Non-disassemble Inspection Technique for AC Main Motors for Rolling Mills

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Abstract:

Since the 1990s, AC variable speed motors have been introduced for driving rolling mills. These motors have output range of several thousands to 10 000 kW, and due to economical considerations, no spare units are kept. Therefore, inspections and repairs have been conducted on-site. However, to conduct inspections, it is necessary to disassemble the motor (remove the rotor from the stator), which incurs significant costs and time. To solve this issue, JFE Steel has developed an equipment that enables acoustic inspection of stator coils without disassembling the motor.

1. Introduction

Steel rolling mills have traditionally been driven by DC motors, but with the development of AC variable speed technology, introduction of AC motors for high-output rolling mills has progressed since the 1990s.[1)2)] The integrity of motors with outputs of around 1 000 kW or less can be maintained by securing spare motors and performing maintenance and overhauls. However, since the output of rolling mill main motors ranges from several thousand to over 10 000 kW, it is economically difficult to keep spare motors, requiring on-site inspections and repairs. Furthermore, to avoid modification of the motor foundation when updating from DC motors, it is often impossible to install a stator shift mechanism for use in inspections, necessitating disassembly work (rotor extraction), which involves significant cost and time.

To eliminate the burden of the disassembly work, JFE Steel developed a device that allows non-disassemble inspection, that is, a wedge tapping device that enables acoustic inspection of stator coil wedges while the stator is inserted in the rotor.

Table 1　Summary of items in disassemble inspection

	Parts	Inspection items	Inspection method
Stator	Armature coils	Contamination, Damage, Discoloration, Cracks, Looseness or breakage of bindings	Visual
		Insulation resistance	Tester
	Wedges in slots	Looseness, Detachment	Tapping inspection
	Iron cores	Contamination, Rusting	Visual
Rotor	Field coils	Contamination, Damage, Discoloration, Deformation	Visual
		Insulation resistance	Tester
	Iron cores	Contamination, Rusting, Deformation	Visual
	Coil brackets	Contamination, Damage, Misalignment, Deformation	Visual

2. Content and Issues of Inspections of AC Mill Motors

2.1 Content of Inspections

The main items checked during a disassemble inspection are shown in **Table 1**. Among these, all the items except for the wedge tapping inspection are either visual inspections or electrical measurements. While an endoscope such as a micro CCD can be used in place of visual inspection, the wedge tapping inspection cannot be performed until the rotor has been disassembled. An example of the rotor removal condition is shown in **Fig. 1**, and an example of the measuring instrument (looseness gauge) used in the tapping inspection is shown in **Fig. 2**.

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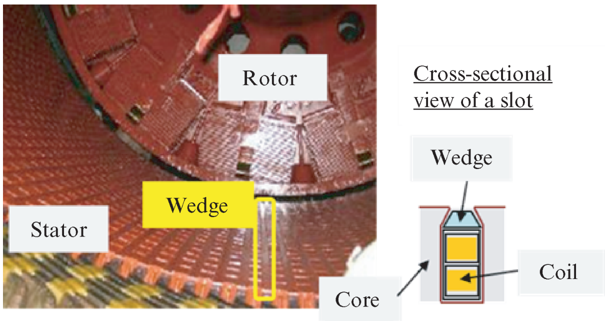

