Development of Damage Diagnostic System for Steel Mill Driveshaft Large Bearings

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This damage analysis system for large-sized bearings and driveshafts is a maintenance system that enables diagnosis and preventive maintenance without disassembling components in service to inspect for flaking failure, wear, etc. Sensing and abnormality diagnostic technology during low-speed rotation with large external disturbance and energy-efficient, high-performance wireless communication technology were indispensable to the development of the system. Although verification by a system model is still being carried out, development is nearly complete, therefore a portion of the concerned technology is introduced in this paper.

Key Words: *driveshaft, flaking failure, wear, preventive maintenance*

1. Introduction

In recent years, the demands for reliability improvement and man-hour reduction concerning equipment maintenance have been increasing. In the case of steel rolling mill equipment, it has been required to extend an interval for regular disassembling and inspections of universal joints (hereinafter called as UJ) for roll driving of rolling mills, which are manufactured and sold by JTEKT. However, under current equipment maintenance, the shortest period among life dispersion range has been commonly taken as the inspection interval, which is an issue for reduction of maintenance man-hours. JTEKT, therefore, has determined to develop a system to enable the diagnostic of life or damage during operation without disassembling and dismounting UJ with the purpose of extending an interval for disassembling and inspecting UJ for roll driving.

The outline of the system currently in development is shown in **Fig. 1**. This system mainly consists of three parts: a cordless unit (the wireless sensor unit equipped with wireless function and sensor), a main unit enabling to send and receive the information with the cordless unit, and a software of damage diagnostic set in the PC unit for diagnostic. In order to develop an adequate system there are multiple issues to be resolved. The main issues identified are as follows: ①detection of flaking and wear during low speed rotation under large external disturbance, ②transmission of sensor signal from rotating driveshaft, ③battery life, ④diagnostic method of flaking and wear. Here, we introduce the details of our approaches for those issues.

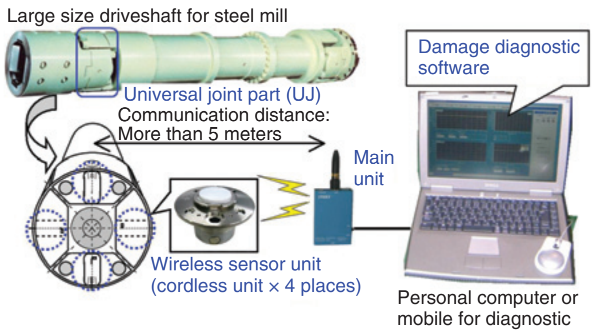

Fig. 1 Structure of maintenance system

2. Principle of Flaking Detection Method

2. 1 Field Environment and Detection Technology

It is a common method for the flaking detection of bearing to conduct diagnostic by the cyclic signal of the vibration acceleration sensor attached to the fixed position as either inner or outer ring is fixed. However, this UJ itself is in rotation, so that it is difficult to conduct diagnostic by this method. In addition, rolling torque in UJ for driving rolling mill roll is extremely large and the rotation of a bearing is extremely low, oscillation of 5° ~ 10° per rotation of driveshaft. Therefore it is generally difficult to conduct diagnostic on flaking by vibration acceleration.

We have developed a new detection method for flaking to cope with this issue and have improved it so that this system can be used even under severe environmental conditions such as in the steel rolling process.

Specifically, we have developed the wireless sensor unit equipped with an eddy current type displacement sensor shown in **Fig. 2** and applied a method of measuring the minute relative displacement of cross and bearing cup. As this method can isolate the inside of a sensor from the outside and make the structure sealed up, it is possible to withstand severe environmental conditions in the rolling mills.

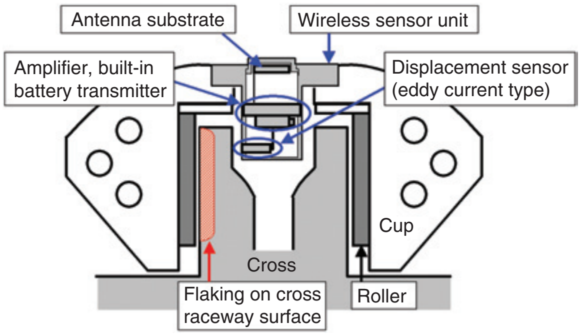

Fig. 2 Cup structure for flaking failure detection

It is considered that the detection method by which relative displacement between the cross and the cup through this displacement sensor is measured[1) has a robust feature to external disturbance (vibration and torque variation, etc.) and one which can detect flaking or wear even at low rotational speed. The verification test has been conducted with miniature model in order to confirm that there will be any change on the displacement signal when flaking or wear occurs.

