3. 생산시스템 제어

Contents

- **Numeric control**
- **Part program**
- **Manufacturing system control**
  - Machining process control
  - Machining condition optimization

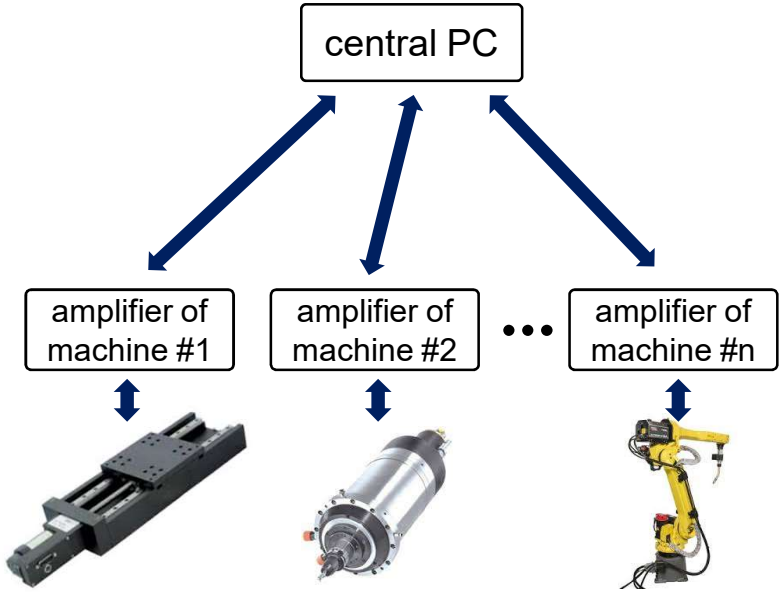
Numeric control (1)

◆ Numeric control

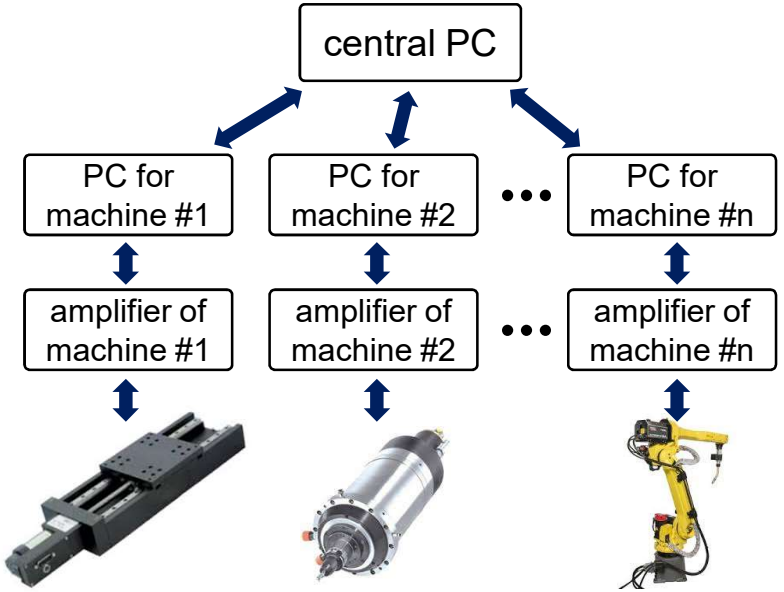
– Control of machines based on the numeric data

▪ Position control of tool and workpiece, tool change, …

<Direct numeric control>



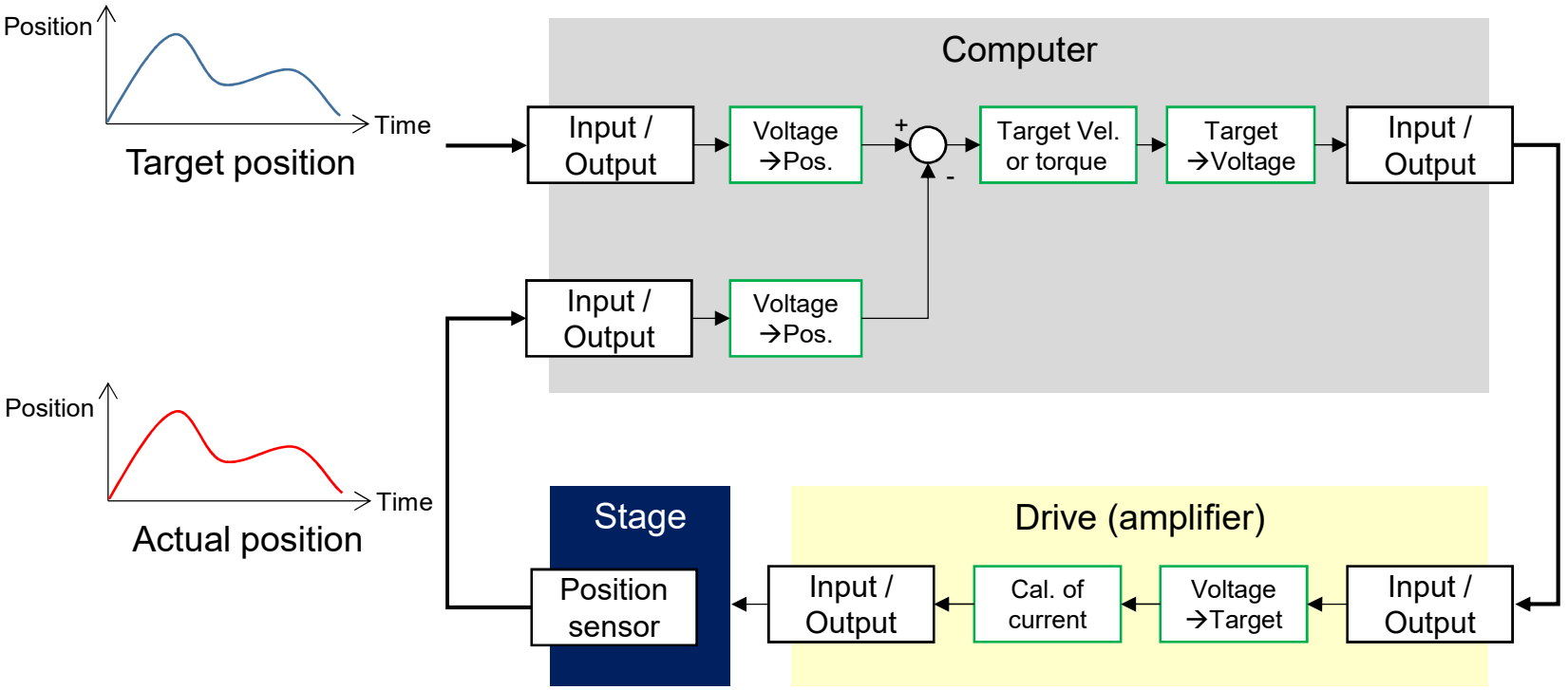
<Distributed numeric control>



Numeric control (2)

