Commentary

Development of Sensor Integrated Bearing “Talking Bearings™”

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There has been a growing demand for equipment condition monitoring using IoT technology to reduce equipment downtime and improve production efficiency. **NTN** has developed Talking Bearings™ that integrate sensors, a power generation unit, and a wireless device to standard bearings, in order to meet this demand. This paper introduces the features, structure, and performance test results of the developed bearing.

1. Introduction

There has been an increased demand to reduce equipment downtime as much as possible to increase production efficiency[1]. Similar strong demands have been made to increase utilization even in power generation facilities and infrastructure. To respond to these demands, it is effective to monitor equipment conditions to prevent sudden equipment stoppages and plan for maintenance and part replacement periods[2] [3].

NTN has developed the “Condition Monitoring System for Wind Turbines (Wind Doctor™)”[4], the “Sensor Integrated Bearing Unit” for Machine Tool Spindles[5], the “Bearing Diagnostic Application for Industrial IoT Platforms”[6], and the “Portable Vibroscope”[7] as shown in **Fig. 1** to meet the needs of condition monitoring at this type of equipment. We have also been releasing devices and analysis software to the market for the purpose of bearing condition monitoring.

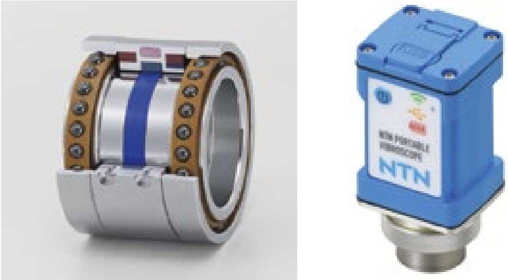
It is important to provide devices that are extremely useful and can detect bearing conditions with high sensitivity to achieve a condition monitoring service that will bring a high level of satisfaction to users. Rolling bearings are incorporated into all kinds of machines such as transport machinery, household appliances and industrial machinery to support rotation. Including sensors in rolling bearings is considered to be an ideal data collection element for monitoring the condition of machines.

With this in mind, **NTN** has developed the sensor integrated bearing “Talking Bearing™” with built-in sensors, a power generation unit and wireless device in a standard bearing**, without changing the bearing size and load carrying capacity. This paper introduces the structure of this developed product, its features, and results from performance tests.

The “Talking Bearing™” detects the bearing condition using sensors and sends the sensor information wirelessly so its name is derived from the fact that we can understand the condition of the bearing as though it is talking to us.

**Rolling bearings that comply with international standards in terms of their boundary dimensions and type

(a) Condition Monitoring System for Wind Turbines「Wind Doctor™」



(b) For Machine Tool Spindles “Sensor Integrated Bearing Unit”

(c) Portable Vibroscope

Fig. 1 Products used for condition monitoring

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2. Features and structure

2.1 Features

This section provides the main features of the developed product.

(1) Advanced condition monitoring and abnormality diagnosis

The sensors are built into the bearing so they can detect bearing conditions with greater sensitivity than if the sensors had been installed on equipment. This can diagnose abnormalities early.

(2) Compatibility

Sensors, a power generation unit and wireless device have been built into a standard bearing without changing the bearing dimensions or load carrying capacity. This makes it easy to replace bearings used on existing equipment.

(3) Very convenient

The sensors and wireless devices operate using the power generated by bearing rotation to automatically send sensor information wirelessly. This requires no cables to supply power or transmit data.

2.2 Structure

2.2.1 Overall structure

The structure of the developed product is shown in **Fig. 2**. A power generator and electronic circuit substrate are arranged at one end of the bearing used at the inner ring rotation. A stator is fixed to the bearing outer ring and coils are held in place by the stator. A rotor (a magnetic ring that is alternately magnetized by the N and S-poles) is also fixed to the bearing inner ring. AC voltage is generated in the coils by the action of electromagnetic induction as the inner and outer bearing rings rotate relative to each other. The electronic circuit substrate, which is mounted with circuits, sensors and wireless devices, is fixed to the bearing outer ring via the stator and also sealed with material that protects the electronic circuit.

