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Development of Magnetostrictive Load Sensor for Motorcycle-Measurement Robot

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Abstract

In order to improve the accuracy and efficiency of evaluation of increasingly high-performance motorcycles, we at Yamaha Motor have developed a control system for automated operation of motorcycles by human-shaped robots. For the indispensable shift load sensor in the system, we had originally used a strain gauge type load cell but were unable to get satisfying results with it regarding sensor sensitivity when subjected to engine vibration conditions, strength and response. To solve these problems, we tried using a magnetostrictive sensor for the first time. In tests in actual use we found that the magnetostrictive load sensor satisfied the requirements of operating conditions for a motorcycle operation control system and measurement system.

1 INTRODUCTION

Recently, motorcycles are having high functionality, high performance, and high speed. Then, riders must be skilled especially during a driving evaluation test. Therefore, a control system using anthropomorphic robot for auto driving of motorcycle has been developed in order to improve the development efficiency. In this control system, the anthropomorphic robot controls the accelerator, shift, and clutch operations to make the driving bench test with auto operation possible. This paper describes the magnetostrictive load sensor, which is absolutely required for this control system.

2 MEASUREMENT SYSTEM FOR MOTORCYCLE DRIVING PERFORMANCE

2.1 EVALUATION TEST EQUIPMENT

Figure 1 shows the photo of the motorcycle measurement system using the robot. In this measurement system, the anthropomorphic robot controls the accelerator, shift, and clutch operations to make the driving bench test with auto operation possible. Use of the robot makes it possible to improve the accuracy and repeatability of the test data.

Figure 1 Motorcycle test using anthropomorphic robot

Figure 2 shows a wind tunnel apparatus for motorcycle driving test. Winds flow from front side of a motorcycle at the same speed as running speed. And motorcycle stays on the Chassis dynamo.

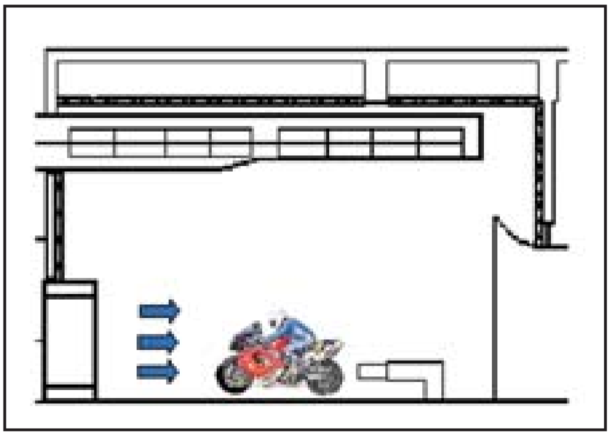


Figure 2 Wind tunnel apparatus

2.2 AUTO DRIVING CONTROL SYSTEM

Figure 3 shows the auto driving control system. The driving patterns can be controlled automatically using the built-in driving programs. And the operator pressing only the start button in the operation room carries out the evaluation test.

The control data is sent into the bench through the I/O control units in order to give drive commands to the robot, and to set the environment and load conditions. At the same time, the statuses of various sensors inside the bench are also sent to the controller through the I/O control units. The controller is built in the control panel and designed to monitor the driving status and record the measured values transmitted from the sensors into the logger.

