Tire Uniformity Machine, LIBROTA®

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Tire uniformity machines are used to inspect the quality of automotive tires. Two capabilities are emphasized, i.e., the measurement repeatability expressed by the variation of measurement values when a tire is measured several times and the cycle time for inspecting each tire. There are various restrictions in reconciling these two, and we have reconsidered the structure of mechanical parts, including spindle and drum, and the control component of the machine. As a result, it has become possible to shorten the cycle time to 18 seconds, 10% faster than before, while improving the measurement repeatability to RFVσ≦1.69 N. This paper reports the outline of the technology introduced for improving the measurement repeatability and cycle time performance.

Introduction [1)]

In 1967, Kobe Steel began the production and sales of tire uniformity machines (hereinafter referred to as "TUMs") for inspecting the quality of tires for passenger cars, trucks and buses. Since then, the company has sold over 800 units. The company's TUMs have been sold mainly in Japan and Southeast Asia so far, and, to win the leading spot, there has been a need to commercialize new TUMs applicable everywhere, including China, Europe, and the U.S., the markets currently dominated by competitors.

In a TUM, two capabilities are emphasized, i.e., measurement repeatability (σ), which evaluates the reliability of measurement when a tire is measured several times and is expressed by the variation of measurement values, and cycle time, which is the time required for inspecting each tire. In order to surpass competitors in these two capabilities and win the leading spot, Kobe Steel engaged in the development and, in 2013, commercialized a new TUM, "LIBROTA® [note 1]." The appearance and basic specifications of Librota are shown in **Fig. 1** and **Table 1**, respectively.

This paper describes the steps taken to improve Librota's measurement repeatability and, at the same time, to shorten the cycle time.

note 1) LIBROTA is a Kobe Steel's trademark registered in the U.S. Librota is also a trademark registered in Japan (No. 5257882). Hereafter, it is simply referred to as "Librota" in this paper.

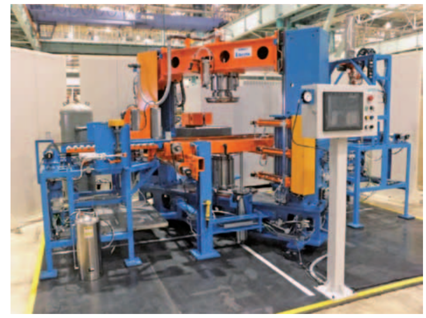

Fig. 1 New tire uniformity machine (TUM): LIBROTA®

Table 1 Base specifications of LIBROTA®

Tire size (bead diameter)	12～28 inch
Tire outside diameter	ϕ 500～ ϕ 1,020 mm
Tire test load	MAX. 18,000 N
Drum size	ϕ 854×406 mm
Repeatability (standard deviation)	1.69 N (215/60R16)
Cycle time	18 s (16 inch)

1. Features of Librota

There are two indicators that show the uniformity of a tire: the radial force variation (RFV), showing how much the force fluctuates in the radial direction of a tire when it rotates with a radius while receiving a load, and the lateral force variation (LFV), showing how much the force fluctuates in the lateral direction during the same action. A TUM is an apparatus for measuring the RFV and LFV (**Fig. 2**).

Conventionally, the tires for passenger cars, sized 13"- 18" in diameter, and the tires for light trucks, sized 15"-24" in diameter, could not be measured on one machine. Librota, on the other hand, has a basic structure that has been significantly modified to widen the range so as to enable the measurement of tires sized 12"-28". In addition, its easy-to-understand operational interface, which introduces a schematic diagram of the machine on the operation screen, permits intuitive and reliable operation. **Fig. 3** shows the main screen.

