Driving Motor and Sensor

The driving motor: it mean both the servo motor, which moves the table, and the spindle motor, which rotates the spindle.
The spindle: is the device that generates adequate cutting speed and torque by rotating the tool or workpiece.

Machine tools, such as turning machines and machining centers, need high torque for heavy cutting in the low-speed range and high speed for rapid movement in the high-speed range. Also, motors with small inertia are needed for machines that frequently repeat tasks whose machining time is very short; for example, punch presses and high-speed tapping machines.
**Encoder:**
An encoder is a sensor of mechanical motion that generates digital signals in response to motion. As an *electro-mechanical device*, an encoder is able to provide motion control system users with information concerning

*position, velocity, direction.*

There are two different types of encoders: linear and rotary. **A linear encoder** responds to motion along a path, while a **rotary encoder** responds to rotational motion.

An encoder is generally categorized by the means of its output. **An incremental encoder** generates a train of pulses which can be used to determine position and speed. **An absolute encoder** generates unique bit configurations to track positions directly.
**Incremental-type encoder:**

It utilizes a transparent disk which contains opaque sections that are equally spaced to determine movement. A light emitting diode is used to pass through the glass disk and is detected by a photodetector. This causes the encoder to generate a train of equally spaced pulses as it rotates. The output of incremental rotary encoders is measured in **pulses per revolution** which is used to keep track of **position** or determine **speed**. A single-channel output is commonly implemented in applications in which direction of movement is not significant. Instances in which direction sensing is important, a 2-channel, quadrature, output is used. The two channels, A and B, are commonly 90 electrical degrees out of phase and the electronic components determine the direction based on the phase relationship between the two channels. The position of an incremental encoder is done by adding up all the pulses by a counter.

Pulse train produced from incremental encoder
Absolute-type encoder

Absolute encoders utilize stationary mask in between the photodetector and the encoder disk as shown below. The output signal generated from an absolute encoder is in digital bits which correspond to a unique position. The bit configuration is produced by the light which is received by the photodetector when the disk rotates. The light configuration received is translated into gray code. As a result, each position has its own unique bit configuration.

Absolute Encoder disk with concentric circle pattern
**Resolver:**

It is a detector of *rotation angle* and *position* and is used as the sensor of a motor. It generates an output in analog format.

A resolver consists of a stator, a rotor, and a rotation transformer. The coils of the stator and rotor are arranged to make the distribution of magnetic flux a sine wave with respect to the angle.

\[
a = \frac{V_{S1}}{V_R}
\]

\[
a = \frac{V_{S2}}{V_R}
\]

\[0° \rightarrow 180° \rightarrow 360°\]

Rotation angle $\alpha$
**Speed sensor:**

A tacho-generator is one of the typical speed sensors.

It can be classified into brush-built-in types and brushless types. 

**A brush-built-in type** has a similar structure to a direct current dynamo. It comprises a stator, which is made from a permanent magnet, and a rotor, which is coiled. As a coil emits a magnetic flux with rotation of the rotor, a voltage is generated and is transmitted to the outside via the brush. 

**The brushless-type** comprises a rotor, being a permanent magnet, a coiled stator, and a single device that detects the position of the rotor.

According to the rotational position of the rotor, the smoothed voltage induced from each coil is output sequentially. 

These two types generate a voltage that is proportional to the rotation speed.
**Linear Movement Guide**

A ball screw and Lead screw is used to move the tool post or table and plays the role of changing the rotation of a servo motor into linear movement. A Linear Movement (LM) guide is used to increase the accuracy and smoothness of the linear movement. An LM guide consists of an M-shaped guide rail and a transferring part. Lubricant is supplied to the surface of the LM guide rail to decrease friction while the transferring part is moving.

In CNC, the displacement length per one pulse output from NC is defined as a **BLU** (Basic Length Unit). For example, if one pulse makes a servo motor rotate by one degree and the servo motor moves the table by 0.0001mm, one BLU will be 0.0001mm.
### Comparison of Lead Screw and Ball Screw

<table>
<thead>
<tr>
<th>Feature</th>
<th>Lead Screw</th>
<th>Ball Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Low</td>
<td>More expensive</td>
</tr>
<tr>
<td>Noise</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Self locking</td>
<td>Self locking</td>
<td>Not self locking</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Low (25-70%)</td>
<td>High (90%)</td>
</tr>
<tr>
<td>Overheating</td>
<td>Overheating</td>
<td>Don't overheat</td>
</tr>
<tr>
<td>Precision</td>
<td>Less</td>
<td>High</td>
</tr>
</tbody>
</table>
As the actual velocity and position detected from a sensor are fed back to a control circuit, the servo motor used in the CNC machine is continuously controlled to minimize the velocity error or the position error. The feedback control system consists of three independent control loops for each axis of the machine tool:

1. **position-control loop,**
2. **velocity-control loop,**
3. **current-control loop.**

In general, the position-control loop is located in the NC and the others are located in a servo driving device.
In the **spindle system of machine tools**, feedback control of velocity is applied to maintain a regular rotation speed.

The feedback signal is generally generated in two ways;  
1. a tacho-generator, which generates an induction voltage (analog signal) as a feedback signal,  
2. and an optical encoder, which generates pulses (digital signals).

The detector can be attached to the shaft of a servo motor or the moving part and the control system can be categorized into the following types according to the location at which the detector is attached.
1. **Closed loop:** the position detector is attached to the machine table and the actual position error is fed back to the control system.
2. Open loop:
It has no feedback. Open loop can be applied in the case where the accuracy of control is not high and a stepping motor is used. Because open loop does not need a detector and a feedback circuit, the structure is very simple. Also, the accuracy of the driving system is directly influenced by the accuracy of the stepping motor, ball screw, and transmission.
3. **Semi-closed loop:**
It is the most popular control mechanism and has the structure shown in Fig. below. In this type, a position detector is attached to the shaft of a servo motor and detects the rotation angle. The position accuracy of the axis has a great influence on the accuracy of the ball screw. For this reason, ball screws with high accuracy were developed and are widely used.
The Components of the CNC system

The CNC system is composed of three units; **the NC unit** which offers the user interface and carries out position control, **the motor unit**, and the **driver unit**.
The CNC software system consists of:

**The MMI (Man Machine Interface) unit**
1. offers the interface between NC and the user,
2. executes the machine operation command,
3. displays machine status,
4. offers functions for editing the part program and communication.

**The NCK (Numerical Control Kernel) unit**, being the core of the CNC system,
1. interprets the part program
2. executes interpolation, position control, and error compensation based on the interpreted part program.
3. controls the servo system and causes the workpiece to be machined.

**The PLC (Programmable Logic Control) unit**
1. sequentially controls tool change, spindle speed, workpiece change, and in/out signal processing
2. controlling the machine’s behavior with the exception of servo control.
The components of a CNC system
The CNC hardware system consist of:
1. CNC,
2. motor drive system,
3. machine tools.

The output of the position control, being the end function of the CNC system, is sent to the motor drive system, the motor drive system operates a servo motor by velocity control and torque control, and, finally, the servo motor makes the moving part move via the power-transmission device.

In the CNC system, the processor modules that process the functions of the MMI unit, NCK unit, and the PLC unit consist of a
1. main processor, (stores user applications)
2. a system ROM (stores part programs)
3. a RAM that, (stores PLC programs).

The process module is connected with an interface that is equipped with key input, display control, external input and system bus.

The CNC system also has an Analog/Digital input/output device for direct communication with external machines and a communication interface for linking an external motor driving device with an input/output module.