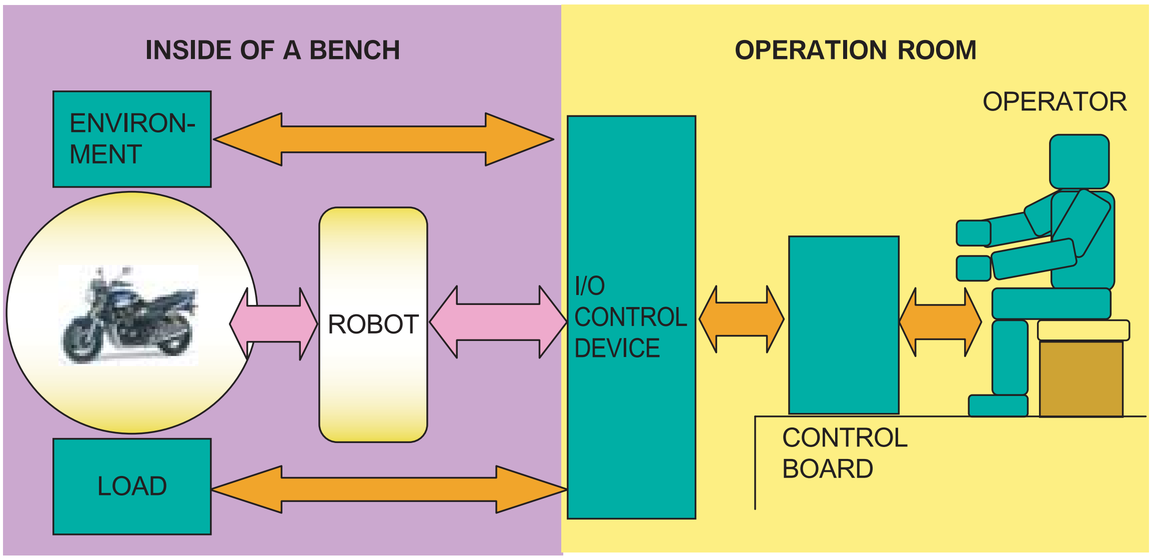


Figure 3 Block diagram of entire measurement system

3 SHIFT LOAD SENSOR FOR MEASUREMENT ASSIST ROBOT

3.1 MEASUREMENT ASSIST ROBOT

Figure 4 shows the control block diagram of the measurement assist robot. Relevant actuators and sensors are mounted in the accelerator, clutch, and shift operation systems. The robot plays two important roles. First, the shift change and accelerator adjustment controlled automatically by actuators to set the output of the motorcycle. Second, the air flow adjustment around the engine, as if a rider is actually sitting on the motorcycle.

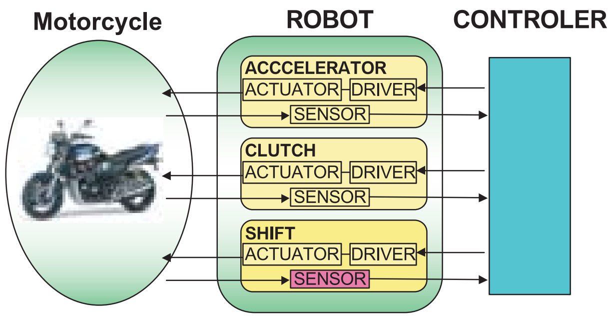


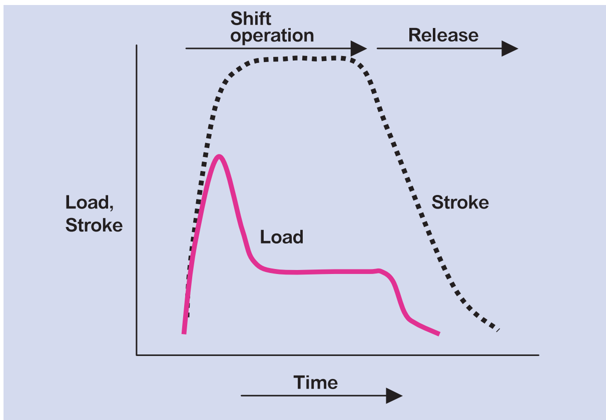
Figure 4 Control block diagram of measurement assist robot

In the driving evaluation, the air flow around the engine including the driver's body may turn into problems. The upper part of the driver's body does not affect the air flow around the engine. Therefore, the robot simulates only the lower part of the driver's body.