◆ Computer aided manufacturing system control

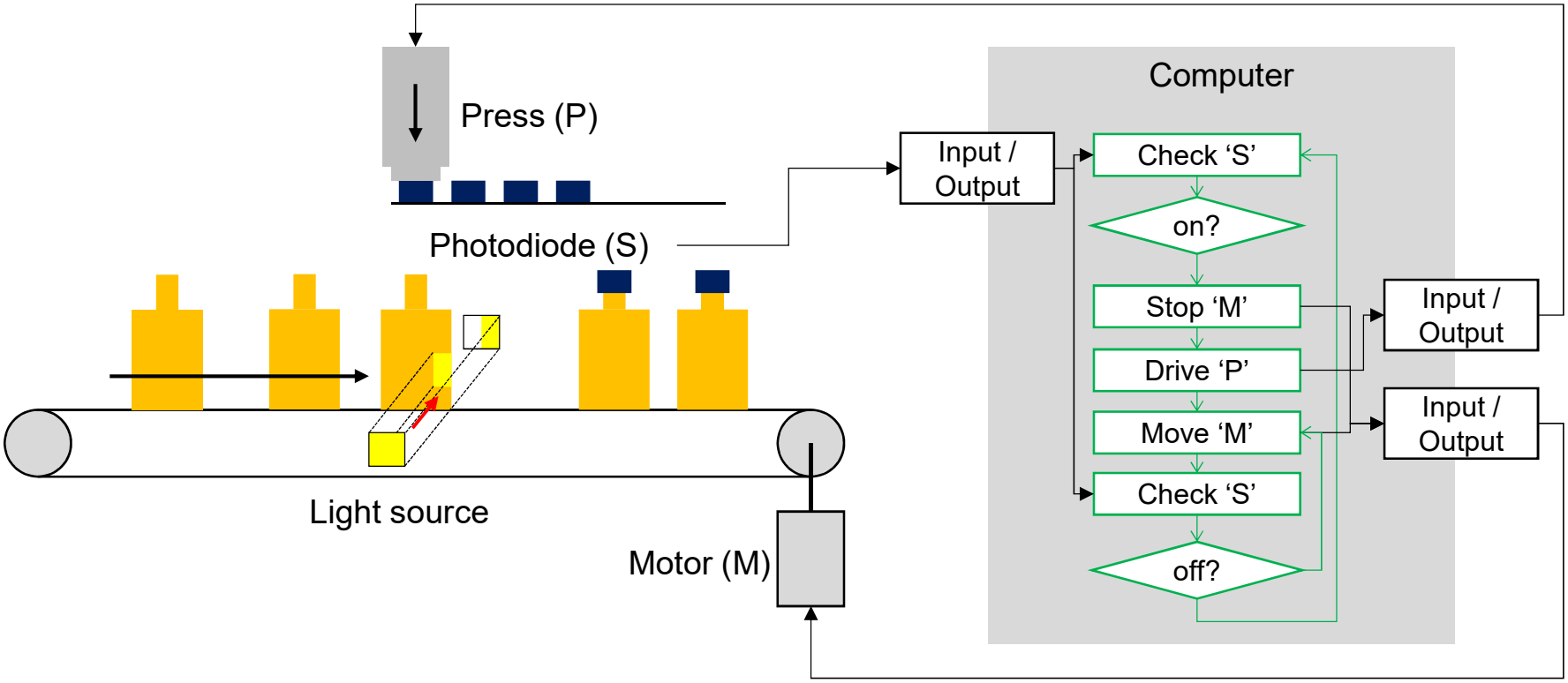
– Motion control (computerized numerical control, CNC)



Numeric control (3)

◆ Computer aided manufacturing system control

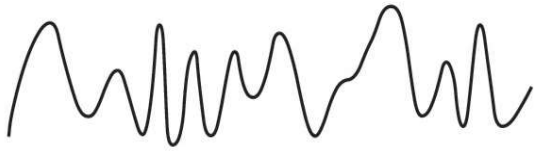
– Process control (programmable logic controller, PLC)



Numeric control (4)

◆ Data exchange among hardware

– Analog voltage



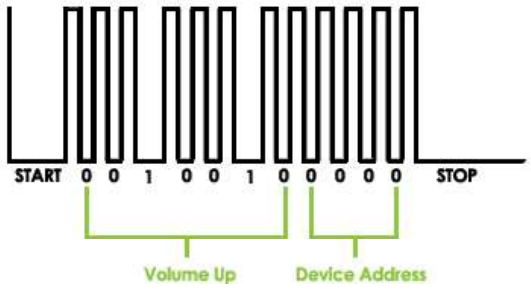
▪ Single data (force, acceleration, …)

– Digital

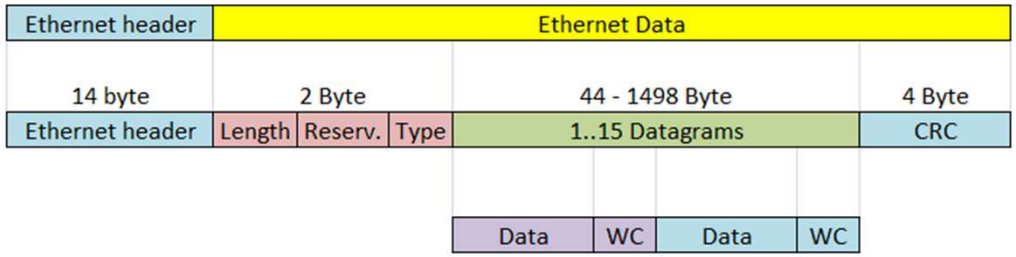
▪ Contact point: on/off signal (limit, …)

▪ Communication: Transmit or receive several numeric data

✓ Ethernet, RS232, CAN, DVI, Bluetooth, IR(remote controller), …



Protocol of IT remote controller



Ethernet data

Part program (1)

◆ Basic concepts

- The NC information is arranged in **block**s.
- Block = a segment on the part → a tool transfer from one point to the next point.
- Typical format
  - N001 G01 X50 Y60 F40 S800