2. 2 Result of Life Test at JTEKT

With the life test equipment shown in **Fig. 3**, verification test has been conducted for flaking and wear detection by a displacement signal. The results are stated as follows:

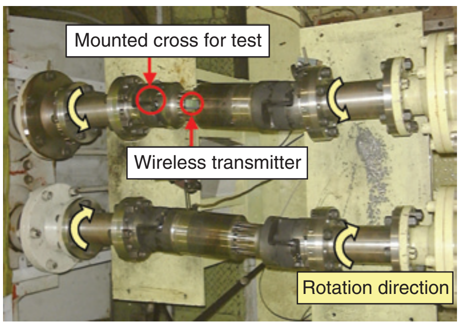

Fig. 3 Life test equipment

At first, the displacement measuring pin has been installed to the cross joint for life test, which is 1/8-size of the actual one (**Fig. 4**), and the eddy current type displacement sensor has been installed to the cup side (**Fig. 5**). This installation is used to measure the displacement between the cross and the cup.

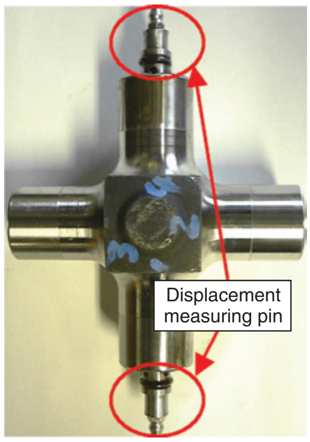

Fig. 4 1/8-size cross joint for life test

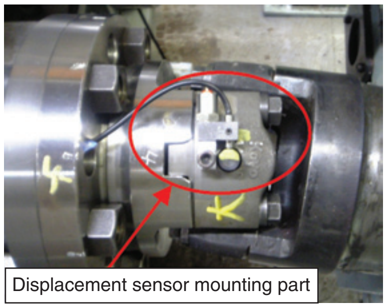

Fig. 5 Eddy current type displacement sensor installation area

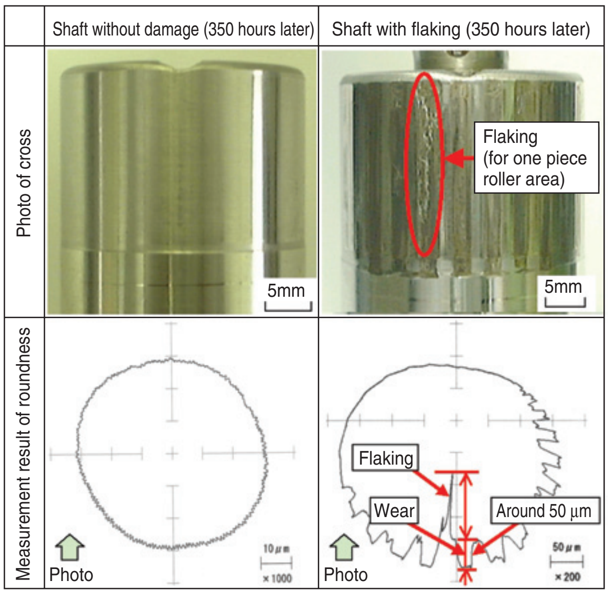

Fig. 6 Condition of cross joint after life test

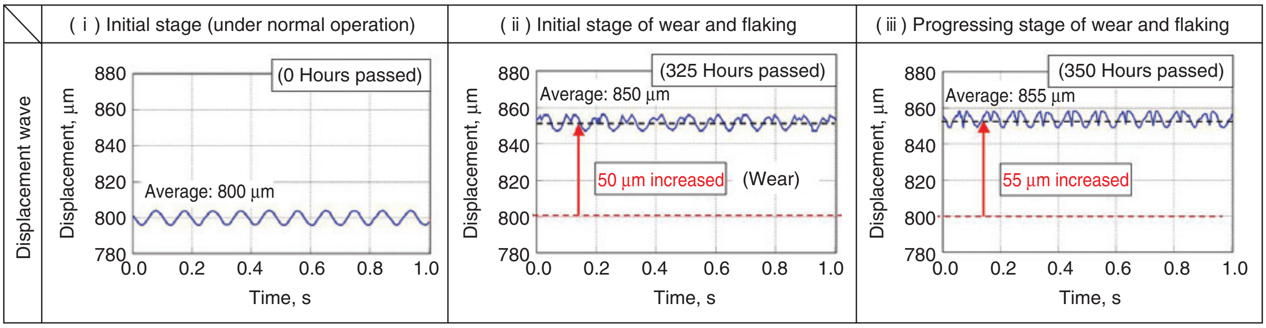

Fig. 7 Change in displacement signal in life test

The effective case depth on the raceway is reduced to 1/5 of normal depth on the two cross shafts with the displacement measuring pin installed in order to make flaking or wear occur at a premature stage.

The test was conducted using the circumferential speed and the loaded torque equivalent to actual machine conditions. The change of the displacement signal was measured up to the stage where flaking or wear occurred. After 350 hours of life test, as shown in **Fig. 6**, it was confirmed that wear had occurred on the 2 pieces of the cross shafts with the effective case depth on the raceway being 1/5 of normal depth, and flaking, equivalent to the size of one piece of "roller," had occurred on one of them. On this life test, the measurement result of the displacement signal is shown in **Fig. 7**.

The results of the following three types of displacement waves below are shown in **Fig. 7** and the study results are summarized below.