Fig. 1 Example of rotor removal condition

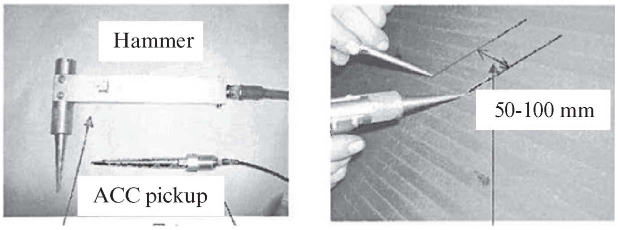

Fig. 2 Example of looseness gauge

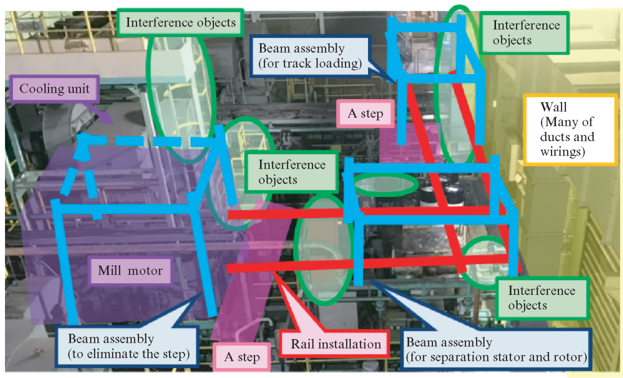

Fig. 3 Ancillary works for mill motor inspection

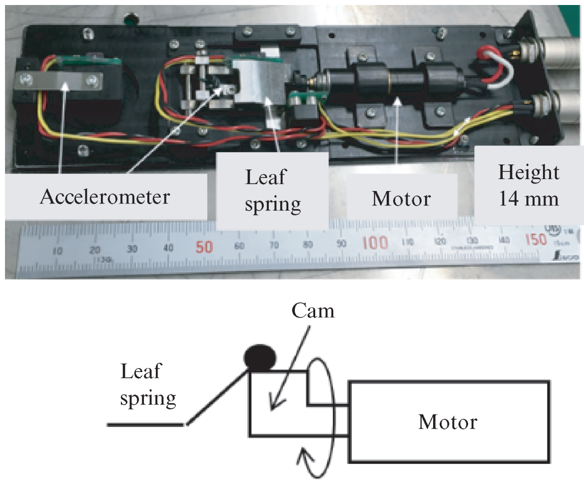

Fig. 4 Internal mechanism and impact principle of striking device

2.2 Issues of Inspections

Many of the main motors of rolling mills have been converted from DC motor drives to AC drives. Due to the constraints of the construction schedule for AC conversion, the motor foundations were reused in most cases, which meant that a mechanism for on-site inspections, such as a stator shift mechanism, could not be installed. As a result, there is a need for disassembly inspections, which incur significant costs, for example, for arranging power lifters. An example of the ancillary work carried out in a disassemble inspection in May 2018 is shown in **Fig. 3**.

In this case, a method that was considered more rational in terms of cost and construction time than use of a power lifter was adopted. This method involved relocating and modifying interfering objects, laying tracks, and assembling beams, and then moving the stator along the tracks to a repair shop for inspection.

3. Development of Small Tapping and Measurement Device

3.1 Device for Synchronous Motor

3.1.1 Overview of Device

AC motors can be broadly classified into synchronous motors (SM) and induction motors (IM), in which the gaps between the stator and rotor of the two types differs based on the results of magnetic circuit design. Synchronous motors generally tend to have a wider gap (12–35 mm) than induction motors (3–4 mm).

Synchronous motors are primarily used in hot rolling finishing mills. Since they are more numerous and have a wider gap than the induction type, development of non-disassemble inspection devices is less difficult. Therefore, development was started focusing on synchronous motors.

As a result, a device that can be inserted, tapped, and measured in a gap with a width of 14 mm or less was developed, making it applicable to about half of the company's variable-speed synchronous motors that lack a stator shifting mechanism.

3.1.2 Mechanism and Tapping Principle of Device

Figure 4 shows the internal structure of the tapping and measurement unit of the device and the principle of tapping. The mechanism is designed to deliver a tapping action with a width of 14 mm by rotating a cam