✓ **N**: Sequence number
✓ **G**: Preparatory word
✓ **X, Y**: Coordinates
✓ **F**: Feedrate
✓ **S**: Spindle speed
✓ **T**: Tool section
✓ **M**: Miscellaneous command

- The block consists of words
  - G01 → word, G → word address

Part program (2)

◆ Preparatory Word, G

Word	Description
G00	Rapid linear motion
G01	Linear interpolation
G02	Circular Interpolation CW
G03	Circular Interpolation CCW
G04	Dwell (a programmed time delay)
G17, 18, 19	X-Y Plane; Z-X Plane; Y-Z Plane (needed for circular interpolation)
G90	Absolute Dimensions
G91	Incremental Dimensions

Part program (3)

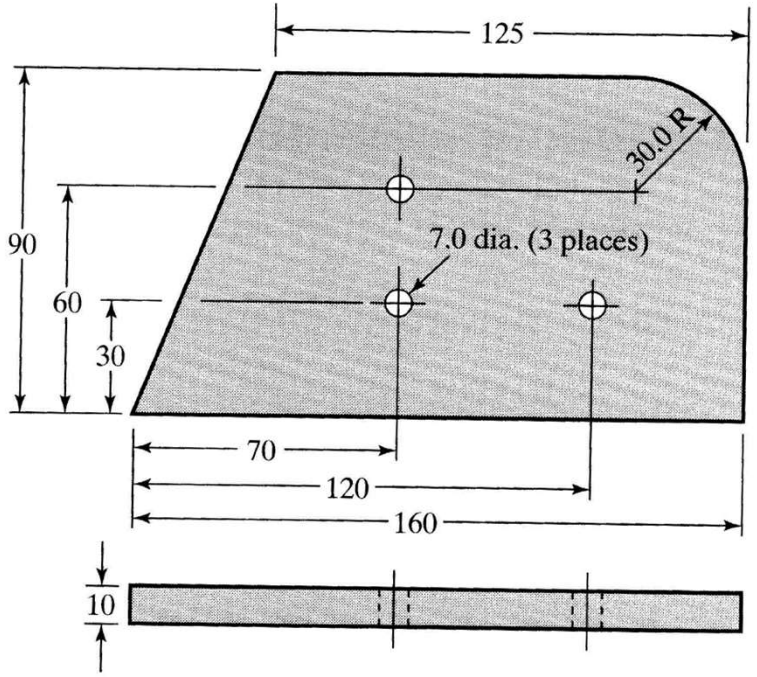
◆ Miscellaneous Words, M

Word	Description
M00	Program stop (stop spindle, coolant and feed)
M02	End of program (stop spindle, coolant and feed)
M03	Start spindle; clockwise rotation
M04	Start spindle; counterclockwise rotation
M05	Spindle off
M06	Tool change
M30	Similar to m02 + tape rewind in NC

Part program (4)

◆ Example1: Manual Part Programming

- Feed: 0.05 mm/rev (F0.05)
- Spindle: 1000 rpm (S1000)
- Move between holes: G00 (PtP)
- Drilling: G01 (linear interpolation in Z-direction)
- Millimeter: G21
- Absolute coordinate: G90
- Define origin: G92



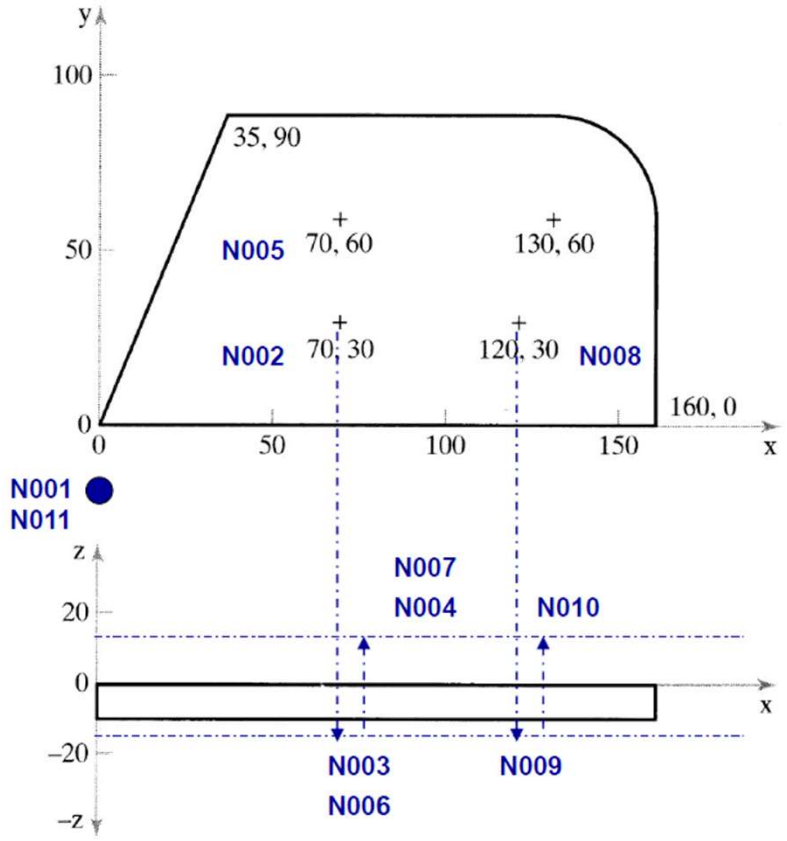
Part program (5)

◆ Example1: Manual Part Programming

– N001 G21 G90 G92 X0 Y-050.0 Z010.0 ;

- N001: Sequence number
- G21: Values are in millimeters
- G90: Absolute coordinate
- G92: Specify location of starting point
- X0: X = 0
- Y-050.0: Y = -50
- Z010.0: Z = 10