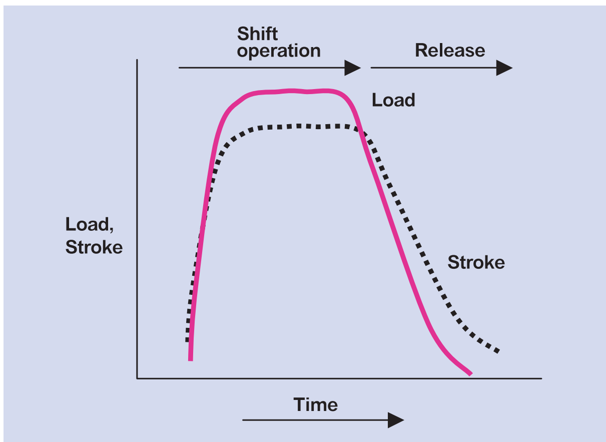
3.2 JUDGEMENT OF SHIFT CHANGE

It is very important for auto driving that it is judged properly whether or not the shift has been changed correctly. Normally, it cannot be judged properly by detecting only the shift stroke. So, the measurement system detects the shift stroke and shift load at the same time. **Figure 5** shows changes in shift load when the shift pedal is operated. Generally, when the shift is changed successfully, it is found that the load decreases halfway during increasing of the shift load. (**Figure 5-1**) If the shift is changed incorrectly, the load does not decrease until the shift operation is released. (**Figure 5-2**)

Then, by detecting both the shift load and shift stroke at the same time, it is possible to judge whether or not the incorrect shift change occurred. Therefore, a highly accurate sensor was strongly required, which can detect changes in shift load under engine vibration conditions.



1) Shift success



2) Shift mistake

Figure 5 Changes in shift load

4 INITIAL TYPE OF SHIFT LOAD SENSOR (STRAIN GAUGE TYPE)

The shift load sensor unit is used not only to detect the shift load, but also to connect the linear actuator with shift pedal. **Figure 6** shows the layout of shift load sensor. And, it was first attempted to detect the shift load using a commercially available strain gauge type load cell. However, since the detection sensitivity of this sensor was low, accuracy necessary for the control could not be obtained. So, the sensor often could not detect incorrect shift change.(**Figure 7-1**)

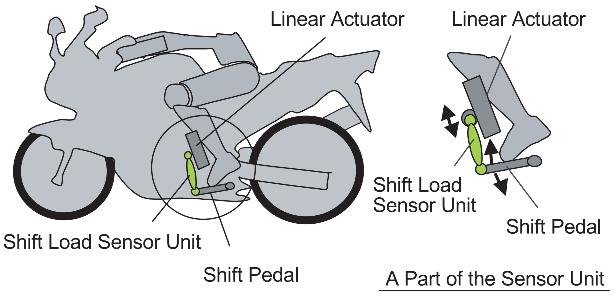
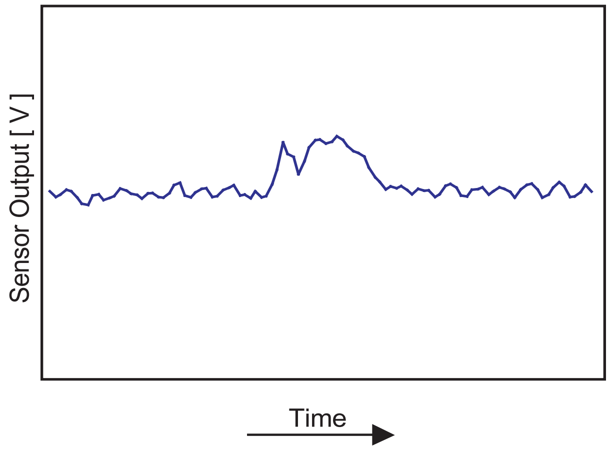


Figure 6 Layout of shift load sensor

Additionally, when the sensor having higher sensitivity was used, the sensor was broken within a short time due to insufficient strength. (**Figure 7-2**) If this type of sensor was broken during auto driving, the actuator was separated from the shift pedal, causing the engine control to become impossible.



1) A detected signal

2) The damaged sensor

Figure 7 Initial type of shift load sensor (strain gauge type)

5 NEW TYPE OF SHIFT LOAD SENSOR (MAGNETOSTRICTION TYPE)

5.1 MAGNETOSTRICTIVE LOAD SENSOR

A magnetostrictive load sensor has been newly developed to solve the problems of the strain gauge type sensor. **Figure 8** shows the outside view of the newly developed magnetostrictive load sensor.