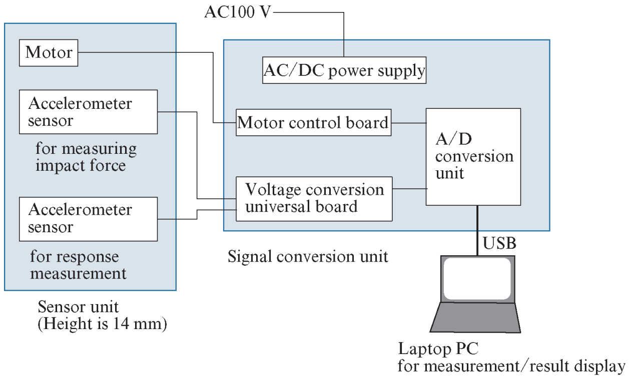

Fig. 5 Measurement system configuration

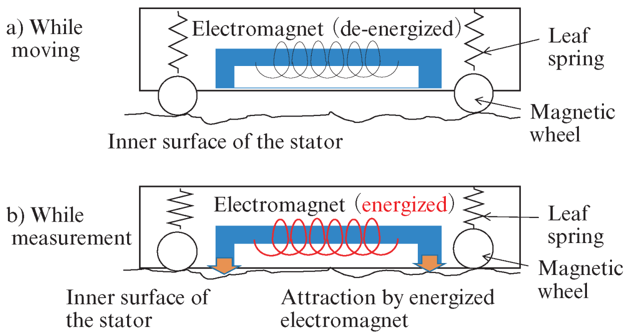

Fig. 6 Attracting mechanism to inner circumference of stator

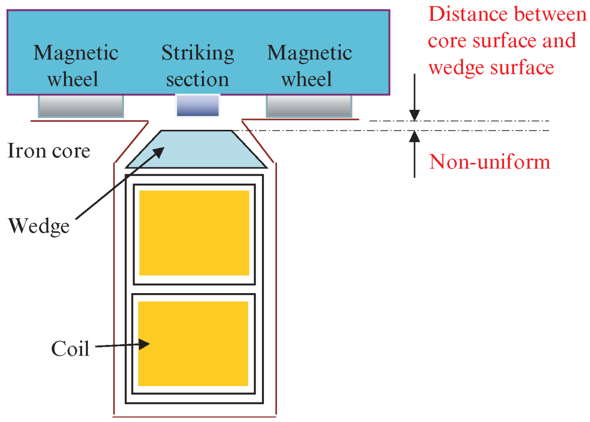

Fig. 7 Non-uniformity of distance between core surface and wedge surface

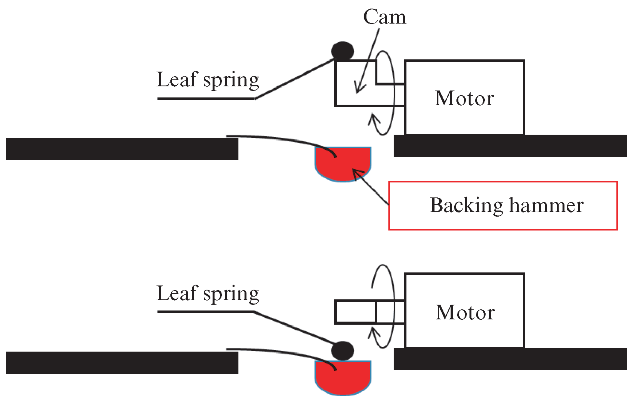

Fig. 8 Backing hammer

with a small motor so as to strike a leaf spring.

Next, **Fig. 5** shows the configuration of measurement system, which consists of a signal conversion unit that performs motor control and signal processing for acceleration (filtering, A/D conversion), and a computer for operation and display.

When conducting wedge tapping inspections on an actual machine, it is necessary to strike in a 360° direction around the inner circumference of the stator, which requires that the tapping and measurement device (hereinafter, insertion unit) be fixed and in contact with the inner circumference of the stator. On the other hand, movement in the direction of the copper bars of the coil occurs within the stator, but considering the surface roughness of the stator inner circumference, it is necessary to elevate the housing of the insertion unit away from the inner surface.

The following mechanism was devised to achieve both fixation during measurement and movement in the direction of the copper bars of the coil:

- Fixation is provided by a permanent magnet wheel (hereinafter, magnetic wheel), which adheres to the inner circumference of the stator.
- During movement, a leaf spring attached to the magnetic wheel elevates the housing.
- During tapping and measurement, an electromagnet is energized to contract the leaf spring, allowing the unit housing to be attracted to the inner circumference of the stator.

This mechanism is illustrated in **Fig. 6**.

In the actual machine, as shown in **Fig. 7**, variations in the measurement results occur due to “unevenness of the distance between the core surface and wedge surface,” which is caused by the surface roughness of the core. To address this, we adopted a method of pre-pressing the contact area with the wedge surface (“backing hammer”) before delivering the tapping action from above (**Fig. 8**).

To prevent propagation of the impact of tapping through the housing to the acceleration sensor on the response side, the acceleration sensor was mounted using the method shown in **Fig. 9**.

