[Technical Article]

High Resolution Sensor Bearing with an Index Signal

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This bearing with a rotation sensor is used for the purpose of speed control and rotational direction detection of servomotors used in, for example, battery forklifts. The sensor outputs two phase A and B signals. **NTN** and **NTN-SNR** have now newly developed a high-resolution rotational sensor bearing with an index signal output.

1. Foreword

NTN has added to its lineup “rotation sensor-equipped bearings” that combine a shaft and a rotation sensor into a unit as products that supports electrical control of industrial machines such as rotation control of servo motors [1),2)]. Using a sensor IC (MPS40S) [3)] made by **NTN-SNR ROULEMENTS**, a member of the **NTN** group, **NTN** has developed, jointly with **NTN-SNR**, a “bearing equipped with a home position signal output type high-resolution rotation sensor” that allows the home position signal (phase Z) to be outputted. Thanks to the Hall elements installed inside, the **NTN-SNR**’s sensor IC is capable of increasing the rotation detection capability by up to 40 times and of outputting the home position signal. In addition, this newly developed product has adopted a connector-based connection system to improve the ease of mounting it to devices, with the power and signal output wires separate from the main body.

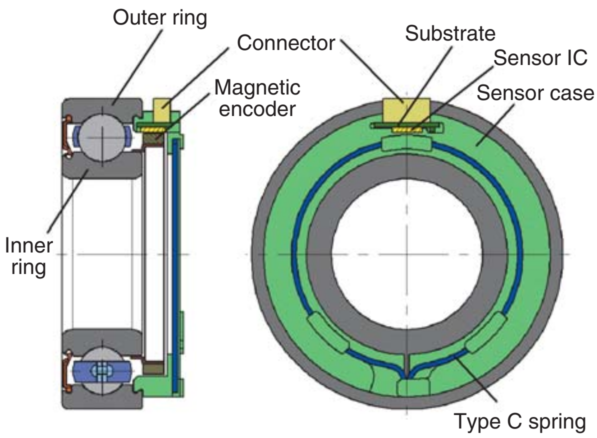

Fig. 1 Structure

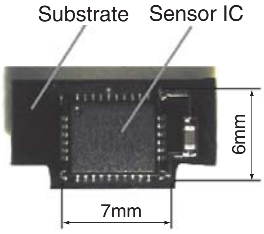

Fig. 2 Sensor IC soldered with circuit board

2. Construction

Fig. 1 shows the construction of the newly developed product.

(1) Inner ring side: a press-fitted magnetic encoder

(2) Outer ring side: A type C spring fastens the sensor case, and the substrate fastened to the sensor case is equipped with a sensor IC and a connector. **Fig. 2** shows how the sensor IC is mounted. A QFN28 package is used to achieve compact implementation.

3. Features

The features of the newly developed product and of the sensor IC used in the product are described below.

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3.1 Features of the newly developed product

The newly developed product has the following features:

(1) Capable of detecting rotation without contact and free from the possibility of performance deterioration due to wear;
(2) A rotational angle resolution of 0.14° is achieved on the 6206 size bearing because the capability of outputting a rotation signal is up to 40 times that of the current product;
(3) Capable of detecting the rotational speed and direction by means of the signal output in phases A and B;
(4) Capable of detecting the home position by means of phase Z signal output (For example, this is applied to the detection of a motor shaft, the position of the steering, and the like.); and
(5) Ease of mounting the bearing as a result of the adoption of a connector-based connection system.

Table 1 shows the comparison of specifications between the newly developed size 6206 product and the current one.

Table 1 Specifications of 6206 size

	Newly developed product	Current product
Number of output pulses from phases A and B	2,560 pulses/rotation	64 pulses/rotation
Resolution	0.14 degrees/pulse	5.625 degrees/pulse
Home position signal	Allowed	—
How to connect signals	Connector-based connection	Wiring-based connection

3.2 Features of the sensor IC

Several Hall elements are installed in a line in the sensor IC (MPS40S). Signals from these Hall elements are combined with a specially designed multiplication circuit; this allows the magnetic pattern in the magnetic encoder to be divided up to 40 times internally to increase resolution. The major features of this IC are shown below and the specifications in **Table 2**.