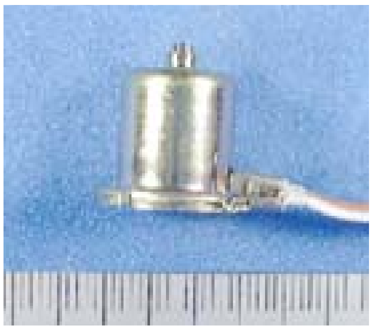


Figure 8 Outside view of magnetostrictive load sensor

This type of a sensor uses a change of the inductance accompanying strain. Because the rate of change is higher than that of the strain gauge type load cell, it has high sensitivity. And it can constitute a sensor with intensity higher than the strain gauge type load cell.

This sensor is small and lightweight, and has excellent responsibility and load resistance. Additionally, the displacement during measurement is very small. Furthermore, a low manufacturing cost can also be achieved since the structure is simple.

Figure 9 shows an example of load characteristics of the sensor. **Table 1** shows the characteristics of the sensor at this time.

Figure 10 shows the durability of this sensor. If this sensor is operated within the allowable load range, it can be operated at least 10^6 times. Blue line and brown line mean stable sensitivity.

Table 1 Characteristics of magnetostrictive load sensor

The maximum permissible load	800N
Non-linearity	3%
Hystersis	5%
Temperature characteristic	0.25mV/C

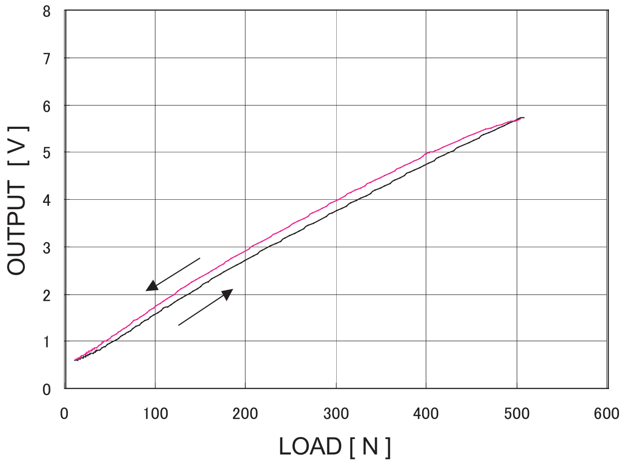


Figure 9 Example of load characteristics

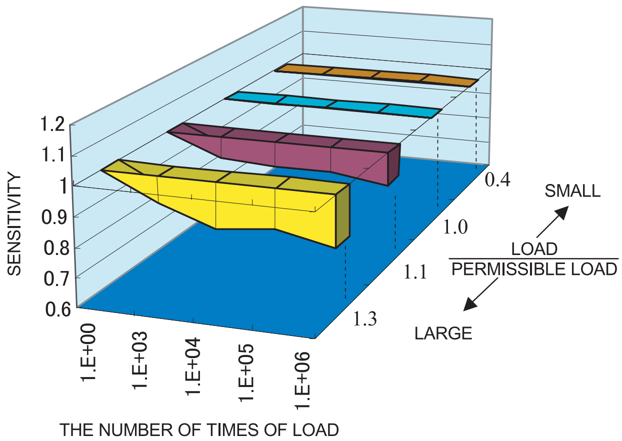


Figure 10 Repeated load test results

5.2 MAGNETOSTRICTIVE SHIFT LOAD SENSOR UNIT

We have developed a new shift load sensor unit using the newly developed magnetostrictive load sensor. **Figure 11** shows the status how this sensor unit is mounted on the actual motorcycle. This sensor has high sensitivity and excellent load resistance compared to the initial type of shift load sensor.


Figure 11 New-type shift load sensor mounting status

Figure 12 shows the structure of the magnetostrictive shift load sensor unit. This sensor unit has a structure, in which the magnetostrictive load cell is sandwiched by the springs. Thus, this structure protects the sensor from the impact and/or overload. Additionally, even if a trouble occurred in the sensor, the sensor holder is not damaged. So, the remote-shift operation can be performed through the operation panel by changing the operation mode to the manual mode.