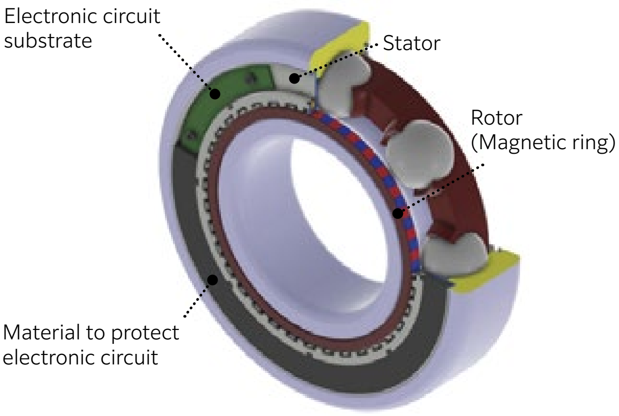

Fig. 2 Structure of Sensor Integrated Bearing “Talking Bearings$^{\text{TM}}$”

2.2.2 Electronic circuit

A functional block diagram and power supply circuit block diagram for the developed product are shown in **Fig. 3** and **Fig. 4**, respectively. AC voltage generated by the power generator is input to the power supply circuit. The power supply circuit rectifies AC voltage into DC current, and also steps down any voltage obtained beyond what is required to the designated voltage. Following this, a fixed voltage required for sensor and wireless module operation is obtained using a step-up/step-down DC-DC converter. The fixed voltage activates the sensors, and the obtained sensor signals are sent by radio waves through the wireless device.

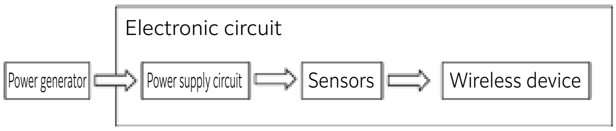

Fig. 3 Functional block diagram for developed product

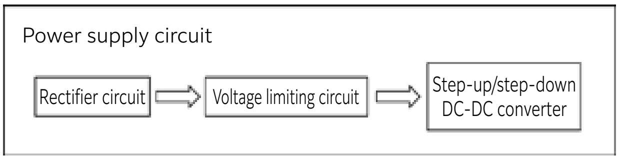

Fig. 4 Power supply circuit block diagram

3. Specifications

Table 1 shows the specifications for the developed product. Such things as acceleration, temperature and rotational speed are provided in the table for items to detect the condition of the bearing. Among these items, rotational speed is obtained by processing the AC current waveform generated by the power generator without using a dedicated sensor. Furthermore, the operating temperature range is set to -40 to 85 ℃ with consideration for the heat resistant temperature of the electronic components mounted in the circuit.

The wireless device uses Bluetooth Low Energy (2.4 GHz) telecommunication standard. Modes (monitoring mode and analysis mode) are selected based on the application to enable sensing. Monitoring mode assumes that monitoring is performed continuously and over an extended period, and sends data obtained for temperature, acceleration and rotational speed at intervals of 0.1 seconds. During this time, acceleration sent in this mode is the RMS value. Analysis mode acquires and sends acceleration data for a given sample number to enable the frequency to be analyzed by the receiver. In addition, switching between monitoring mode and analysis mode can be done using dedicated software installed on a computer.

Table 1 Specifications for Sensor Integrated Bearing "Talking Bearings^{TM}"

Bearing	Type	Deep Groove Ball Bearing
	Number	63-series, bore diameter code 14 or higher
Sensing	Acceleration	Radial detection direction Detection range of ±50 G Frequency band from 11 kHz (3 dB) Sensitivity 40 mV/G
	Temperature	Detection range of -50 to 150 °C
	Rotational speed	Resolution of 16.7 min^{-1}
Communication	Standard	Bluetooth Low Energy (2.4 GHz)
	Transmitted data	[Monitoring mode] Temperature, acceleration (RMS value), rotational speed (communication interval: 0.1 second) [Analysis mode] Acceleration
Usage conditions	Allowable rotational speed	Conforms to bearing number
	Rated load	Conforms to bearing number
	Rotational speed that can be transmitted	500 min^{-1} or more
	Operating temperature range	-40 to 85 °C