(1) A single IC package is capable of outputting signals from phases A, B, and Z, with the assembling of a sensor made easy;
(2) The adoption of an ultra-small IC package allows assembling to be performed in a small space;
(3) A decrease in the magnetism in the encoder can be detected;
(4) Equipped with a self-diagnosing function that monitors the state of the sensor IC and encoder and if an abnormality (an extreme abnormality of the magnetization pitch, for example) occurs, the function provides notification that an error occurred.
(5) The width of the magnetic pole, number of multiplication, and form of signal output can be specified by programming;
(6) With the phase difference between phase A and phase B signals being accurate, an increase in the resolution can be achieved by means of quadruplication processing.

Table 2 Specification of sensor IC

Required magnetic flux density	±5 mT or more
Power supply voltage	5V±10%
Current consumption	40 mA max
Compatible width of magnetic pole (that can be specified)	1.15–3 mm
Maximum frequency of input magnetic field	5kHz
Number of multiplication (that can be specified)	1x, 2x, 4x, 8x, 16x, 32x, 5x, 10x, 20x, 40x
Signal output	Phase A, Phase B, Phase Z
Output form (that can be specified)	5 V TTL level or open drain
Package	TSSOP20 or QFN28
Acquired certification	AEC-Q100※

※Certification standard for the stress test for automotive integrated circuits

4. Characteristics of the output waveform

Fig. 3 shows the comparison of the rotation signal output waveform between the current product and the newly developed one in terms of the magnetic pole of the magnetic encoder. The current product outputs a signal of a single pulse per pair of N-S magnetic poles (64 pulses per rotation), while the newly developed product outputs a signal of 40 pulses (2560 pulses per rotation). The rotation signal shown in **Fig. 3** denotes phase A signal only, for both the current and the newly developed product. In reality, rotation signals from two phases are outputted; that is, phase A signal and phase B signal having a 90-degree phase difference from phase A (a phase difference equal to a quarter pulse). The rotation signal from the newly developed product is multiplied 40 times inside the sensor IC compared to the rotation signal from the current product. **Fig. 4** shows how to generate the home position signal by using a magnetic encoder. The magnetization pattern of the magnetic encoder is composed of double row tracks layed out in the axial direction. Of the two tracks, the track that is magnetized in equal pitches is called the HR track and the one magnetized in uneven pitches is called the RP track. They have the following roles:

HR track: For outputting signals from phases A and B

RP track: For outputting signals from the home position (phase Z)

The portion in the RP track near the position at which the home position signal is detected is magnetized so that the magnetic phase differs from other positions. The home position signal is outputted when the magnetic force of the RP track exceeds the threshold value at the position at which the polarity of the HR track changes (the zero crossing position).