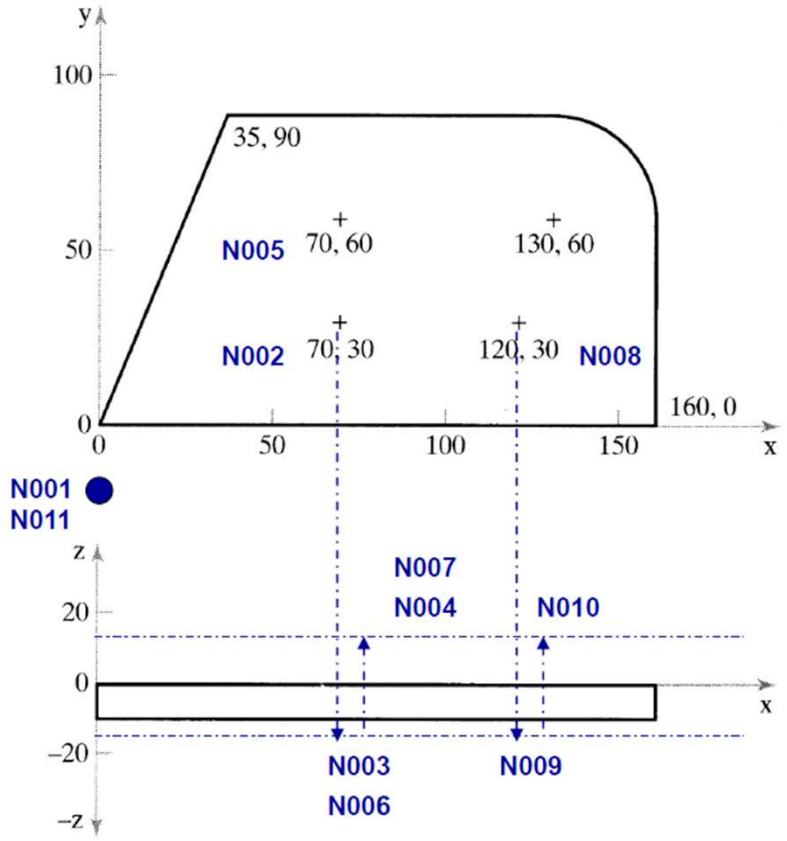
– N002 G00 X070.0 Y030.0 ;



Part program (6)

◆ Example1: Manual Part Programming

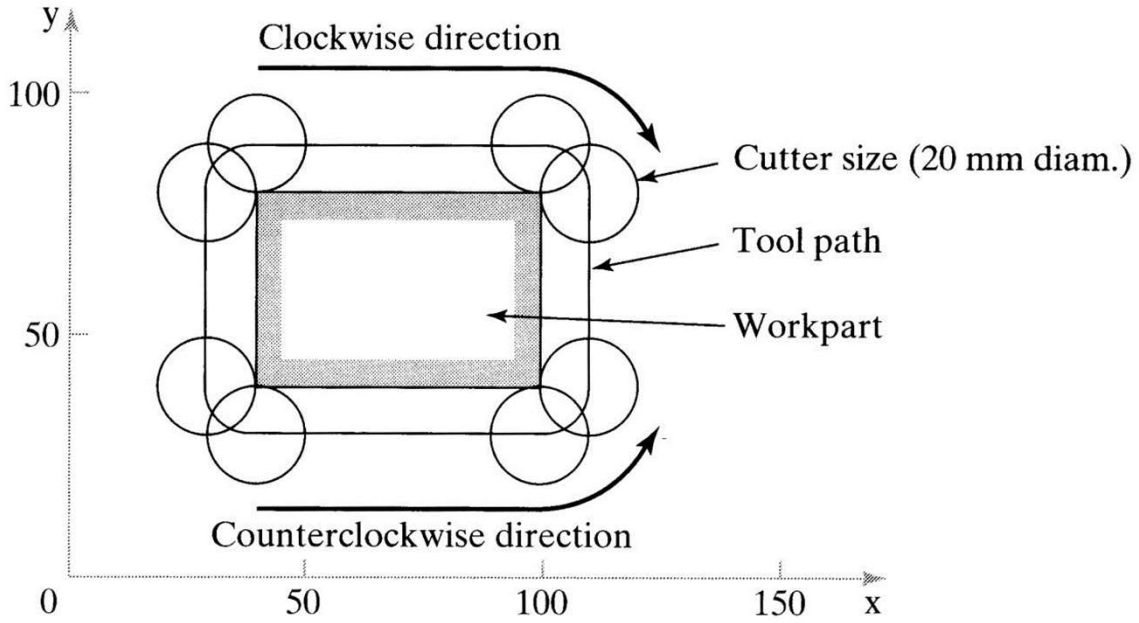
- N003 G01 G95 Z-015.0 F0.05 S1000 M03 ;
  - G95: Specify feed/rev for drill
- N004 G01 Z010.0 ;
- N005 G00 Y060.0 ;
- …
- N012 M30 ;



Part program (7)

◆ Example2: Cutter offset compensation

- G40: Cancel cutter offset compensation
- G41: For left side of part (Clockwise)
- G42: For right side of part (Counterclockwise)

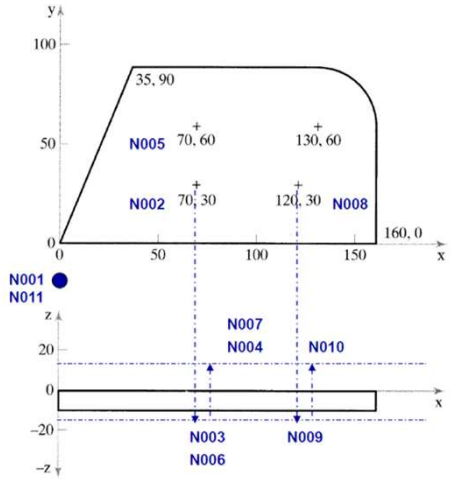


Part program (8)

◆ Example2: Cutter offset compensation

- N001 G21 G90 G92 X0 Y-50.0 Z10.0 ; Define origin of axis
- N002 G00 Z-25.0 S1000 M03 ; Rapid to cutter depth, Turn spindle on
- N003 G01 G94 G42 Y0 D5 F40 ; Engage part, start cutter offset

G94: specify feed per minute in milling and drilling
G42: offset comp. for right-side of the part
D5: Cutter diameter is in register #5
F40: set feed to 40 mm/min



- N004 G01 X160.0 ; Mill lower part edge
- N005 G01 Y60.0 ; Mill right straight edge
- N006 G17 G03 X130.0 Y90.0 R30.0 ; Circ. interpolation around arc

G17: Select x-y plane in milling
G03: Circ. Interpolation, ccw
R30: Radius of the circle is 30

