGV (automated guided vehicle) is used to transport pallets from the unload/load station to the machines.

Application:
An aircraft parts manufacturer needed parts transfer mobility, in/out parts queue, cutting tool library, and quality control management for production of high technology parts.

Wire-guided vehicles offer interdepartment transfer capability as well as in-cell transport. The QC center manages the machining accuracy for continuous flow of acceptable parts. Parts are scheduled in batch and/or random, controlled by a management computer.

The machines are equipped with telemetry probes, adaptive control, bulk tool storage, and complete tool management.
# FMS Features

<table>
<thead>
<tr>
<th>TABLE 26-1</th>
<th>Common Features of Flexible Manufacturing Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallet changers</td>
<td></td>
</tr>
<tr>
<td>Multiple machine tools: NC or CNC</td>
<td></td>
</tr>
<tr>
<td>Automated material handling system (to deliver parts to machines)</td>
<td></td>
</tr>
<tr>
<td>Computer control for system: DNC</td>
<td></td>
</tr>
<tr>
<td>Multiple parts: Medium-sized lots (200–10,000) with families of parts</td>
<td></td>
</tr>
<tr>
<td>Random sequencing of parts to machines (optional)</td>
<td></td>
</tr>
<tr>
<td>Automatic tool changing</td>
<td></td>
</tr>
<tr>
<td>Inprocess inspection</td>
<td></td>
</tr>
<tr>
<td>Parts washing (optional)</td>
<td></td>
</tr>
<tr>
<td>Automated storage and retrieval (optional, to deliver parts to system)</td>
<td></td>
</tr>
</tbody>
</table>
Examples of FMS

FIGURE 26-6
Examples of machining centers—FMC and FMS designs.
Examples of FMS

FIGURE 26-6
Examples of machining centers—FMC and FMS designs.
40.2 Basic Principles of Numerical Control

- NC uses processing language to control the movement of the cutting tool, workpiece or both
- NC machines can duplicate parts with repeatability and accuracy improved over conventional machining.
- NC greatly increases the productivity of a single shop
- Setup and fixturing can be made more universal, decreasing setup time, increasing production rates.
- Greater accuracy and precision does not necessarily translate into higher cost
Motion Control in NC Machines

**FIGURE 26-7** The part (above) to be machined on the NC machine (below) has a zero reference point. The machine also has a zero reference point.
How CNC Machines Work

• CNC use two forms of control
  – 1. Point to Point: which is typically open loop control
  – 2. Contouring: which is typically closed loop control

• CNC machines typically have a Machine Control Unit (MCU) on board that takes input from the data processing unit (DPU) and control-loop unit (CLU) to move the position of each axis and direction of feed, to produce the final product.
FIGURE 26-8 NC and CNC systems are subdivided into two basic categories: point-to-point controls or contouring controls.
FIGURE 26-9 The table of the CNC machine (above) is translated with a ball screw mechanism, and its location is detected with a resolver. The schematic below shows how the table is located with respect to the spindle axis of the machine tool.
Motion Control

- NC machines use electric motor drives with position feedback provided by transducers.
- Older system used DC motors with analog transducers.
- Newer system use AC servomotors, or stepper motors with optical encoders for better accuracy, reliability, lower power consumption and performance to weight ratios.
- Recirculating ball screws drives or linear accelerators help improve accuracy by removing backlash in the drive systems.
- Canned program routines are used when repeated common features are used in the part designs.
Ball Screw Details

FIGURE 26-10 The ball lead screw shown in detail provides great accuracy and position to NC and CNC machine tools.
Canned Routines

FIGURE 26-11 Canned or preprogrammed machining routines greatly simplify programming CNC machines. (Courtesy of Heidenkain Corporation, Elk Grove Village, ILL.)
FIGURE 26-12 The location of the corner of the end mill (left) or the tip of a single-point tool (right) must be known with respect to the tool setting points so that tool dimensions are accurately set.
Part Programming

• NC coding uses a common language.
• Programmers must first establish a reference or zero point.
• Next the part is programmed, defining each step necessary to produce the part.
• Each step defines the x, y, and z location, plus the spindle speed, feed speed, and tool changes from the previous step.
• Following coding, the code is verified, typically by computer simulation
• Finally the code is fed into the machine, either by tape or computer interface
Example of Part Programming

FIGURE 26-13 Example of programming a part in a vertical-spindle NC machine.
Example of Part Programming

**FIGURE 26-13** Example of programming a part in a vertical-spindle NC machine.
Example of Part Programming

FIGURE 26-13 Example of programming a part in a vertical-spindle NC machine.