Uniformity measurement is conducted in accordance with the operating conditions specified in a recipe prepared for each type of tire. The recipe selection allows the measurement of various types of tires. These recipes are important in making accurate measurements, and their preparation requires high

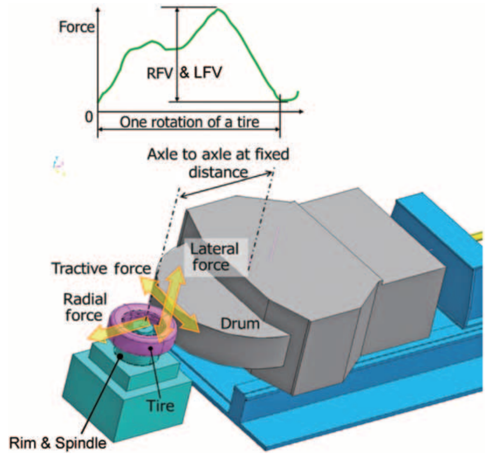

Fig. 2 Measurement mechanism of tire uniformity

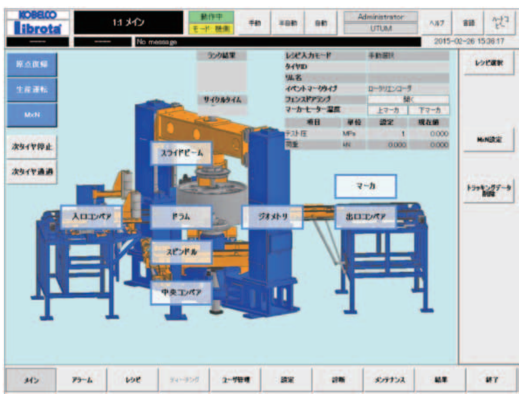
Fig. 3 Main operation screen of LIBROTA®

expertise.

Librota is equipped with a semi-automatic mode to facilitate and ensure the preparation of these recipes. In the semi-automatic mode, parameters are recorded in a recipe for each operation block while tires are being processed in the same manner as in the automatic operation. Preparing a recipe while confirming the same work as the automatic operation facilitates the setting of the optimum conditions of the operation. Maintenance and troubleshooting can also be executed from this screen, making the screen more user friendly.

On the performance side, the goal was set to achieve the repeatability and cycle time of $\sigma \leqq$ 1.69 N and 18 seconds or less, respectively, which exceed the values for previous machines, RFV $\sigma \leqq$ 2.4 N, cycle time and 20 seconds, and to surpass the competitors. One of the challenges in attempting to achieve the trade-off of improving measurement repeatability and shortening cycle time was to stabilize the tire pressure in as short a time as possible.

2. Measurement repeatability

In order to improve the measurement repeatability of a TUM, the following three points are known to be important for the principal measurement part shown in Fig. 2:

(1) Reducing "rim vibration," which affects the variations in rotational runout;
(2) Reducing "drum vibration," which affects the variations of the reaction force from the tire; and
(3) Reducing the "inner pressure variation," which affects the variation of the spring constant of the tire.

This section describes the technology adopted to reduce the influence of these factors to achieve the target measurement repeatability.

2.1 Rim vibration [2]

Reduction of rim vibration is required to show a significant improvement in accuracy in comparison with that of Kobe Steel's previous machines. Since it turned out to be difficult to achieve the target with the mere improvement of the conventional technologies, a new approach was studied.

The previous TUM spindles use tapered roller bearings for retaining the radial direction during low-speed rotation and for holding the high load in the axial direction caused by the tire pressure after the upper and lower spindles are fastened. In developing Librota, a study focusing on the spindles for machine tools was conducted with the intention of employing high accuracy angular bearings. In the case of previous machines, the introduction of air inside the tire at the beginning of each test generates a separating force that acts to move the upper and lower spindles apart. This force acts on the tapered roller bearing on one side of the tire, reducing the preload on the bearing on the other side of the tire and weakening the restraining force against runout in the radial direction.