(i) The normal wave at the initial stage conditions

(ii) The displacement wave at the initial stage of flaking (325 hours later)

(iii) The displacement wave at the developed stage of flaking (350 hours later)

According to these results, the average value of the displacement wave has increased by approximately 50 µm from the initial stage condition (i) to the occurrence of the initial flaking (ii), and then the average value has increased to 55 µm at the stage after 350 hours passed (iii). Due to the fact that the amount of displacement is almost equal to 50 µm, the wear amount shown in **Fig. 6**, it can be considered that the average value of the displacement wave has increased due to wear. The measurement result of average value changes of the displacement wave in the life test is shown in **Fig. 8**.

Figure 8 clearly shows that the average value of the displacement wave has sharply increased 250 hours after the initial stage conditions. The explanation for the large displacement value of the cross and the cup can be attributed to the "roller" falling down on the wear area of the cross (**Fig. 9**).

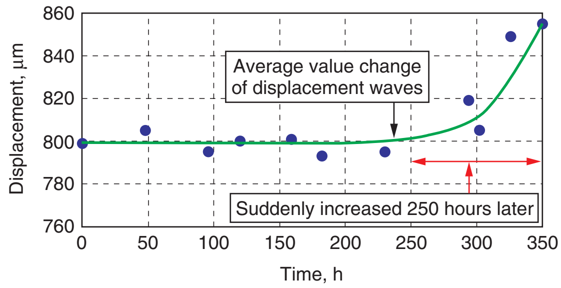

Fig. 8 Plot of displacement function over time

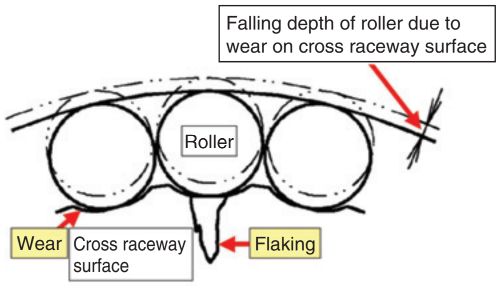

Fig. 9 Principle of displacement waveform change

As shown in **Fig. 7**, every displacement wave results in a sign wave, which is attributable to eccentricity between the displacement measuring pin and the center of cross shaft shown in **Fig. 4**, and has nothing to do with flaking or wear. **Figure 7** (ii) shows that the displacement wave has a periodic disturbance, and **Fig. 7** (iii) shows that the disturbance of the displacement wave becomes excessive. It is proposed that there can be an influence when the "roller" passes the raceway surface damaged due to flaking. From the above viewpoints, the test results are summarized below:

· Due to wear, the average value of displacement wave increased.