(c) Programming the outer contour
Example of Part Programming

**FIGURE 26-13** Example of programming a part in a vertical-spindle NC machine.
Example Code for Part in Figure 26-13

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
<th>P9</th>
<th>P10</th>
<th>P11</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>190</td>
<td>190</td>
<td>100</td>
<td>100</td>
<td>70</td>
<td>70</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>160</td>
<td>130</td>
</tr>
<tr>
<td>y</td>
<td>10</td>
<td>130</td>
<td>130</td>
<td>105</td>
<td>105</td>
<td>130</td>
<td>130</td>
<td>20</td>
<td>10</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>z</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

- G01 Y130 F200  Straight line from starting point to P2
- G01 X100  Straight line from P2 to P3
- G01 X105 F150  Straight line from P3 to P4
- G02 X70 Y105 R15  Radial arc, clockwise, with 15 radius
- G01 Y130 F200  Straight line from P5 to P6
- G01 X10  Straight line from P6 to P7
- G01 Y20  Straight line from P7 to P8
- G03 X20 Y10 R10 F150  Radial arc, counterclockwise with 10 radius
- G01 X190 F200  Straight line from P9 to P1
- G00 X160 X100  Rapid traverse to point P10
- G01 Z20 F150  Down feed at point P10
- G01 X130 Y45 Z10  Straight line from P10 to P11
- G01 Z35 F200  Retraction from workpiece
- G00 X300 Y300  Rapid traverse away from workpiece
NC Program Language

<table>
<thead>
<tr>
<th>NC Word</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td><em>Sequence number:</em> identifies the block of information</td>
</tr>
<tr>
<td>G</td>
<td><em>Preparatory function:</em> requests different control functions, including preprogrammed machining routines</td>
</tr>
<tr>
<td>X, Y, Z, B</td>
<td><em>Dimensional coordinate data:</em> linear and angular motion commands for the axis of the machine</td>
</tr>
<tr>
<td>F</td>
<td><em>Feed function:</em> sets feed rate for this operation</td>
</tr>
<tr>
<td>S</td>
<td><em>Speed function:</em> sets cutting speed for this operation</td>
</tr>
<tr>
<td>T</td>
<td><em>Tool function:</em> tells the machine the location of the tool in the tool holder or tool turret</td>
</tr>
<tr>
<td>M</td>
<td><em>Miscellaneous function:</em> turns coolant on or off, opens spindle, reverses spindle, tool change, etc.</td>
</tr>
<tr>
<td>EOB</td>
<td><em>End of block:</em> indicates to the MCU that a full block of information has been transmitted and the block can be executed</td>
</tr>
</tbody>
</table>
Cutter Offset

FIGURE 26-14 Two classic problems in NC programming are the determination of cutter offset and interpolation of cutter parts.
40.3 Machine Center Features and Trends

- MC’s range from simple 2 axis systems to large multi-axis systems.
- System features can be very simple to systems that include automated tool change and workpiece transfer.
- MC system are not limited to milling, but include:
  - Turning centers
  - Punching and Blankling centers
  - EDM centers
  - Laser centers
  - Water jet centers
  - Flame cutting centers
Modern machining centers will typically have horizontal spindles with rpms up to 15,000, dual pallets, and cutting-tool magazines holding 40 to 100 tools.
FIGURE 26-16 This CNC turning center has a multiple-axis capability with two spindles and a 12-tool turret with X, Y, and Z control as well as axis control of the spindles.
Process Accuracy

FIGURE 26-17 Process capability in NC machines is affected by many factors.
Probes

**FIGURE 26-18** (a) Probe carried in the tool changer can be mounted in the spindle (b) for checking the location of part features accurately.
40.4 Ultra-High-Speed Machining Centers (UHSMCs)

- UHSMCs are used to rapidly produce dies
- They include exceptionally high spindle speeds and material removal rates
- They utilize ceramic ball bearings to improve spindle stiffness and spindle speeds.
UHSMC versus Traditional Die Manufacturing

FIGURE 26-19 The process to manufacture dies for forging processes is shown on the left. Using ultra-high-speed machining centers reduces the sequence to two steps.
Ultra-high-speed machining centers (UHSMCs) are being developed with ceramic ball bearings in the spindles, synchronized ball screws on the X-axis to reduce distortion (due to inertia) in the moving components. ("Development of Ultra High Speed Machining Center", Toyota Technical Review, vol. 49, No. 1, September 1999.)