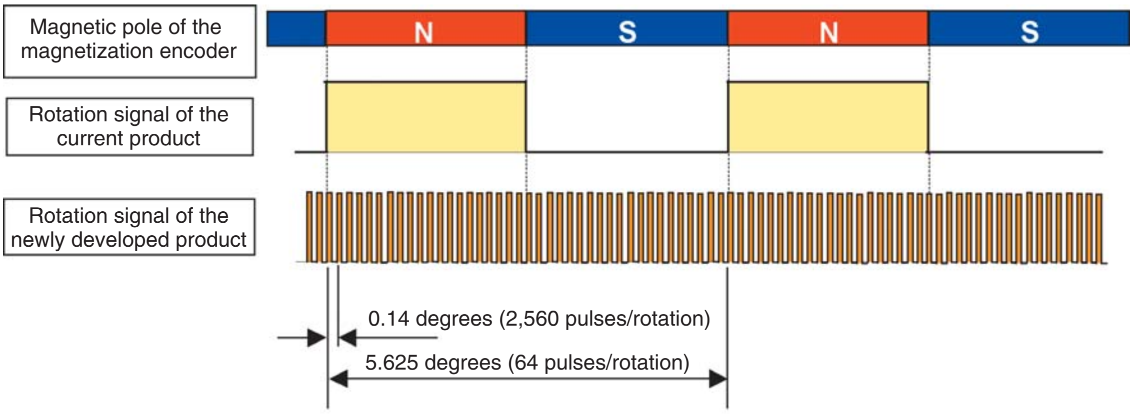

Fig. 3 Comparison of output form of current product and newly developed product

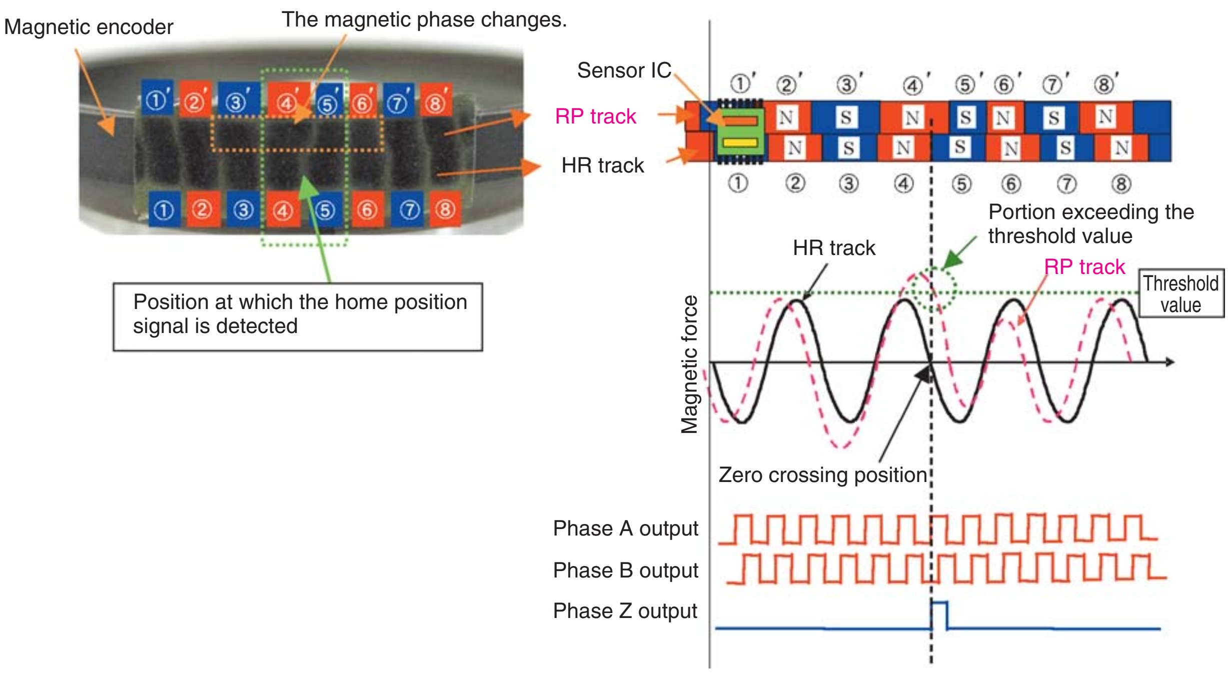

Fig. 4 Generation of output wave form of index signal

5. Important specifications of different parts

Tables 3 to **5** show important standard specifications of the newly developed product.

(1) The specification for the bearing is selected considering the use of the bearing in supporting the motor;
(2) Adoption of a magnetic encoder magnetized in double tracks; and
(3) Two of the core wires of the five-core connector are assigned to each of the ground connections and one to each of phases A, B, and Z signal outputs.