In order to solve this problem, an attempt was made to suppress the runout in the radial direction by placing, on the other side of the tire, an angular bearing that can maintain the retaining force in the radial direction even when the axial load is applied. In general, placing a bearing that receives the separating force near the tire can retain the separating force more effectively. For this reason, a pair of tapered roller bearings is arranged in the upper and lower spindles so that the tapered rollers face each other on the side with the smaller rotating radius. More specifically, a high-load/high-accuracy spindle (**Fig. 4**) was devised, in which angular bearings and tapered roller bearings are combined.

A prototype spindle with this structure was made to confirm that the rim vibration can be reduced to

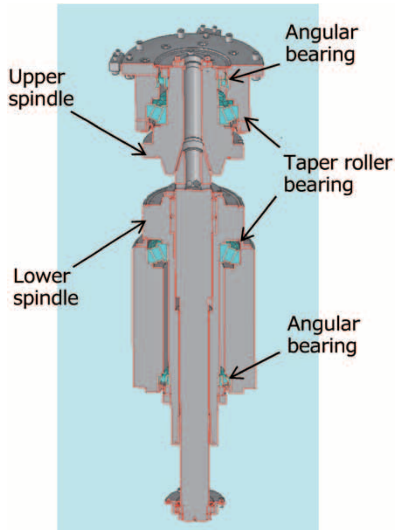

Fig. 4 Spindle structure

one-fifth of that of the conventional machines.

2.2 Drum vibration

In addition, a significant improvement in accuracy, compared with that of previous TUM drums, needed to be made in drum vibration to achieve the target repeatability. For this reason, the issue was approached from the angles of structure and manufacturing technology.

2.2.1 Drum structure

Previous machines employ bearings with tapered rollers, and the axial load received by the drum is rather small. Librota, on the other hand, employs bearings that have been changed to an angular type, the same type as adopted in the spindle, to reduce the vibration of the drum.

Moreover, its rib structure was completely revised to minimize the amount of drum deformation when the load is applied to the tire.

2.2.2 Manufacturing technologies

A drum requires a drum shaft that serves as the rotating axis. The drum shaft is fitted with a load cell for detecting the reaction force from each tire. In the case of Librota, a jig was devised to finish the drum shaft with high accuracy and to reduce the runout of the drum shaft itself. For the drum, the circumference polishing process to finish the shape was revised.

A prototype drum (**Fig. 5**) incorporating these measures of drum vibration reduction was made to verify that the drum vibration had been reduced to less than half of that of previous machines.

2.3 Variation of tire pressure

The tire pressure must be stabilized as much as possible during the tire measurement. In order to improve the measurement repeatability, during the inspection, we aimed at keeping the pressure fluctuation of tires within 0.05% of the set tire pressure of 200 kPa.

2.3.1 High-speed control

The electromagnetic valves used for the air circuit shown in **Fig. 6** were chosen to respond to input signals faster than the previous machines. In addition, the electric pneumatic (EP) regulators and pressure sensors used for the tire pressure control were selected on the basis of their excellent accuracy and repeatability. Moreover, the high-speed control cycle of the controller has improved the pressure repeatability, reducing pressure fluctuation during the test. In the end, the control cycle necessary to stabilize tire pressure was found.