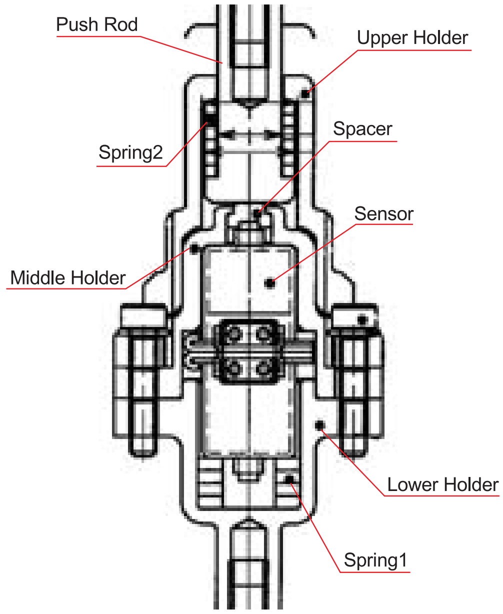


Figure 12 The structure of the sensor unit

5.3 RESULTS OF APPLICATION OF LOAD SENSOR UNIT TO MEASUREMENT SYSTEM

Figure 13 shows the obtained load signals. As the sensitivity is improved when compared to the initial type shift load sensor, the incorrect shift change is detected properly. Thus, the measurement of the test results can be made automated.

Figure 14 shows an example of the test course driving pattern. In addition to this driving pattern, this measurement system has been used for auto driving with various driving patterns until now. It is said that the system has been operated properly.

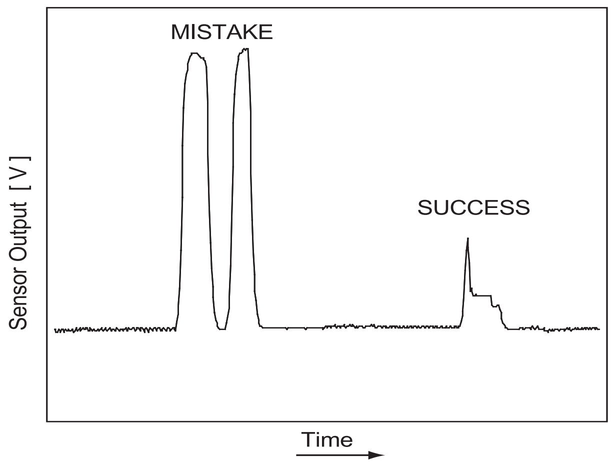


Figure 13 Results of measurements using magnetostrictive shift load sensor

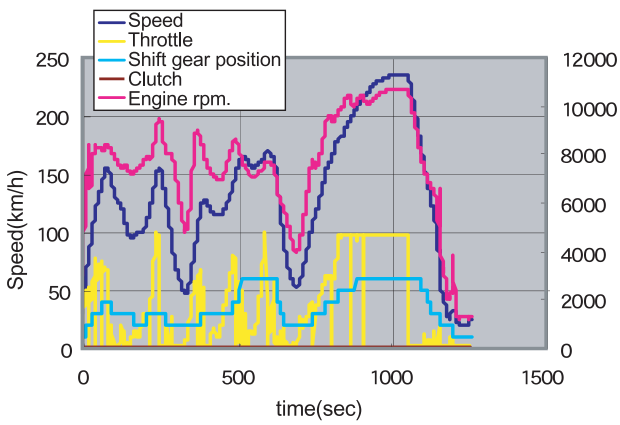


Figure 14 Test course driving pattern

6 CONCLUSION

In the auto driving evaluation system of the motorcycle using the measurement assist robot, a magnetostrictive shift load sensor has been newly developed to detect the shift load. Using this load sensor, the shift change can be controlled properly in the auto driving evaluation system.

This sensor was mounted on a motorcycle and used for the evaluation with various driving patterns. As a result, it was verified that this sensor provides the sensitivity and strength necessary for the control.

Development of the magnetostrictive shift load sensor makes it possible to detect incorrect shift change, which was the subject in the conventional measurement system, in the auto driving evaluation system of the motorcycle using the measurement assist robot. As it is planned to bring this measurement system to the commercial stage, it will be promoted to make the sensor unit more compact and lightweight. And, it is also planned to provide various measurement items by improving the reliability and compatibility with the hardware. This magnetostrictive sensor is small, lightweight, and less expensive, and provides the excellent sensitivity, strength, and responsibility, which are sufficient for practical use. Therefore, this sensor is applicable to not only this measurement system, but also a wide variety of other control systems. We will strive to pursuit this possibility.

■ LITERATURE

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