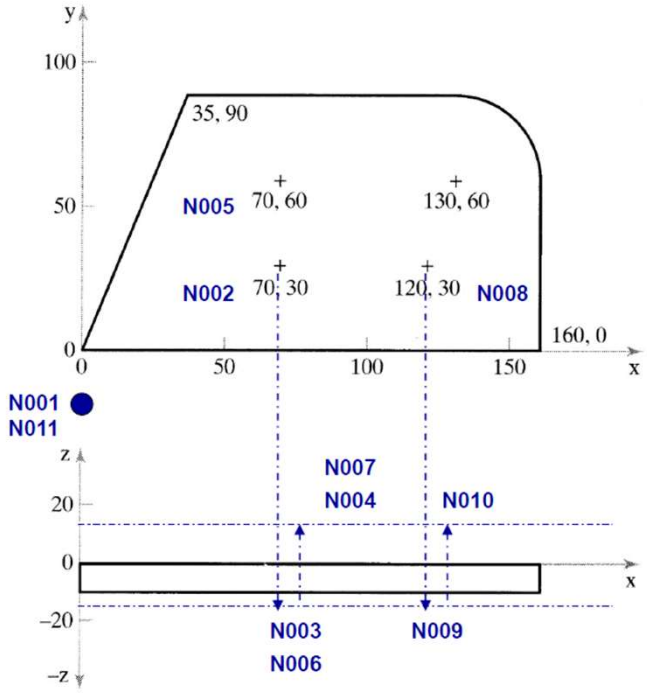
Part program (9)

◆ Example2: Cutter offset compensation

- N007 G01 X35.0 ; Mill upper edge
- N008 G01 X0 Y0 ; Mill left part edge
- N009 G40 G00 X-40.0 M05 ; Rapid exit from part, cancel offset

G40: Cancel offset comp.
M05 (=M5): Spindle stop

- N010 G00 X0 Y-50.0 ; Rapid move to starting point
- N011 M30 ; EOP, stop machine



Machining process control (1)

◆ Definition

– Modification of tool trajectory to improve productivity (machining accuracy, machining speed, …)

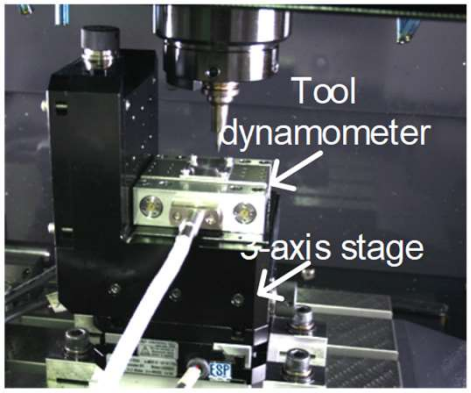
– Examples

- Adjusting feeds and speeds to suppress chatter
- Initiating an emergency stop in response to a tool breakage
- Rewriting a part program to minimize burr formation
- …

Machining process control (2)

◆ Milling: Tool deflection compensation

Approach



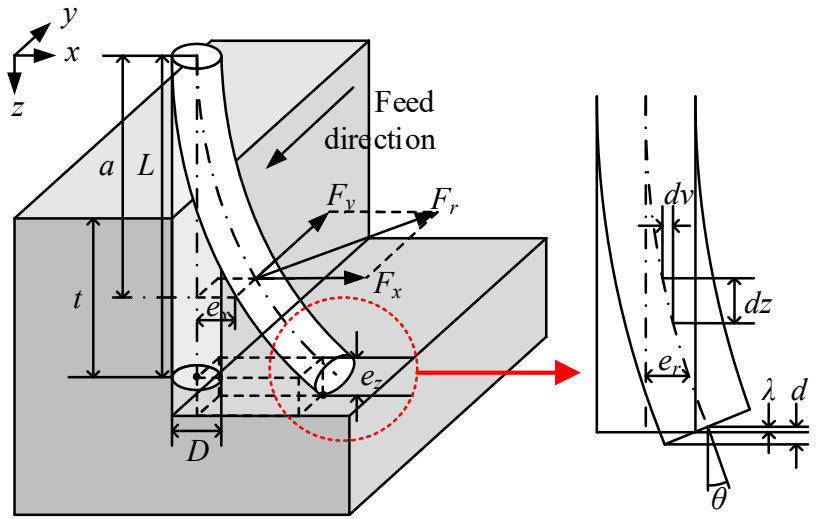
Experimental setup for
tool deflection compensation

Measuring x, y and z
directional forces

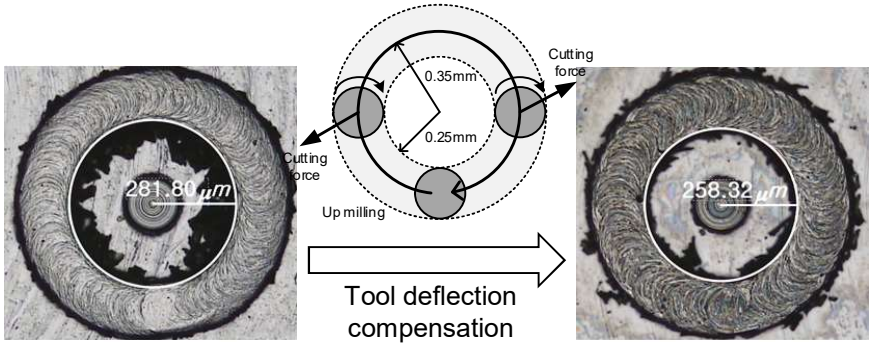
Calculating
machining errors

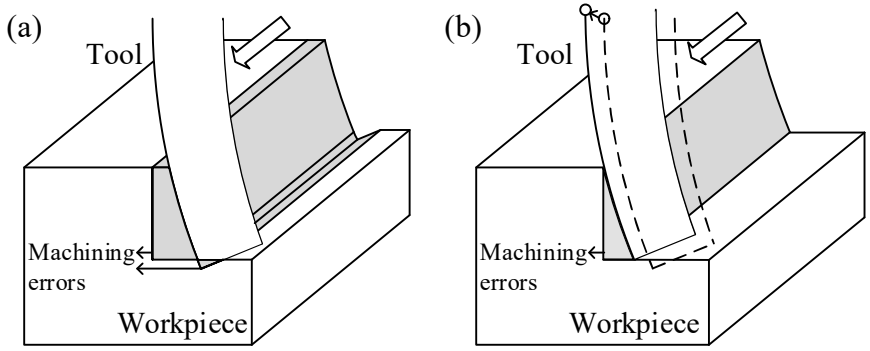
Feedback control of
3-axis stage

Torque command
for 3-axis stage

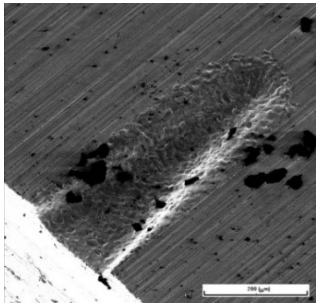


Results



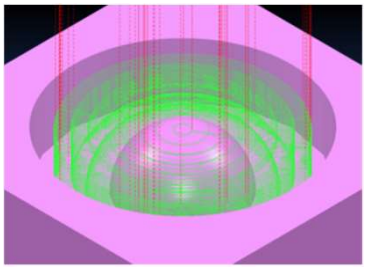


Machining process control (3)