In addition, to avoid variations in the measurement results caused by the initial instability of adhesion at each tapping position, we adopted a process in which the first few taps (set by parameters in the measurement software) are excluded from the average calculation.

3.2 Device for Induction Motor

Next, we considered the development of a device

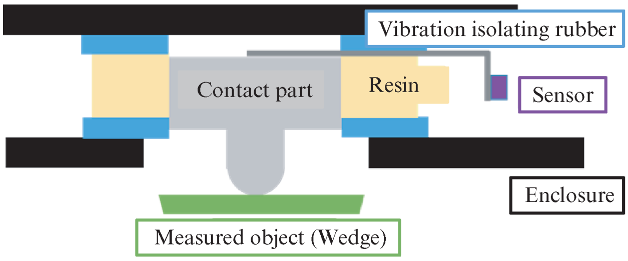

Fig. 9 Response-side accelerometer mounting method

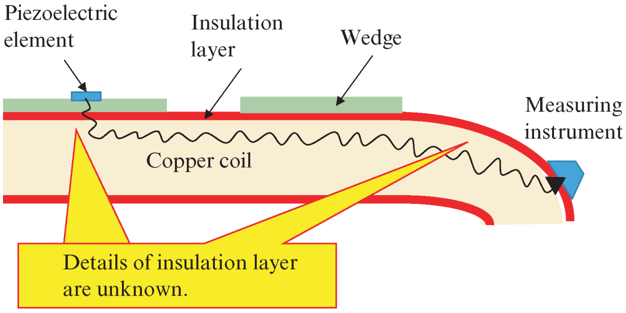

Fig. 10 Idea for acoustic measurement method

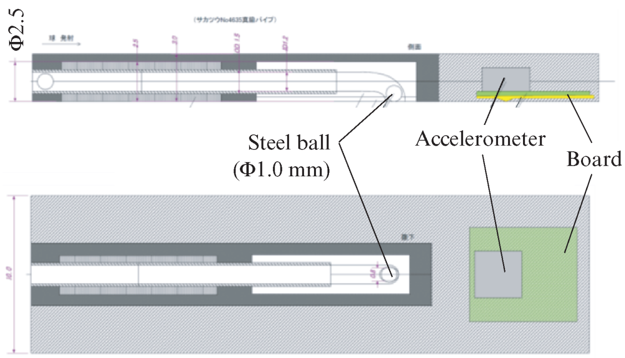

Fig. 11 Idea for steel ball shooting method

for induction motors, which average significantly narrower gaps. Three tapping and measurement methods were proposed, as outlined below, and some were actually designed and prototyped.

(1) Acoustic Measurement Method

Tapping is performed from the wedge using some form of device (such as a piezoelectric element), and the acoustic response is measured at the coil end for evaluation (**Fig. 10**).

(2) Steel Ball Shooting Method

A small steel ball is shot to deliver a tapping action, and the response is measured (**Fig. 11**).

(3) Discharge Method

An electric discharge is generated in the gap to create a tapping action, and the response is measured (**Fig. 12**).

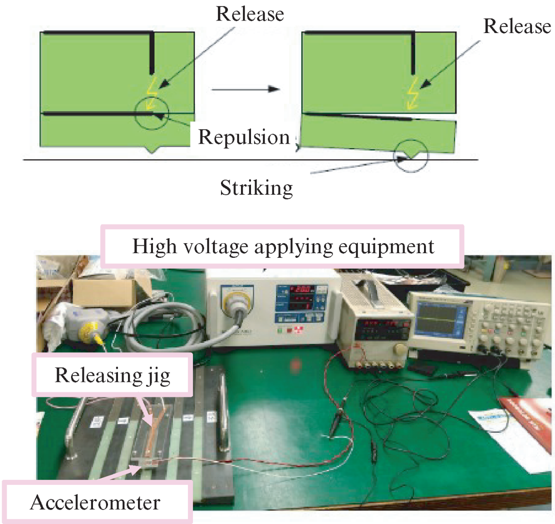

Fig. 12 Idea for high voltage application

However, for the following reasons, none of these methods could be adopted. Therefore, development of the device for induction motors was discontinued.