· Due to disturbance on the raceway surface, the periodic disturbance occurred on displacement wave

If these phenomena can be normally observed, it is considered to be possible to detect wear and flaking by actual machines.

3. Wireless Technology

3. 1 Wireless Sensor Unit

In order to transmit the displacement signal of rotating UJ to the outside the incorporation of wireless technology is necessary. To achieve this we have started to develop a wireless sensor unit equipped with wireless function. Here outlines of wireless sensor unit and the wireless technology are mentioned below. The appearance of the wireless sensor unit developed is shown in **Fig. 10**, its structure in **Fig. 11** and the wireless circuit block in **Fig. 12**.

The wireless sensor unit must be designed with a structure that is easy for mounting and dismounting on the driveshaft and for replacement of the battery. The feature of this unit has a lid made of resin which is placed as a doorway for radio wave so that there is no deteriorated communication performance by containing wireless substrate inside the steel unit. Due to such severe environments of rolling mill as large impact torque, the mold treatment has been made overall on the wireless substrate.

Fig. 10 Appearance of wireless sensor unit

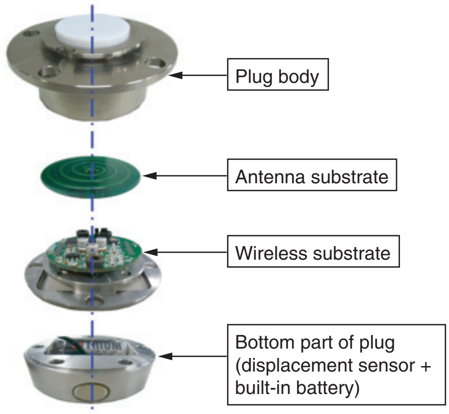

Fig. 11 Structure of wireless sensor unit

3. 2 Required Specifications on Wireless Communication

Specifications on wireless communication required for driveshaft damage diagnostic are shown in **Table 1**.

At first, when developing wireless devices, the problem is which wireless frequency band range is to be used. The frequency band range for common wireless devices is shown in **Fig. 13**, but unlicensed low-power service range, for which an application to the authorities is not required, has been selected with consideration of commercial production.

In regards to communication (modulation) method, the digital method (FSK Modulation), which is less affected by level fluctuation or noise from the viewpoint of the required specifications, is adopted. At the same time, in order to realize multi channels, two-way communications, and improved communication quality etc., various information is added to the transmission code which functions the transmission information. Consequently,