◆ EDM: Tool wear compensation

CAD software



CAM software

G01 Z-.0039
X.015 Y.0088
X.0141 Y.0102

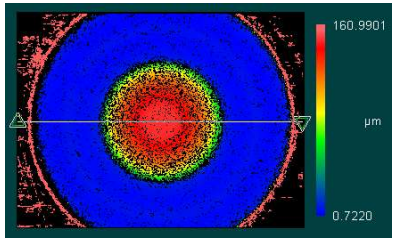
CNC part program
Without compensation

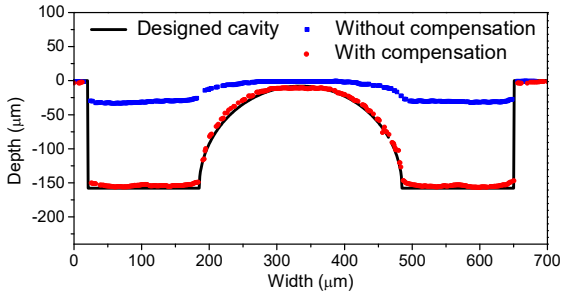
Tool wear compensation program

G01 Z-0.0040
X0.0150 Y0.0088 Z-0.0003
X0.0141 Y0.0102 Z-0.0002

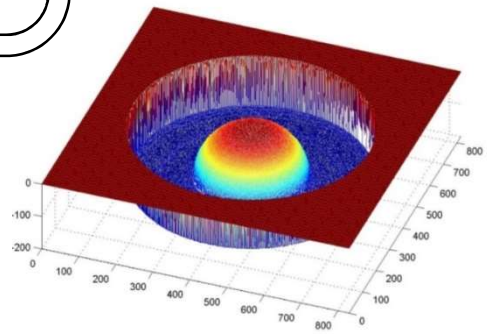
Compensated tool path

EDM machine tool





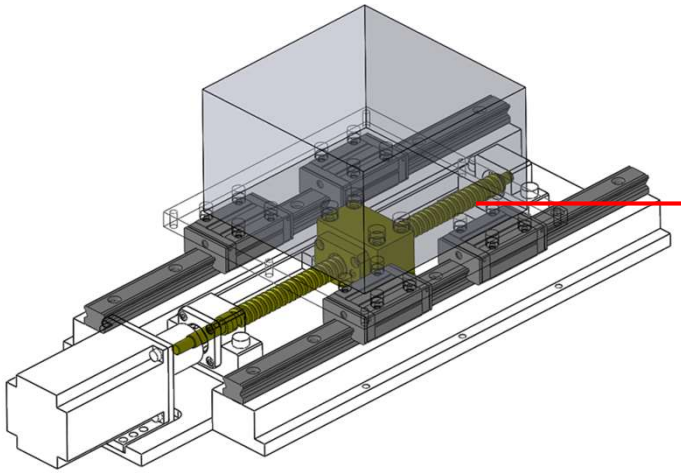
Machined cavity

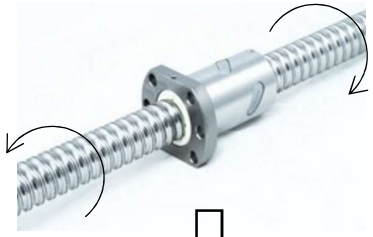


Simulated cavity

Machining process control (4)

◆ Modeling & compensation of ball screw torsion





Torsion of ball screw during acceleration & deceleration

Table position calculated by **rotary encoder**

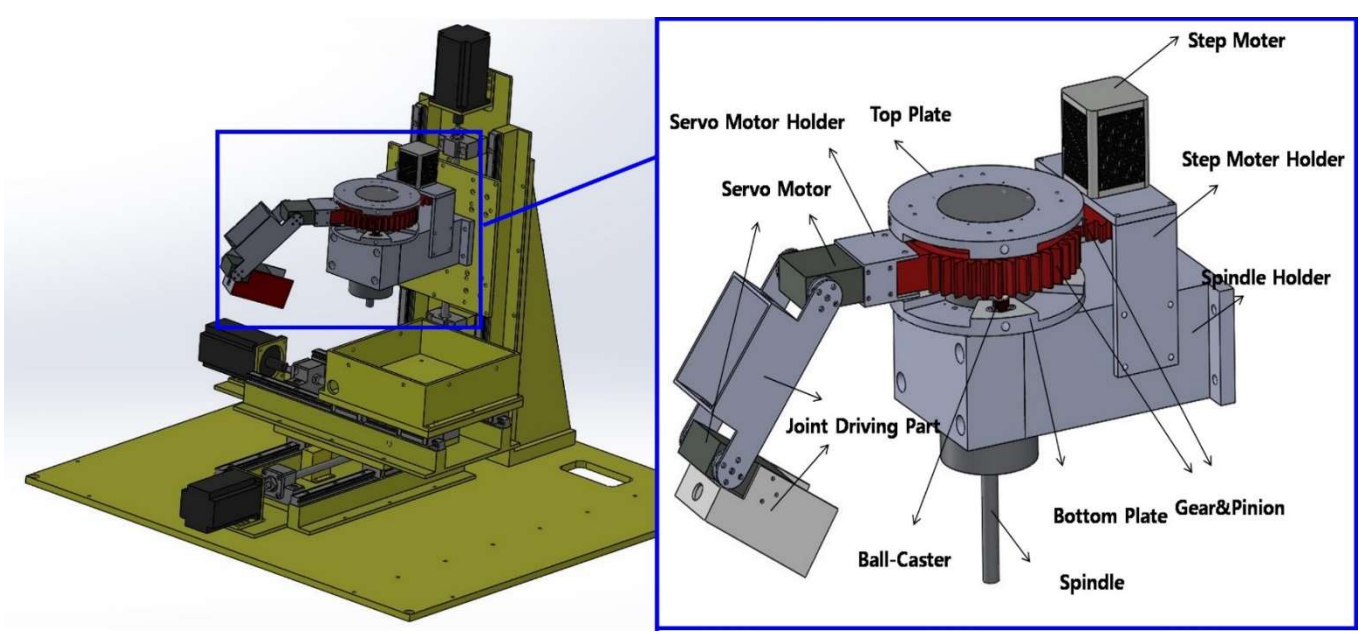
Table position calculated by **linear scale**

