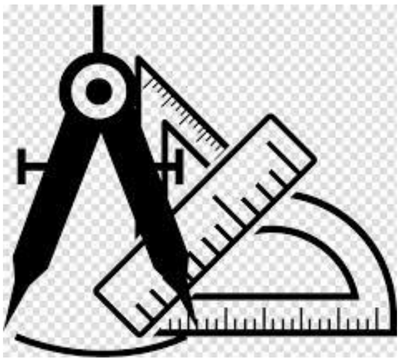
DEPARTMENT OF MECHANICAL ENGINEERING

24ME403 - METROLOGY & MEASUREMENTS

Dr. A. ARUL MARCEL MOSHI,

ASSOCIATE PROFESSOR / MECH.



UNIT V: ADVANCES IN METROLOGY

CO5: To inspect the quality control in Manufacturing Industries with advances in Measurement.

Role of sensors in achieving closed-loop control in smart machine tools.

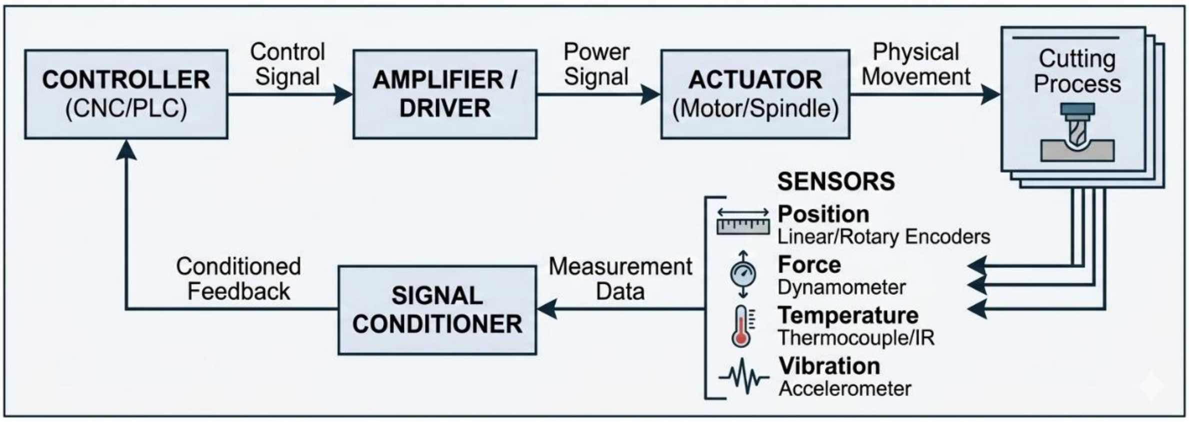
The need for Closed-loop control in Smart machines:

Traditional machine tools often operate on an open-loop control system. In this system, the controller sends a command to the machine's actuator (e.g., "move the tool 10 mm"), but it has no way of verifying if the command was actually executed accurately. Factors like cutting forces, thermal expansion, vibration, and wear can cause discrepancies between the commanded position and the actual position.

Smart machine tools, a cornerstone of Industry 4.0, overcome this limitation by employing closed-loop control. This system constantly monitors the actual output and feeds this information back to the controller to correct any errors in real-time. Sensors are the critical components that bridge the gap between the physical process and the digital controller, providing the 'feedback' signal that makes closed-loop control possible.

The principle of Closed-loop control with sensors:

The fundamental role of sensors is to provide precise, real-time data about the machine's state. This data is compared to the desired state, and any difference (error) is used to generate a corrective action. A schematic diagram illustrating this principle is shown below:



Role of different sensors in the control loop:

Different sensors are deployed on a smart machine tool to monitor various aspects of the machining process. The data from each is used for specific closed-loop control functions.

i) **Position sensors:**

Role: To measure the exact position of the machine's slides (X, Y, Z axes) and the spindle orientation.

Examples: Linear scales (optical or magnetic) and rotary encoders.

Control action:

- The controller commands a position.
- The linear scale measures the actual slide position.
- The feedback is compared to the command. If the slide is not at the correct position (e.g., due to ball screw backlash or thermal expansion of the leadscrew), the controller sends an additional signal to the motor to correct the error. This is the most fundamental level of closed-loop control, ensuring geometric accuracy.

ii) **Force and Power sensors:**

Role: To measure the cutting forces or the power consumed by the spindle motor. These are direct indicators of the cutting load.

Examples: Piezoelectric dynamometers, strain gauges integrated into tool holders or spindles, and power transducers on the motor drive.

Control action:

- A sudden spike in cutting force could indicate a tool breakage or a hard spot in the material.
- An increase in force beyond a set threshold can trigger an automatic reduction in feed rate or spindle speed to prevent tool breakage or damage to the workpiece.
- If the force decreases unexpectedly, it might indicate tool wear, prompting a tool change request. This is known as Adaptive Control.

iii) **Temperature sensors:**

Role: To monitor the temperature of critical machine components like spindle bearings, guideways, and the machine structure itself. Thermal growth is a major source of inaccuracy.

Examples: Resistance Temperature Detectors (RTDs), thermocouples, and infrared cameras.

Control action:

- Sensors detect a temperature rise in the spindle.
- This data is fed into a thermal compensation model within the controller.
- The controller calculates the expected thermal expansion of the spindle and automatically adjusts the tool position (e.g., offsets in Z-axis) to compensate for the error, maintaining accuracy even as the machine warms up.

iv) Vibration sensors:

Role: To detect the violent form of self-excited vibration that ruins surface finish and damages tools and spindles.

Examples: Accelerometers mounted on the spindle housing or workpiece table.

Control action:

- The accelerometer detects characteristic vibration frequencies associated with chatter.
- The controller can instantly adjust the spindle speed (a technique called "spindle speed variation") or change the toolpath slightly to disrupt the chatter condition, ensuring a stable and high-quality cut.

Integration for Smart Functionality:

The true power of these sensors is realized when their data is integrated. A smart machine tool uses a central processor to fuse data from multiple sensors to make intelligent decisions. For example, during a high-precision finishing cut:

- Position sensors ensure the tool is following the programmed path.
- Temperature sensors provide data for thermal compensation.
- Vibration sensors confirm the cut is stable.
- Force sensors verify that the tool is sharp and the load is consistent.

If the vibration sensor detects a slight increase in amplitude, the system might correlate this with a gradual rise in cutting force from the force sensor. The controller could then diagnose the onset of tool wear and make a minor adjustment to the feed rate to prolong tool life and complete the cut successfully.