4. Examples of use

Fig. 5 shows communication configuration examples for the developed product. When constantly monitoring the equipment conditions for a long period of time, the amount of received data will be extremely large so it is best to send the data to a device such as a data logger that can store a large volume of data, and configure the device to ensure it can import the data to a computer or similar terminal. Moreover, when wanting to carry a computer or tablet into the workplace each time to check the condition of the equipment, a configuration that allows direct communication with the computer or tablet is effective. The developed product can communicate with devices that comply with telecommunication standards without needing to change the installed communication program, enabling the appropriate usage method to be selected as required.

The use of dedicated software enables the developed product to communicate with a computer or similar device to display sensor data. **Fig. 6** and **Fig. 7** show examples of displaying data for monitoring mode and analysis mode, respectively. Monitoring mode displays the change over time for acceleration, temperature and rotational speed. Also, when acquired data exceeds a pre-defined threshold, a warning will display. Analysis mode displays the acceleration time waveform and frequency analysis results.

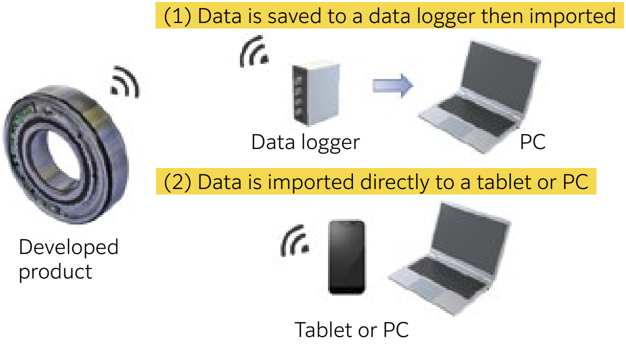

Fig. 5 Communication configuration examples

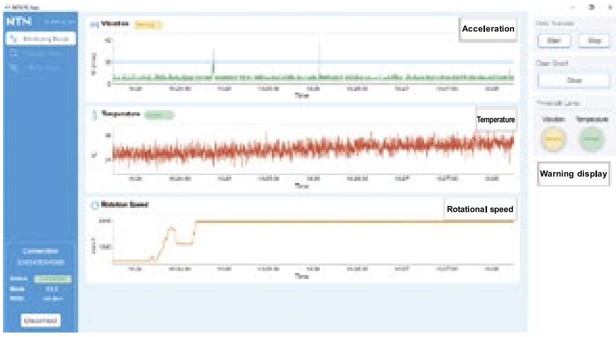

Fig. 6 Example of data displayed in monitoring mode

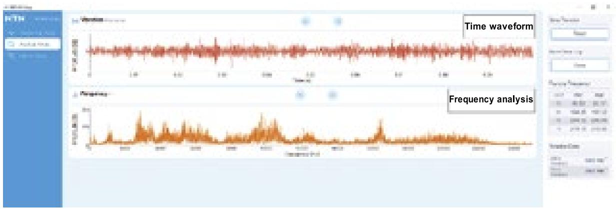

Fig. 7 Example of data displayed in analysis mode

5. Performance test

5.1 Vibration detection performance

To check the vibration detection performance of the developed product, an abnormal bearing with a defect resembling spalling (simulated spalling) on the raceway surface was used. This abnormal bearing was compared with a normal bearing without any defects to observe the vibration detected by the built-in sensor. The vibration detection performance was also compared using the acceleration sensor provided on the outside of the bearing (hereafter, external sensor) and the built-in sensor.

5.1.1 Test machine and test conditions

Fig. 8 shows a schematic drawing of the testing equipment. The bearing being tested is rotated by a shaft fitted to the inner ring of the bearing. A radial load also acts on the bearing being tested through a stand that sways on a pivot point. The external sensor is installed on the stand, and its specifications are provided in **Table 2**. The external sensor is compared with the built-in sensor (see **Table 1**), and their detection range is about the same. However, the external sensor has a wider frequency band. The acting radial load was set to 784 N. This load is quite small when compared to the basic dynamic load rating of 115 kN for deep groove ball bearing 6314.