Table 3 Specification of bearing

Bearing size	6206 (φ30×φ62×16)
Radial internal clearance	C3 (0.013–0.028 mm)
Sealed-in grease	Motor-use long life grease
Seal	Contact type rubber seal
Cage	Ribbon steel sheet cage
Allowable rotational speed	4687min^{-1} ※
Working temperature range	-40 to +120˚C

※Limit imposed by the sensor response frequency (5 kHz)

Table 4 Specification of magnetic encoder

Rubber material	NBR
Magnetic material	Ferrite
Number of magnetized poles	64 N poles and as many S poles
Direction of magnetization	Radial direction (Double tracks)
Surface flux density	17 mT or more (at a gap of 0.5 mm)

Table 5 Specification of connector

Number of terminals	5
Applicable wire size	AWG26

6. Evaluation tests

The evaluation tests described in Subsections 6.1 to 6.4 were conducted to measure the accuracy of sensor output. The accuracy of sensor output is evaluated by means of the adjoining pitch error, duty ratio, and phase difference defined below. (See **Fig. 5**.) The specified range to be used as an evaluation standard was determined by taking into consideration error factors arising from the measuring system (such as accuracy in fabricating an encoder) and installation errors. If an error exceeds this range, an abnormality is suspected.

(1) Adjoining pitch error (%)
$|(T_n - T_{n+1})|/T_n \times 100$: Maximum in a single rotation
Specified range: 10% or less
(2) Duty ratio (%)
$T_p/T_n \times 100$:: Maximum in a single rotation
Specified range: 35 to 65%
(3) Phase difference (degrees)
$T_{AB}/T_n \times 360$: Maximum in a single rotation
Specified range: 45 to 135 degrees

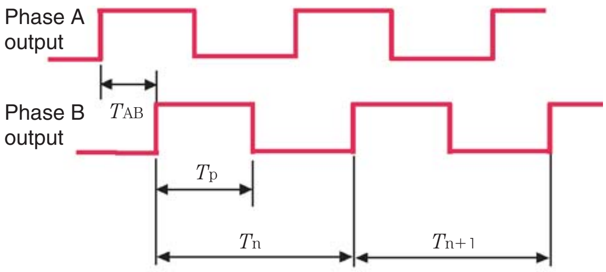

Fig. 5 Definition of sensor output accuracy

6.1 High temperature shelf test (at 120˚C)

Output accuracies of sensors that underwent a high temperature atmosphere condition of 120˚C for 0, 300, 600, and 1,000 hours were measured at room temperature. **Fig. 6** shows the test results. The initial sensor output accuracy was maintained after each of the different shelf test hours.

6.2 Low temperature shelf test (at -40˚C)

Output accuracies of sensors that underwent a low temperature atmosphere condition of -40˚C for 0, 300, 600, and 1,000 hours were measured at room temperature. **Fig. 7** shows the test results. The initial sensor output accuracy was maintained after each of the different shelf test hours.

6.3 Thermal shock test

(-40˚C×60 minutes⇔Room temperature×10 minutes⇔120˚C×60 minutes)

The thermal shock test was conducted between -40˚C and 120˚C, and output accuracies of sensors that underwent 0, 100, 600, and 800 cycles were measured at room temperature. **Fig. 8** shows the test results. The initial sensor output accuracy was maintained after each of the different numbers of cycles.

