Environment-proof High-accuracy MP Scale

In 1970, Mitsubishi Heavy Industries, Ltd. (MHI) started to manufacture and market scales under a technical alliance with Inductosyn Corp., a scale manufacturer in the U.S. This alliance was formed for the establishment of position detection technology as the core of enhancing machine tool positioning accuracy. After the product name was changed to MP (Mitsubishi Precision) Scale in 1990, MHI continued with its original technology-incorporated and market needs-addressed product development. At present MP Scale is used in machine tools and presses not only in house, but also by our customers as a harsh environment-resistant, high-speed/high-accuracy scale.

This paper introduces the Linear MP Scale, which detects the linear position, and its downsized and performance-improved controller (A/D converter) for the MP Scale, as well as the Rotary MP Scale with a built-in A/D converter for angle detection.

1. Features of MP Scale

   (1) High accuracy

   The basic function of a machine tool depends upon how fast a tool and a workpiece can be moved and how precisely the position can be determined.

   The desired position to be detected using a machine tool is where the tool contacts the workpiece to be machined or the so-called machining position. For high-accuracy positioning by a machine tool, a high-accuracy scale that can be mounted near the machining position becomes necessary.

   The Linear MP Scale for linear position detection is accurate up to 5 μmp-p/m in spec. (for the MPLC series), and in addition, its thickness of 19 mm (Figure 1) makes it thin enough to be mounted near the machining position. Figure 2 shows an example of the Linear MP Scale mounted on a horizontal machining center. The machine’s accuracy can be improved by mounting the scale near the machining position so as to limit the effect of the machine’s yawing.

   ![Figure 1 Linear MP Scale](image)

   The Linear MP Scale is composed of a fixed part scale and a moving part slider, which are not in contact and are spaced-mounted. It is unbreakable as the base material is iron.
The Rotary MP Scale is also thin at 19 mm and has an accuracy of 2 seconds p-p in spec. (for the MPRZ-1236B). Furthermore, unlike general rotary scales, since a detection pattern has been prepared for the entire 360° circumference, even if eccentricity occurs such as due to a load or mechanical backlash and play, the resulting error is cancelled out (Figure 3).

(2) High-speed detection

Because of the movable side's high-speed sliding, a scale should desirably have no parts that wear such as bearings. The MP Scale is a non-contact open type with its fixed part separated from its moving part so it has no parts that wear. Depending upon the type of A/D converter, the Rotary MP Scale can detect thickness down to as low as 10,000 min⁻¹, and therefore is used not only on a rotational axis of a rotary table, etc., but also around the main shaft of a lathe that rotates at a high speed (Figure 4).
(3) Resistance to environment

Customers need a scale that satisfies not only high speed, high resolution, and high accuracy, but also long-term stability to maintain high-rate operation.

MP Scale is an electromagnetically induced open-type detector with no parts that wear or deteriorate as a factor for accuracy degradation. Moreover, its iron base, unlike a glass one, is unbreakable.

Since machine tools are found in environments in which coolant, chips, shavings, etc., easily scatter on the scale, it is important for the scale to be environment-proof.

In the case of an optical scale, the scale is generally an encased package type to be protected from coolant, etc., within which bearings, seals, and other parts that wear exist. Furthermore, air purging* and other measures are undertaken in order to limit the amount of foreign matter entering the scale, but if purged air or other mist causes clouding and/or condensation on the scale surface or detection head, sometimes the position cannot be detected.

* To send compressed air into the scale from outside, using a hose, to eliminate foreign matter by the pressure.

The MP Scale is theoretically unaffected by water, oil and condensation since it is electromagnetically induced. Based on over 40 years of successful utilization on machine tools, improvement efforts have been accumulated for environmental resistance, realizing the redundancy of air purging despite being an open-type scale. Figure 5 shows an example of experiments where the Rotary MP Scale operated normally even when submerged, and Figure 6 represents an actual case of the Linear MP Scale operating normally and stably for 7 years, even under oil-smeared conditions.
In addition, since a detection pattern has, unlike in general scales, been prepared over a wide range, the influence of scale division errors is mitigated due to the averaging effect, even if a small amount of foreign matter is on the divisions (Figure 7).

Here, some examples of extreme cases are introduced and the test results of the scale surface covered by pieces of iron or copper or water droplets are shown (Figure 8). Pieces of iron and copper block the light completely and also affect the action of electromagnetic induction as the principle on which an MP scale operates, but the position was detected with only slightly deteriorated accuracy. At the same time, on the water droplet-covered surface, there was no change in accuracy.

Figure 7  Influence of general scale and MP Scale divisional errors

Figure 8  Influence of foreign matter adhered to scale surface
Position is detected almost normally, even on a scale surface with adhered pieces of iron or copper or water droplets.
2. Linear MP Scale line-up

The Linear MP Scale is available in 3 series (Figure 9), meeting a variety of applications.

1. MPLN
   The most compact 30 mm-wide type for small aircraft.

2. MPLC
   Wider with a width of 58 mm but more accurate than the MPLN and used for general aircraft products.

3. MPS-C
   For large aircraft with the same size (of 58 mm in width) and accuracy as those of MPLC. With a length of 1 meter or less per scale, several scales can be put together to extend the stroke. The long scales of other companies are commonly of a one-piece type, requiring stroke-specific order/inventory management, but the MPS-C series can connect short-stroke products for greater convenience in terms of management.