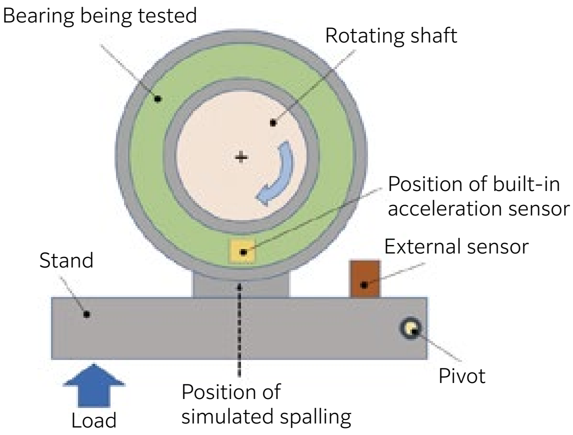

Fig. 8 Schematic drawing of testing equipment

5.1.2 Bearing being tested

Table 3 provides the specifications for the bearing being tested and **Fig. 9** shows a schematic drawing of the simulated spalling formed on the bearing outer ring. Cylindrical-shaped simulated spalling was formed at 1 location at the bottom of the groove on the outer ring raceway surface, and its size was set based on the size of the contact ellipse due to elastic deformation of the bearing parts. More specifically, the diameter of the simulated spalling was set to 0.87 mm, which is twice the diameter of the contact ellipse minor axis when the test radial load of 784 N was applied. **Fig. 10** shows an external photo of actual spalling that occurred during the damage end stage, as an example of spalling that occurs on a bearing. The size of the simulated spalling was made sufficiently small in comparison to end stage spalling with the aim of evaluating vibration detection performance during the initial stages of damage.

Table 2 Specifications for the external sensor

External sensor	Detection range	±60 G
	Frequency band	3 Hz to 25 kHz (3 dB)
	Sensitivity	100 mV/G

Table 3 Specifications for the bearing being tested

	Normal bearing	Abnormal bearing
Bearing	Deep groove ball bearing 6314	
Seal	Non-contact type (one side)	
Grease	Thickening agent: Urea-based Base oil: Poly-alpha olefin	
Simulated spalling	No	1 location at the bottom of the groove on the outer ring raceway surface ϕ0.87 × depth of 0.1 mm

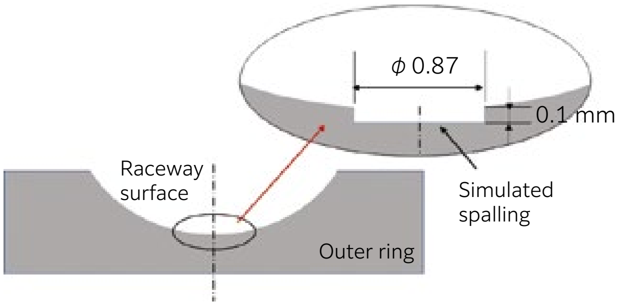

Fig. 9 Schematic drawing of simulated spalling

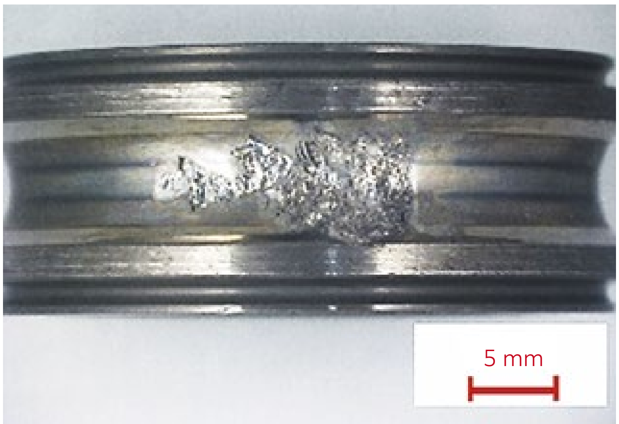

Fig. 10 Example of spalling damage

5.1.3 Test results

Fig. 11 shows the built-in sensor output when rotating the normal sensor and abnormal sensor at 2 000 min^{-1}. Each time the rolling element passes the simulated spalling on the abnormal bearing, an obvious spike in acceleration was detected. If a defect of about the same size as the simulated spalling created this time occurs on the raceway, it would be possible to detect an obvious abnormality with the developed product.