(1) Acoustic Measurement Method

Because many items are treated as confidential by the motor manufacturers, it was not possible to obtain information on the materials and characteristic data of the insulation layers.

(2) Steel Ball Shooting Method

Although we proceeded to the design stage, we could not devise a practical method for recovering the steel ball.

(3) Discharge Method

This device reached the prototype stage, but failed to deliver an effective tapping action.

4. Results of Verification with Actual Motor

4.1 Verification of Developed Device

4.1.1 Reproduction of Wedge Loosening with Spare Stator

An in-house spare stator (11 kV, 13 000 kW, 8 P) was used to reproduce wedge looseness by replacing the wedge liners with liners of various thicknesses. This was done to verify performance of the newly-developed small tapping testing device for synchronous motors described in Section 3.1 in comparison with conventional looseness measuring devices. The results are shown in **Fig. 13**.

4.1.2 Verification Using Stator Removed due to Aging Deterioration

Verification of the small tapping inspection device

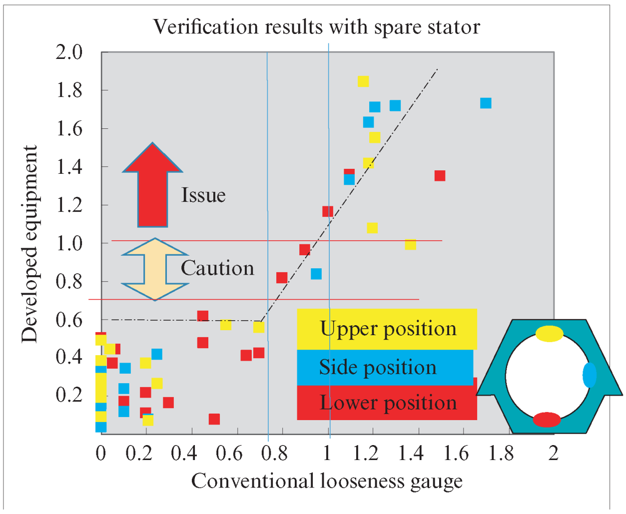

Fig. 13 Verification results of developed equipment with spare stator

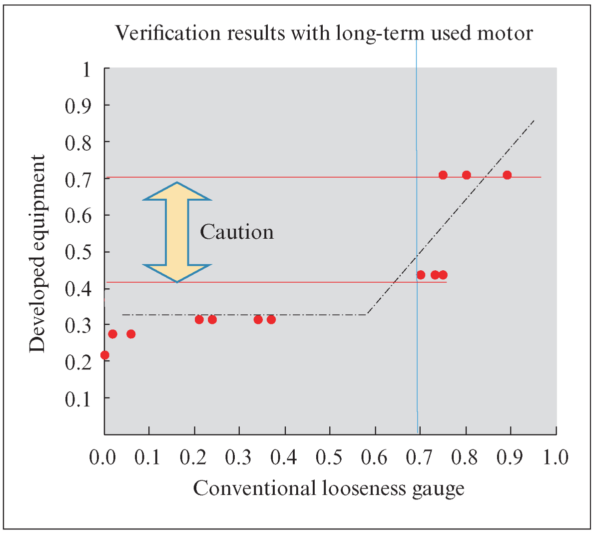

Fig. 14 Verification results with long-term used motor

(compared to conventional looseness measuring devices) was conducted using a motor (3.3 kV, 8 500 kW, 4 P) that had been removed in a renovation of the aging equipment after approximately 35 years of operation, during which actual wedge looseness had occurred. The results are shown in **Fig. 14**.

4.2 Results of Verification of Developed Device

As shown in Fig. 13 and Fig. 14, there is a good correlation between the measurement results of the developed small tapping inspection device and the conventional looseness measuring device. These results confirmed that the developed device can be used to assess the condition of wedge looseness in stator coils.

5. Conclusion

This paper presents the development of a non-disassemble inspection technique for AC main motors used in rolling mills. In comparison with conventional disassembly inspections, significant reductions in cost and time can be achieved by conducting wedge tapping inspections without removing the rotor, contributing to improved efficiency in on-site inspections. In the future, we will continue to make improvements with the aim of applying this technology to other motors. In addition, we also plan to conduct on-site demonstration test to clarify the challenges for practical application and seek solutions.

References

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