2.3.2 Measures against electric noise

A TUM uses a number of servo motors for

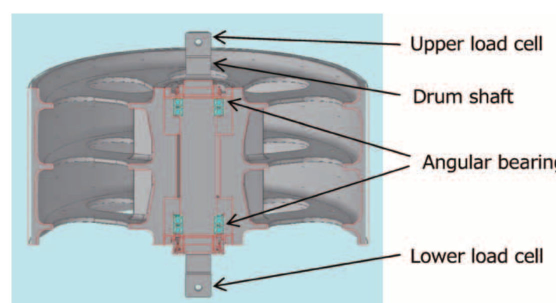

Fig. 5 Drum structure

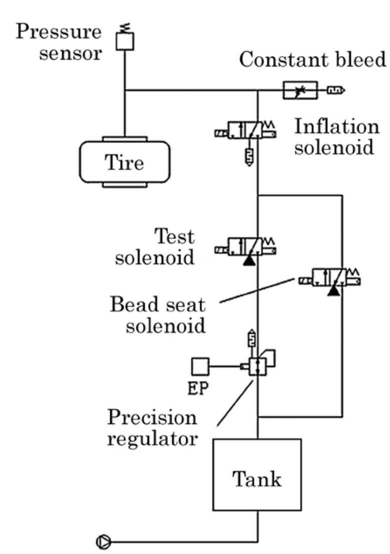

Fig. 6 Air circuit for tire inflation

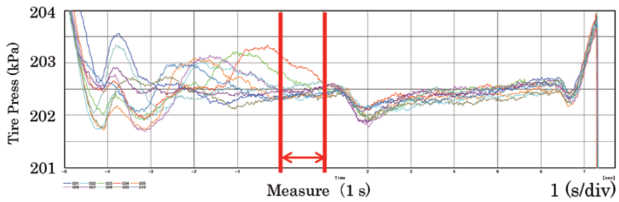

Fig. 7 Tire pressure before noise reduction

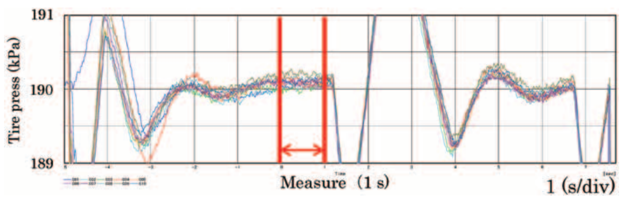

Fig. 8 Tire pressure after noise reduction

machine operation. It was found that the electric noise generated from these servo motors adversely affects the control of tire pressure. As shown in **Fig. 7**, mixed noise makes it difficult to suppress the fluctuation of inner pressure to within 0.05% of the set value. To this end, a study was conducted to reduce the noise generated from the servo motors and to prevent the noise from intruding into the control equipment.

As a result of implementing various measures that were required, it was confirmed that the tire pressure variation at the time of inspection had been decreased to allow the pressure to be controlled within 0.05% of the parameters, as shown in **Fig. 8**.

3. Cycle time

Passenger vehicle tires produced at tire factories are subjected to 100% inspection, and thus the shortening of cycle time is directly linked with productivity improvement. Therefore, a TUM is required to operate with as short a cycle time as possible.

3.1 Downsizing of machine [3)]

In the development of Librota, the working strokes and weight of the apparatus were reviewed in pursuit of thorough downsizing. The revision of the elevation mechanism of the spindle is an example. In the measurement zone of a TUM, a function for raising and lowering the spindle is required to chuck the tire with the rim. Kobe Steel's previous TUMs and those of competitors use hydraulic power to raise and lower the spindle. Librota has a structure in which ball screws arranged in the left and right guide frames are synchronically controlled by their respective servo motors to raise and lower the upper spindle. The separating

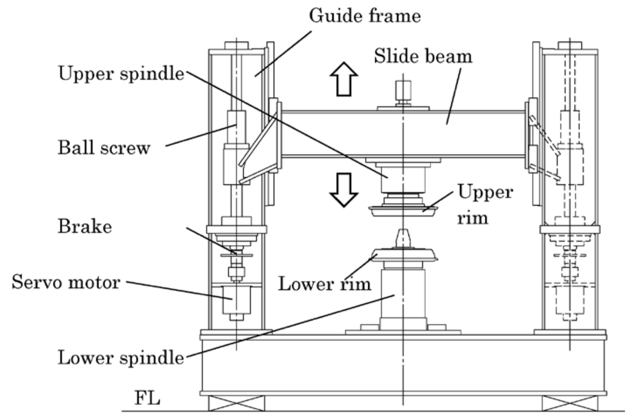

Fig. 9 Mechanism of spindle elevator

force caused by tire pressure is retained by a brake mechanism. **Fig. 9** shows the elevating mechanism of the spindle in Librota. This structure has increased the ascending and descending speed of the spindle and thus shortened the cycle time. Moreover, the use of servo motors has eliminated the need for a hydraulic system, facilitating maintenance. Furthermore, without the risk of oil leakage, it is now possible to install the spindle lifting/lowering unit on top of the machine. This has successfully eliminated the need for a floor pit.