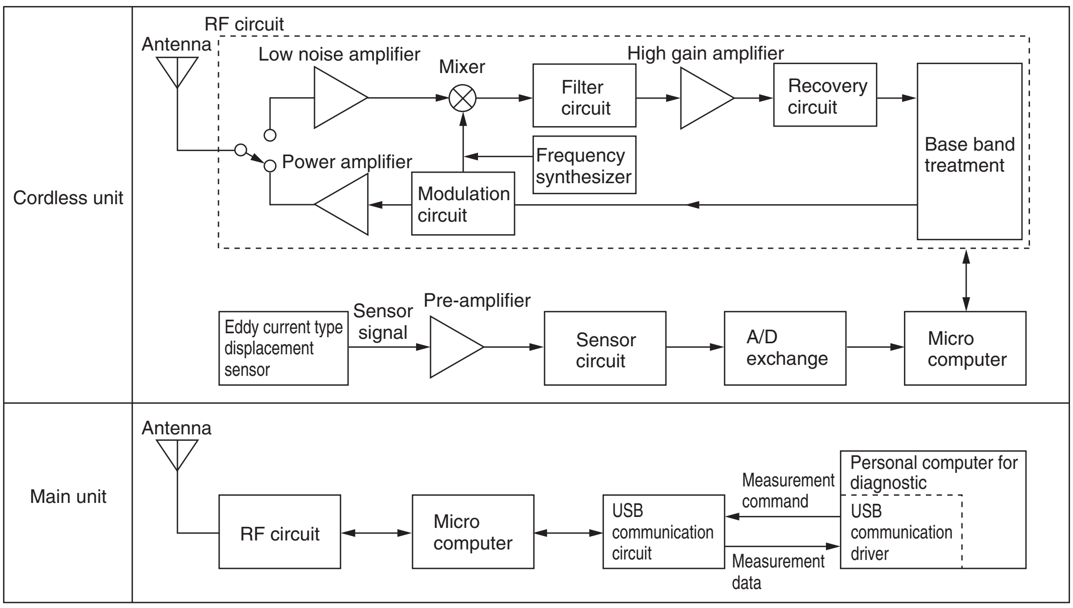

Fig. 12 Wireless circuit block chart

Table 1 Specifications of wireless communication

No	Items	Target value	Explanation
1	Wireless frequency	Unlicensed low-power service range	License or application not required
2	Communication (modulation) method	FSK method	Strong communication method against external disturbance, transmission of DC signal possible
3	Multiple channels complied	32 stations	Possible to send to & receive from multiple cordless units, software ID complied
4	Two-way communications	–	Measurement command and mode change possible from PC for diagnostic.
5	Continuous data transmission	For 120 seconds	Data collection during rolling (one pass) possible
6	Communication distance	5 m	Communication distance of more than 5 meters
7	Battery drive	3V drive	Small size battery to be selected (1 pc. of battery), low power circuit
8	Low power consumption	Battery life of more than one year	Longer battery life achieved by intermittent driving

original transmission code is determined as shown in **Fig. 14**.

3. 3 Selection of Battery and Realizing Longer Life

The selection of battery has been a big problem among the required specifications shown in **Table 1**. Methods such as self-generation or power supply from outside have been studied. Considering the necessary current, size and stability, etc., the power supply by the primary battery can be considered as a practical level. Therefore, the thionyl chloride lithium battery, as shown in **Table 2**, has been selected, and by adopting the battery, an effort to save electricity has become indispensable.

Table 2 Lithium battery specifications

Items	Contents
Appearance	
Size	$\phi 17 \times 33$
Mass	13 g
Voltage	3.6 V
Capacity	1 700 mAh

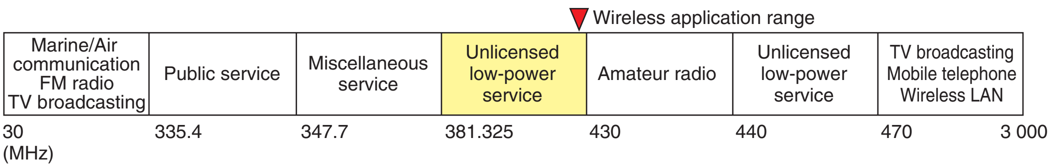

Fig. 13 Frequency range used in this wireless technology[2)]

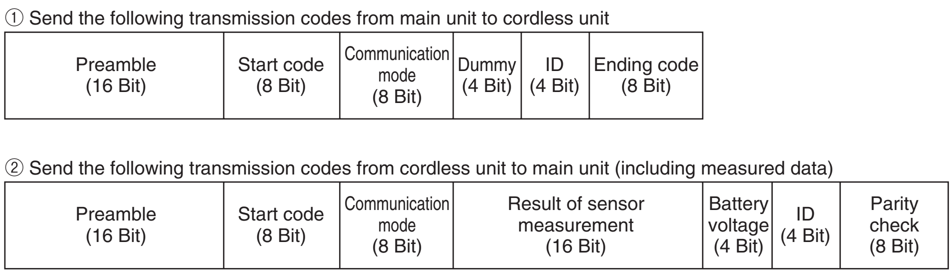

Fig. 14 Wireless transmission code

Due to the labor intensive work necessary to change batteries in the field the target of one year was determined to be practical. The development target for the battery life has been set as more than one year.

Currently there are wireless devices featuring the battery life with more than one year on the market. Most of them are the type that transmits ASCII code on the simple ON/OFF signals or temperature only once a day. Wireless devices required to transmit continuous data for 120 seconds have a battery life, in many cases, that is around several hours or days.

A standard countermeasure for longer battery life is an intermittent driving method. This is the method for a cordless unit to check the measuring instruction once every several seconds against a main unit. The longer the checking interval is made, the smaller the power consumption is. This can result in attaining the longer battery life. In order to achieve the calculated battery life of more than one year, it has been proven that when using a lithium battery for a compact type cordless unit shown in **Table 2**, the intermittent driving with a 30 second interval is required. However, this interval brings a waiting time of the maximum 30 seconds before the measurement; there was a problem that made timely measurement impossible.