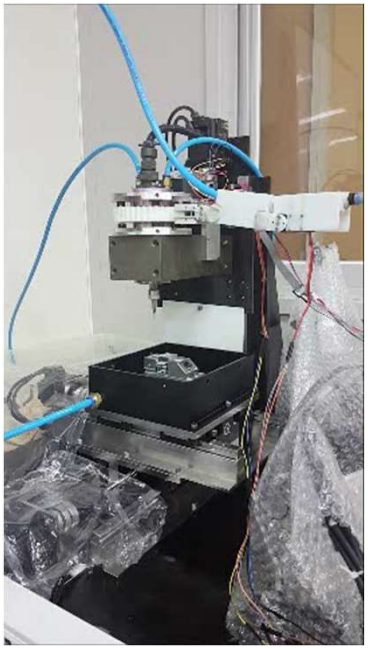
Deterioration of position control performance

Configuration of feedforward control system to compensate ball screw torsion

Machining process control (5)

◆ Intelligent cutting-oil supplier





Real-time monitoring of feed drive torque + G-code
→ Calculation of machining status (direction, side or slot milling, …)
→ Automatic control of nozzle position

Machining condition optimization (1)

◆ Machine tool energy consumption reduction

- Measurement & analysis of the energy consumption

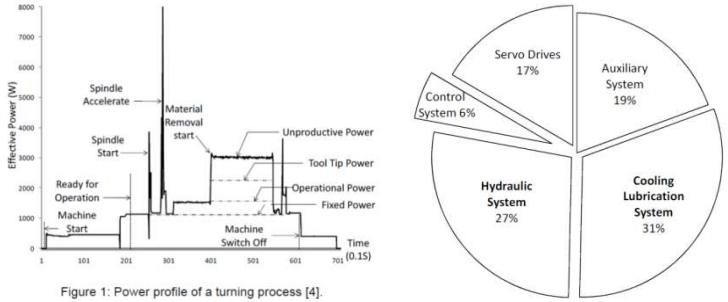
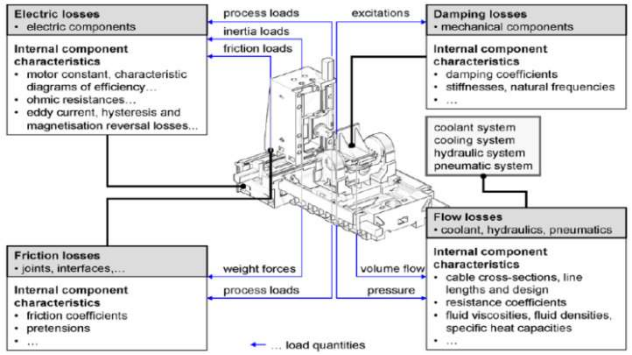
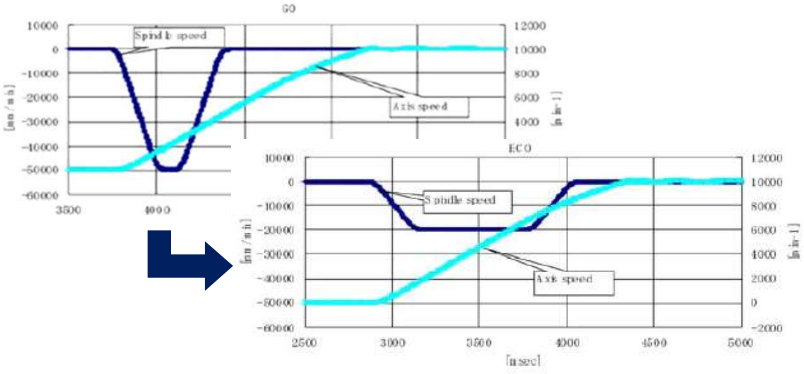


Figure 1: Power profile of a turning process [4].