3. A/D converter with better performance

The A/D converter is an external controller to be connected to the MP Scale that calculates the position from electromagnetic induction signals of the scale to output positional information to an NC device. It is generally mounted on the control panel. Recently, this A/D converter was downsized and had its performance improved, and thus a new A/D converter (K type) was developed. Table 1 shows a comparison with the existing product (J type).

<table>
<thead>
<tr>
<th></th>
<th>Existing J type</th>
<th>New K type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>160 x 160 x 40 mm</td>
<td>85 x 57 x 40 mm</td>
</tr>
<tr>
<td>Power supply</td>
<td>AC100V x 0.4 A</td>
<td>DC5V x 0.35 A</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.05 μm</td>
<td>0.01 μm</td>
</tr>
<tr>
<td>Gain adjustment</td>
<td>Necessary</td>
<td>Unnecessary</td>
</tr>
<tr>
<td>Interpolation accuracy adjustment</td>
<td>The interpolation accuracy adjustment volume is used to correct errors of the converter while monitoring the accuracy.</td>
<td>The machine is made to move at a constant speed so that interpolation errors can be automatically obtained for value-based compensation.</td>
</tr>
<tr>
<td>DIN rail fitting</td>
<td>×</td>
<td>○</td>
</tr>
</tbody>
</table>
(1) Downsizing
   Downsized to 1/5 the volume of the existing device.

(2) Wire saving
   The J type requires AC power supply wiring, while the K type can be driven by the NC device’s DC5V power supply, eliminating the need for power supply wiring.

(3) Higher resolution
   The resolution (= minimum detection unit) was improved from conventional 0.05 μm to 0.01 μm while preserving the capability to detect signals at the same high speed of 1,800 m/min as the J type.

(4) Eliminating need for gain adjustment
   For the J type, it was necessary to manually adjust the amplitude of the gain volume of the scale signals, while on the other hand, the K type no longer requires such manual adjustment due to automation.

(5) Automated interpolation error compensation
   A scale is generally divided into equal pitches and the position within one pitch is determined through electric divisional compensation (interpolation). The error within a one-pitch range is called an interpolation error, which repeatedly appear on each division as periodic errors. The J type can reduce the periodic component of an interpolation error, using the adjustment volume, but is necessary to measure the error by a method such as using a laser for adjustment.

   For the K type, on the other hand, if the scale is made to slide at a constant speed, the periodic component of an interpolation error is automatically extracted and memorized to be corrected. As a result, neither laser measurement nor volume adjustment is required. Moreover, even the periodic component that the J type failed to remove completely is corrected.

   Since an interpolation error also depends upon the scale itself and how the scale is mounted, the fact that the compensation of interpolation errors can be handled on machine (with the scale remaining on the machine tool) by the customer is another excellent feature.

   Like in the actual case shown in Figure 10, the addition of the K type A/D converter’s interpolation function to the MP Scale not only permits the removal of periodic errors, but also improves accuracy.

![Figure 10](Image)

---

4. Rotary MP Scale with built-in A/D converter

In response to the recent needs for more compact machinery, as well as for control panel downsizing, MHI developed the Rotary MP Scale MPZA series with a built-in A/D converter and made it more compact.

(1) Compactness
   The MPZA series has 2 models at present (Table 2), and the small caliber-type MPZA2024A is 13% smaller in outer diameter than the existing product (MPRZ536A+ADB-20J70 controller) and the controller has also been downsized by 96% to be built into the scale (Figure 11). In addition to a thickness as thin as 20 mm, the scale has proven to be able to contribute to downsizing of machine tools (Figure 12).
Table 2  Main data on MPZA series

<table>
<thead>
<tr>
<th>Item</th>
<th>MPZA-2024A</th>
<th>MPZA-6036A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer/inner diameter</td>
<td>110/20 mm</td>
<td>200/60 mm</td>
</tr>
<tr>
<td>Accuracy (peak to peak)</td>
<td>5 seconds p-p</td>
<td>4 seconds p-p</td>
</tr>
<tr>
<td>in seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>$2^{23}$/rev</td>
<td>$2^{23}$/rev</td>
</tr>
<tr>
<td>(8388608 pulses/revolution)</td>
<td></td>
<td>(8388608 pulses/revolution)</td>
</tr>
<tr>
<td>Speed (maximum</td>
<td>10,000 min$^{-1}$</td>
<td>10,000 min$^{-1}$</td>
</tr>
<tr>
<td>response rotating speed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connectable NC</td>
<td>FANUC, Mitsubishi CNC, Siemens</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11  Comparison with existing product components

Figure 12  Mounted MPZA2024A

(2) High accuracy

As a rule, the smaller the scale diameter, the worse the interpolation errors. This is because the circumferential error $\Delta$ of r-diameter rotary scale divisions has easily depended on factors such as the manufacturing conditions, and it is roughly calculated as $\Delta/r$ in terms of angle. The MPZA has achieved both compactness and high accuracy, using devised patterns and an error compensation function (Figure 13).

Figure 13  Error compensation function of MPZA2024A

Toward the future, MHI intends to expand and improve built-in controller-type products to maintain an attractive lineup.