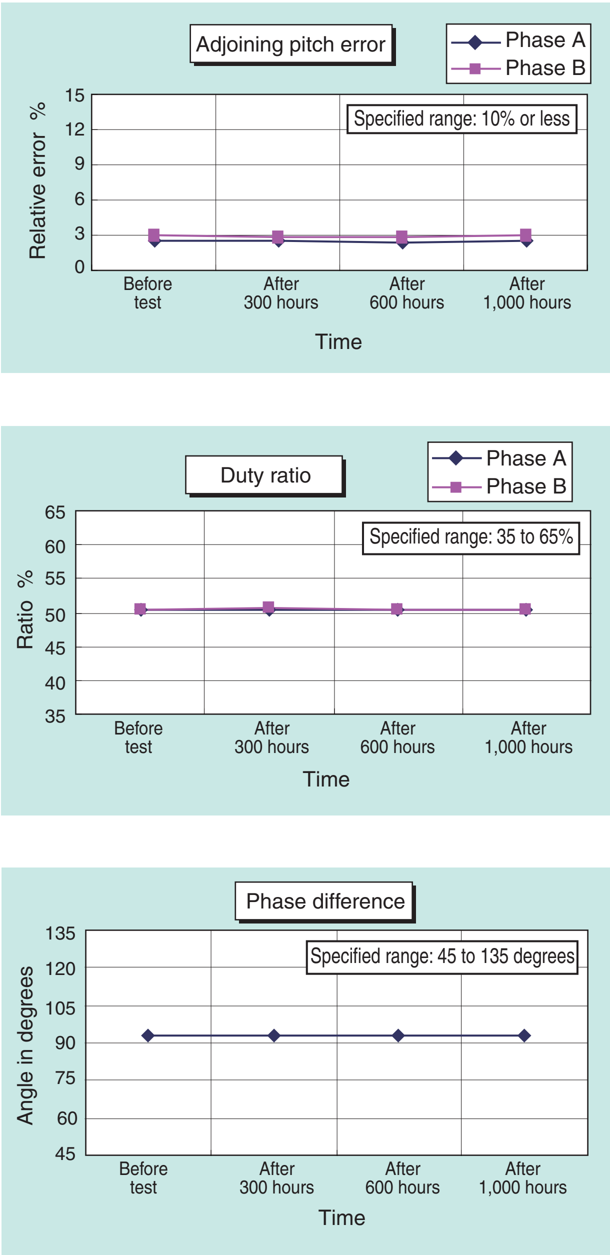

Fig. 6 Result of high temperature environment test

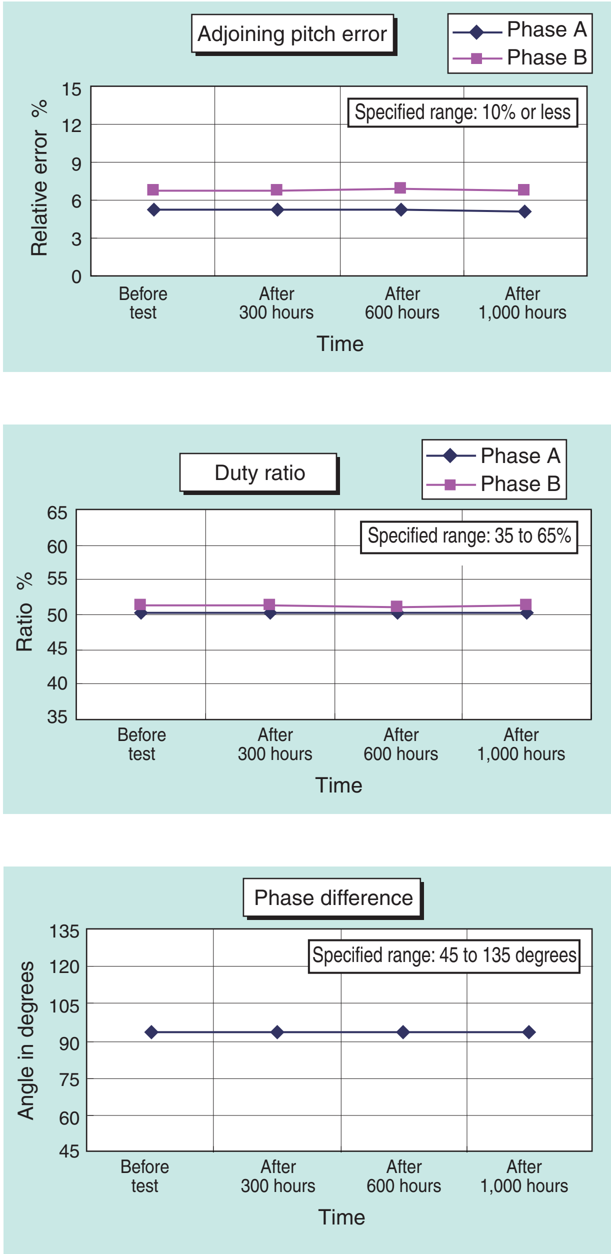

Fig. 7 Result of low temperature environment test

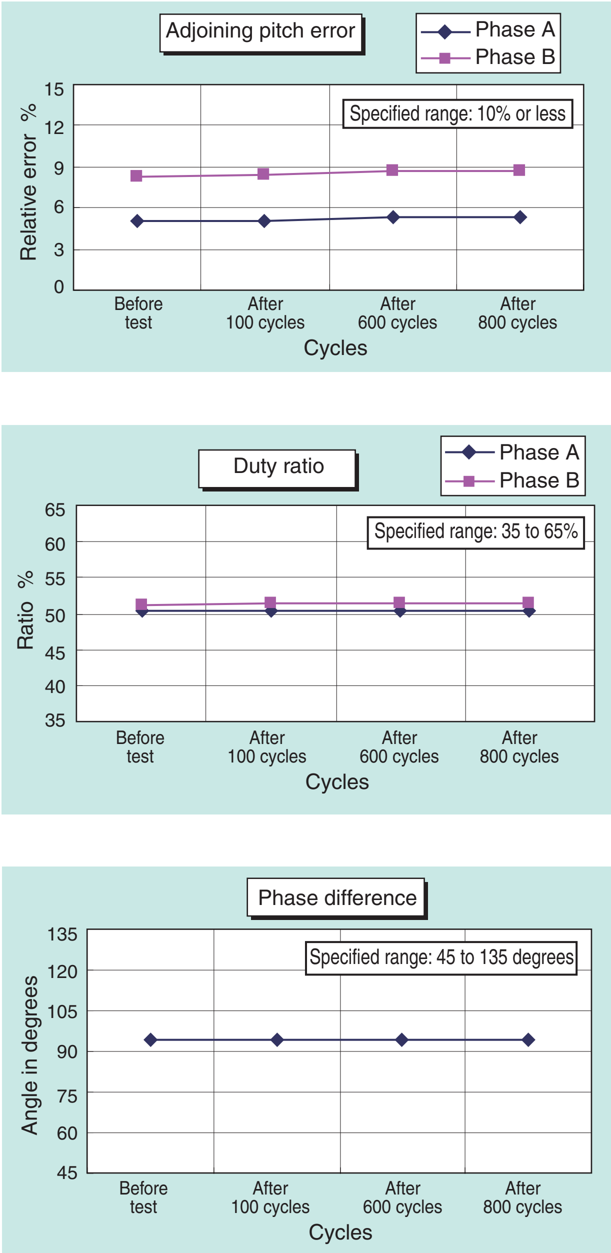

Fig. 8 Result of heat shock test

6.4 Vibration test

Sensor output accuracies were measured at room temperature before and after undergoing vibration under the conditions shown in **Table 6** and **Fig. 9**. A cycle of frequencies varying continuously from 5 Hz to 200 Hz in 15 min was repeated. **Fig. 10** shows how the vibration test was performed and **Fig. 11** shows the test results. The initial sensor output accuracy was maintained after 24-hour (96 cycles) vibration.

Table 6 Condition of vibration test

Frequency (Hz)	5	38.62	200
Acceleration (G)	0.5	30	30
Amplitude (mm)	10	10	0.37
Vibration condition (one cycle)	The frequency is varied gradually from 5 to 200 and then down to 5 Hz in 15 minutes.		
Direction of vibration	Axial direction		
Test duration	24 hours (96 cycles)		