Therefore, as a countermeasure for the longer battery life, the two mode methods of a pause mode and a stand-by mode for measurement have been incorporated to achieve the smaller power consumption and longer battery life, as shown in **Fig. 15**.

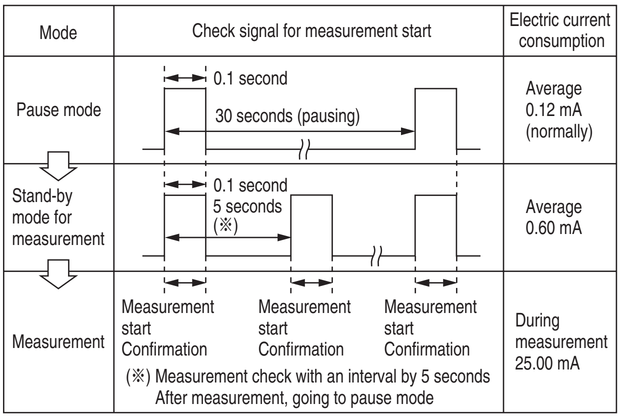

Fig. 15 Two-modes intermittent operation method

Specifically, the cordless unit is normally on pause mode and carries out to check once every 30 seconds for the main unit. When carrying out measurement, the mode change operation is requires, that is, the mode is switched from the pause mode to the stand-by mode for measurement. Under the stand-by mode for measurement, as the cordless unit carries out to check for measurement start with a cycle of once every 5 seconds for the main unit, the timely measurement is made possible. After the measurement, the sequence is set to be automatically returned back to the pause mode. Consequently, both the longer battery life and the countermeasure for response deterioration are compatible. It becomes possible to achieve the longer battery life of more than one year. In meeting these requirements we have been able to develop the wireless device which satisfies all the necessary specifications, shown in **Table 1**.

4. Diagnostic Software

4. 1 Outline of Diagnostic Software

The flaking diagnostic screen, a representative screen of diagnostic software, is shown in **Fig. 16** and the history and tendency control screen in **Fig. 17**. The diagnostic can predict or detect, from original signal treatment or tendency control, the forecast for occurrence of damage on raceway surface by flaking or wear observed at the JTEKT life test as mentioned above.

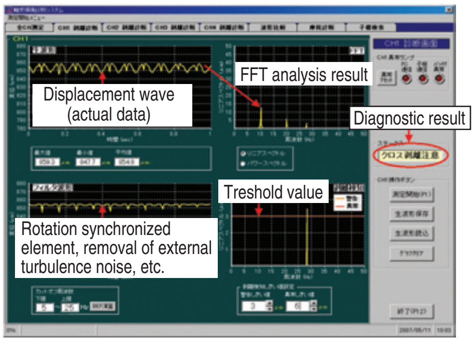

Fig. 16 Flaking failure diagnosis screen

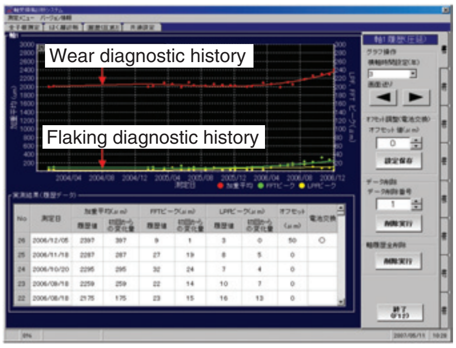

Fig. 17 History and tendency control screen

Currently, the verification has been already taken with a 1/8-size model of the actual machine, and the verification with the full sized machine is being prepared. Finally, after confirming the result of diagnostic in the field and accumulating the achievements of the system, steps to realize actual products will go into motion.

5. Conclusion

We have explained the detection technology, the wireless technology and the damage diagnostic software developed as the driveshaft damage diagnostic system for steel mills. The explanation has been focused mainly for the detection technology, but we have completed our laboratory evaluation for the respective development issues and these results of verification have satisfied the target performance.

After confirming the significance of damage detection on raceway surface by flaking or wear with actual driveshafts, in the future we would study for an application of this technology for roll neck bearings for rolling mills and bearings for equipments for wind power generation.

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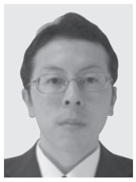

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