The revision of these mechanical structures has led to the reduction of the occupied volume to approximately 30% of that of the previous machines.

3.2 Adopting high-speed controller

As shown in **Fig. 10**, the operation of the machine follows the program in the controller, which repeats the sequence of the status check (thick horizontal line) and action (shaded box). Here, the delay time due to the fieldbus communication cycle consists of:

- the time from the detection of the actual state to the detection of the condition by the controller and
- the time from the operation command by the controller to the actual start of the operation.

The TUM operation related to cycle time includes hundreds of status checks and actions, which leads to cycle time delay for the number of fieldbus communication cycles. The cycle time is also affected by the processing capacity of the controller CPU, which influences the program execution speed.

Therefore, a decision was made to construct a control unit with a controller capable of high-speed processing with a short task cycle and a high-speed communication fieldbus with a short communication cycle (**Fig. 11**).

Performance evaluation by a breadboard test confirmed the cycle time of 18 seconds.

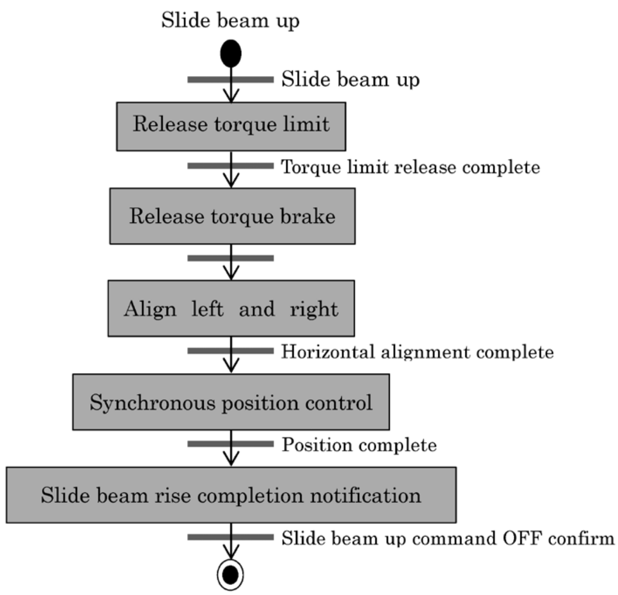

Fig.10 Flow of elevating operation for spindle

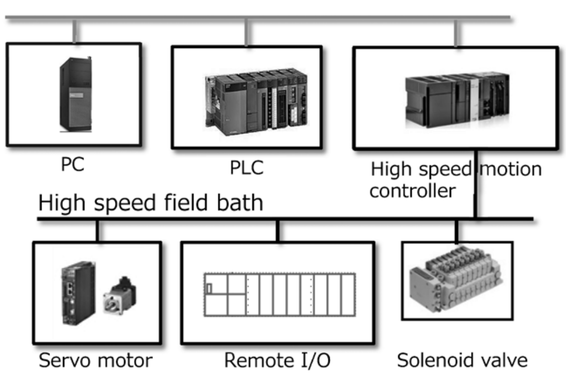

Fig.11 Controller configuration

Conclusions

Kobe Steel resolved the trade-off between improved measurement repeatability and short cycle time, and since Librota's commercialization in 2013, more than 70 units have been sold, mainly in China and Southeast Asia. It can respond to diverse needs with the optional apparatuses required for tire quality inspection, including a sheet-of-light laser geometry system, which inspects a tire's circularity and concave/convex abnormality on a plane, and a shoulder grinder, which grinds the edge of a tire to reduce vibration and noise.

Kobe Steel will strive to expand the lineup of TUM responding to the wide range of customer needs, while developing the market in Europe and the U.S., and continue its activities to take the lead in the world market.

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