Next, **Fig. 12** shows a comparison between the built-in sensor and external sensor for the acceleration measured at the abnormal bearing. **Fig. 12** shows the results of conducting envelope processing and frequency analysis (fast Fourier analysis) on the data output in **Fig. 13**. Finally, **Fig. 13** lists the rotational speed (103 Hz) of the rolling element relative to the outer ring and the higher-order rotational speeds. The sensor output when the rolling element passes the simulated spalling is greater for the built-in sensor in comparison with the external sensor. Frequency analysis also shows that the built-in sensor is more sensitive and can better detect vibration at high frequency.

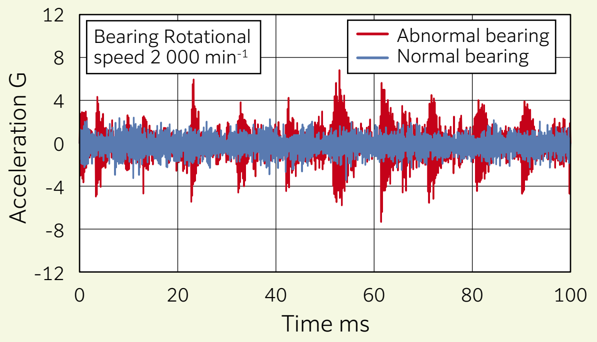

Fig. 11 Comparison of normal bearing and abnormal bearing built-in sensor output

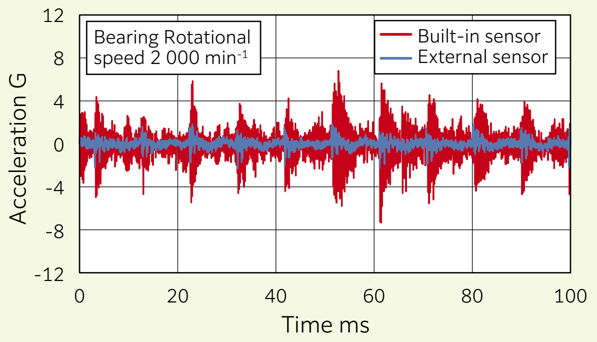

Fig. 12 Comparison of acceleration for built-in sensor and external sensor with abnormal bearing

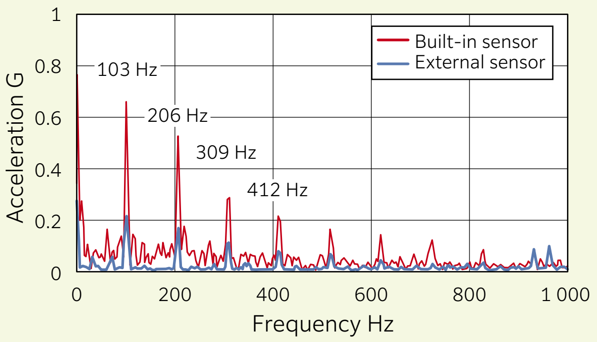

Fig. 13 Comparison of frequency analysis for built-in sensor and external sensor

5.2 Temperature detection performance

Measured values taken from a thermocouple affixed to the outer circumferential surface of the bearing outer ring were compared with measured values taken from the built-in temperature sensor. The bearing being tested was the normal bearing shown in **Table 3**, and it was measured using the testing equipment shown in **Fig. 8**. The rotational speed was taken as being up to the allowable rotational speed of 4 600 min^{-1} (value listed in the **NTN** catalog) for deep groove ball bearing 6314 (grease lubrication, non-contact seal). Measurements were taken by repeatedly increasing rotation and holding for two hours at increments of around 1 000 min^{-1}. Measurement results are shown in **Fig. 14**. The results show that there is no significant difference in the values measured with both sensors in either the transient region after rotation was increased or the steady-state region when rotation was held. Thus, the developed product has the same temperature detection performance as when affixing a thermocouple to the bearing outer ring.