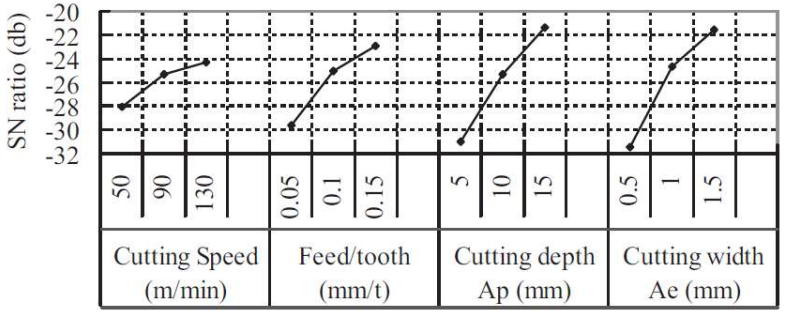
- Design optimization



- Process control



- Optimization of the machining conditions

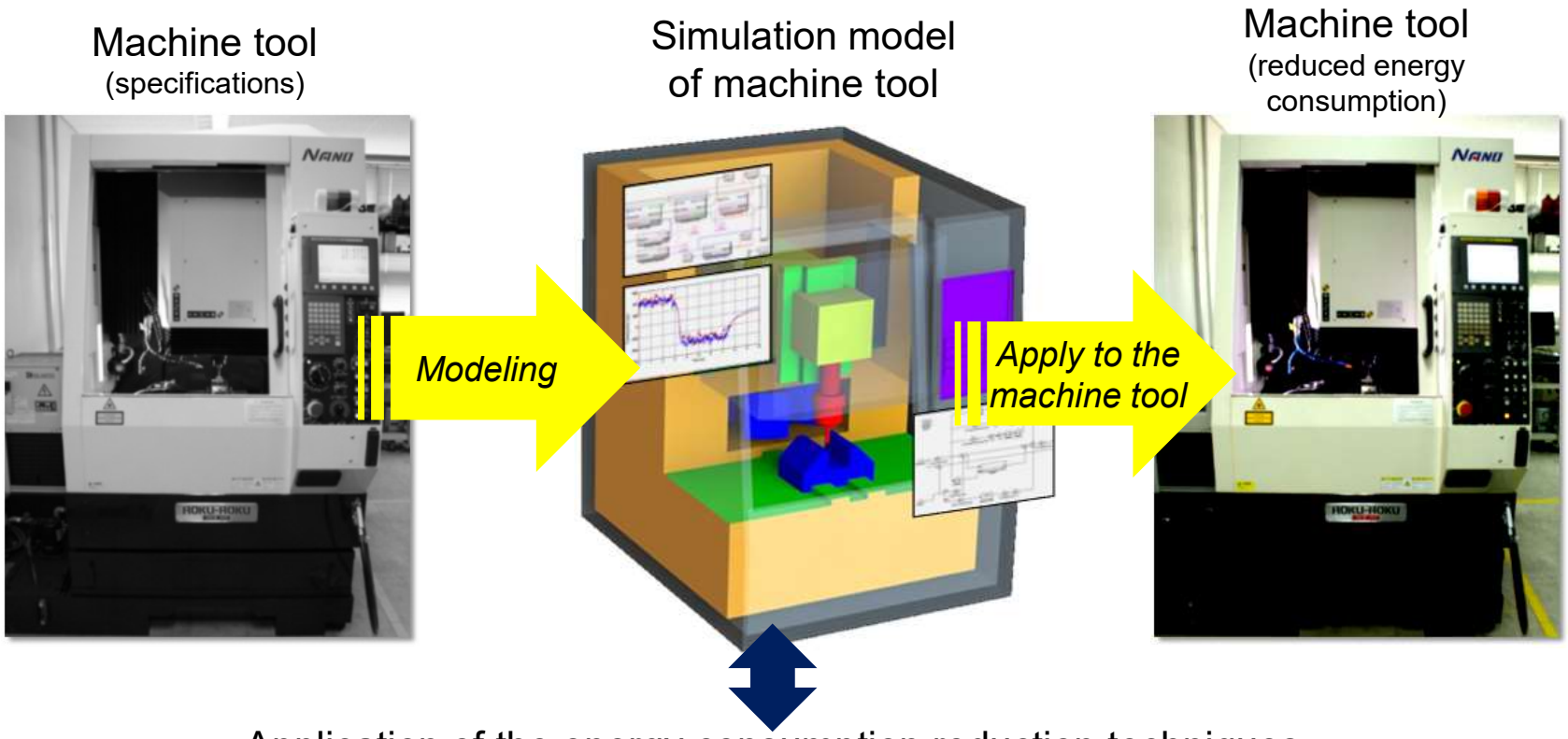


Factorial effect graph (end milling)

→ Limited application to a variety of machine tools and machining conditions

Machining condition optimization (2)

◆ Approach: CPS based energy saving

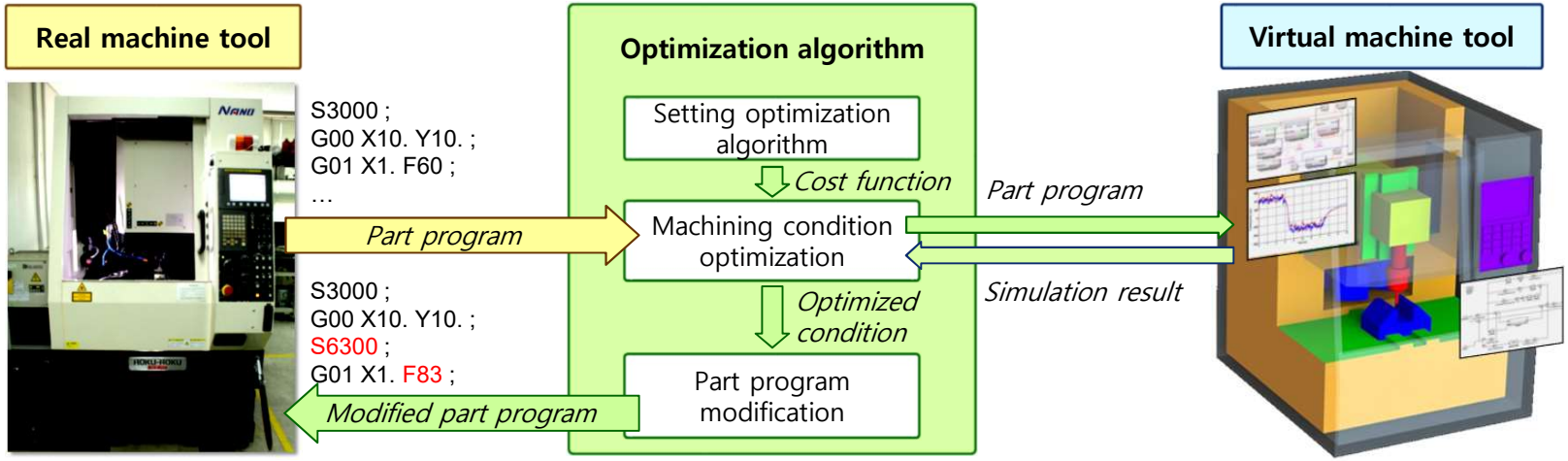


Application of the energy consumption reduction techniques
(design optimization, process control, optimization of the machining conditions, …)

→ Various energy consumption reduction techniques can be tested using VMT without waste of resources

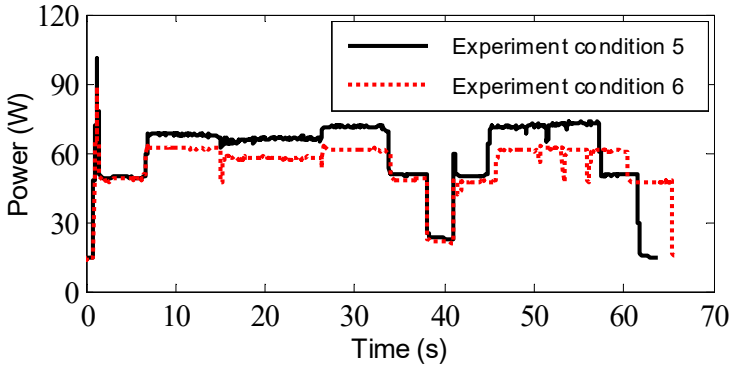
Machining condition optimization (3)

◆ CPS based energy saving



– Result

Machining condition	*w*	*v*	Machining time (*sec*)	*E* (*kJ*)
1	4000	15	270	12.9
2	8000	30	139	7.0
3	12000	45	97	5.5
4	16000	63	73	3.9
5	20000	75	64	3.8
6	12,380 – 15,740	63 – 75	66	3.3



Electrical power consumption profiles