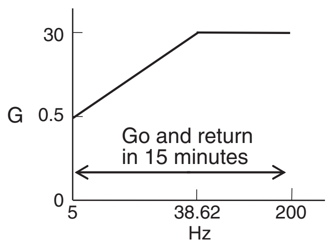

Fig. 9 Relation between vibratory acceleration and frequency

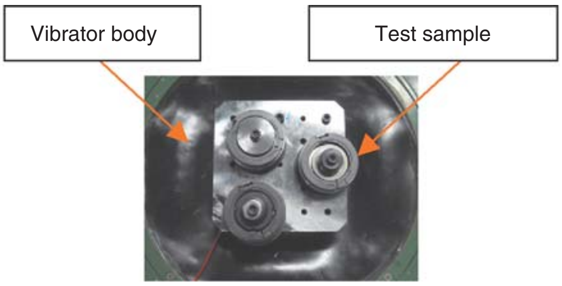

Fig. 10 Condition of vibration test

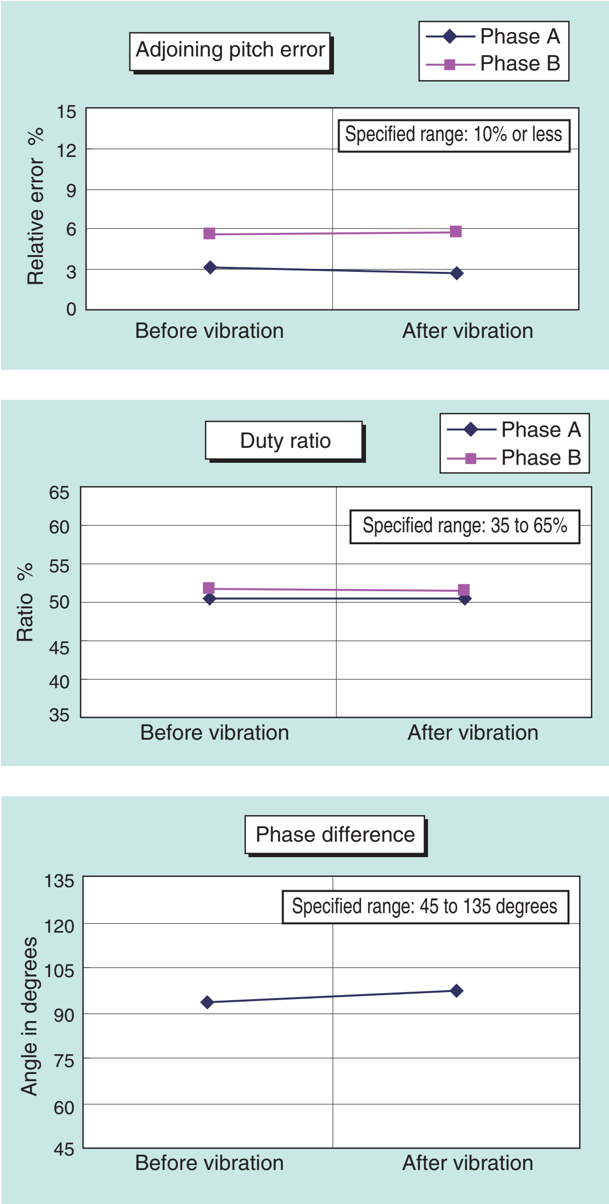

Fig. 11 Result of vibration test

6.5 Results of evaluation

These results show that:

(1) The initial accuracy of the sensor output is within the specified range, allowing one to judge the initial performance to be without problems. The sensor output accuracies remained within the specified range after the sensors had undergone the high temperature, low temperature, thermal shock, and vibration tests, allowing one to ascertain product durability;

(2) The difference observed in adjoining pitch errors between phase A output and phase B output is estimated to be due to the effect of the magnetic field of the RP track of each phase.

7. Afterward

In this paper, the authors have introduced a newly developed technology for a high resolution sensor bearing with an index signal (built to the specification of phase A and B output pulses of 2,560 pulses/rotation). They will make efforts to advance commercialization development of rotation sensor bearings using this new technology.

They will also continue pushing ahead aggressively to broaden the market reach of high resolution rotation sensor bearings built to the specification of 1,280 pulses per rotation. This product has already completed the commercialization development stage.

References

1) H. Ito and K. Koike, Bearing with Integral Revolution Sensor, NTN Technical Review No. 69.
2) T. Koike, T. Ishikawa, H. Ito and N. Mizutani, Improvement of Leakage Magnetic Flux Resistance of Integrated Sensor Bearings, NTN Technical Review No. 71 (2003) 74-79.
3) P. Desbiolles and A. Friz, Development of High Resolution Sensor Element MPS40S and Dual Track Magnetic Encoder for Rotational Speed and Position Measurement, NTN Technical Review No. 75 (2007) 36-41.

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