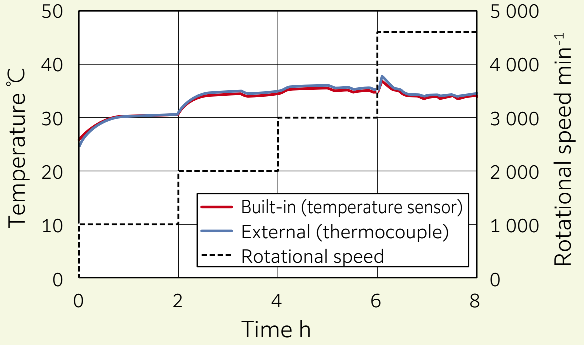

Fig. 14 Comparison of temperature taken with the built-in sensor and external thermocouple

5.3 Temperature increase characteristics

Fig. 15 shows the generated power and running torque of the developed product in relation to rotational speed. Here, the generated power is the sum of the power consumed by the circuit and the power loss from the power generator. Also, the running torque is equivalent to the running torque of the entire bearing with built-in sensor, including the friction loss during bearing rotation and the generated power mentioned above. **Fig. 15** shows the values measured after holding for two hours at each rotational speed. The generated power is small at 1 to 2 % in contrast with the power loss of the entire bearing calculated from the running torque and rotational speed, and incorporating the power generator and circuit into the bearing is also estimated to have a minor effect on the bearing temperature.

Fig. 16 shows the results measured for the temperature on the actual bearing. The bearing temperature was measured with a thermocouple affixed to the outer ring outer circumferential surface and the built-in sensor. **Fig. 16** shows the value increase from ambient temperature after holding for two hours at each rotational speed. There was no significant difference between the standard bearing and developed product, showing that the developed product has the same temperature increase characteristics as the standard bearing.

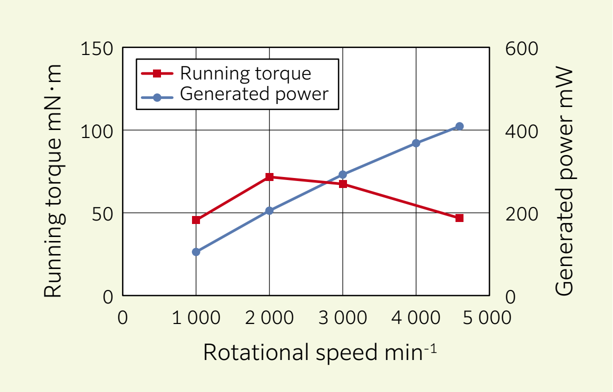

Fig. 15 Generated power and running torque for the developed product

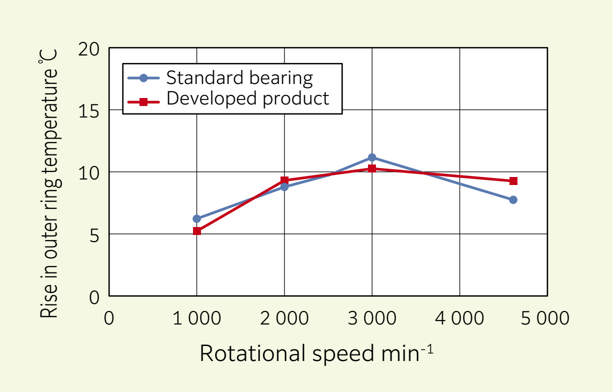

Fig. 16 Temperature increase characteristics for the developed product and standard bearing

6. Summary

To respond to efforts towards reducing downtime at manufacturing sites, **NTN** has developed the Sensor Integrated Bearing “Talking Bearing$^{\mathrm{TM}}$” which has sensors, a power generation unit and wireless device built into a standard bearing. The performance of this product was verified in this paper. We predict that demand for equipment condition monitoring will increase in the near future, and further improvements in functionality will be required. **NTN** will continue to develop equipment condition monitoring and contribute towards improving production efficiency through its improvements in the function of “Talking Bearing$^{\mathrm{TM}}$” and releasing products in the market.

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