Product Introduction

Development of "KADS" - An Electronically-Controlled Suspension System for Motorcycles

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1 Introduction

Motorcycles equipped with semi-active suspensions have been available in the European market since around 2012. These motorcycles are mainly sold in advanced models such as Adventure, Street, Tourer and Supersports. The market is still expanding and is expected to continue growing in the future too.

KYB has developed and commercialized a semi-active suspension system integrating the electronic control unit (hereinafter "ECU") hardware (hereinafter "HW") and software (hereinafter "SW"), tuning tools, sensors, front fork (hereinafter "FF") and rear cushion unit (hereinafter "RCU"). The following gives a general outline of the system.

2 Overview of System

2.1 System Components

Fig. 1 shows the components of the system. KYB is responsible for the development of the parts within the blue rectangle, and the customer is responsible for the development of the parts within the red rectangle.

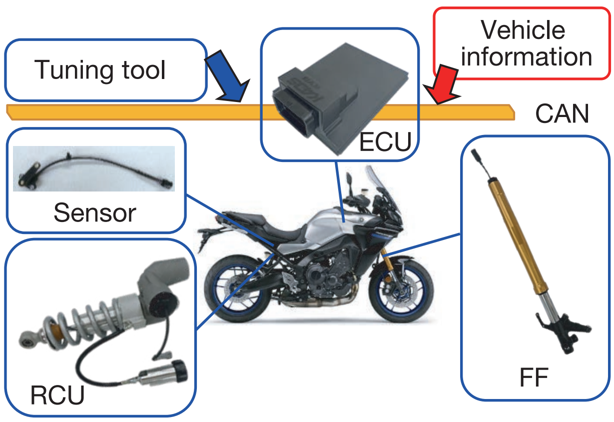


Fig. 1 Components of "KADS"

This new product has been achieved by integration of KYB-specific hydraulic and control technologies and is named "KADS" for branding (Fig. 2).

Fig. 2 "KADS" trademark

"KADS" Note 1) stands for KYB "Actimatic Damper System." The word Actimatic is a coined word from Active and Automatic and represents a high kinematic performance obtained through automatic adjustment. "KADS" achieves both the basic performance (riding comfort) and the kinematic performance focusing on the typical vehicle behaviors, i.e., "running," "cornering" and "braking."

Note 1) "KADS" and "Actimatic Damper System" are trademarks owned by KYB Corporation.

2.2 System Concept

"KADS" is based on KYB's original concept called "Ground-Hook," which provides the rider with the sensation of being grounded to the road - a feeling of security, just like a tire (Fig. 3).

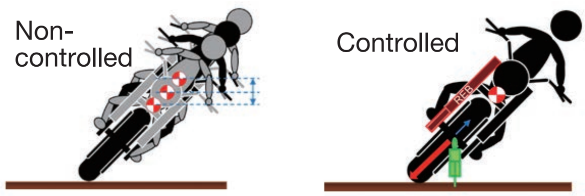


Fig. 3 Shift in center of gravity during cornering

Table 1 Center of gravity for controlled/non-controlled cases

Event	Control	Center of gravity	Effect (adhesion)
Shift in center of gravity	No	Unstable	No
	Yes	Stable	Yes

It may be difficult for beginner riders to maintain the banking angle properly against the vehicle speed while cornering. They are likely to apply the brakes or to put the motorcycle upright and often eventually make the center of gravity of the motorcycle unstable. For the non-controlled case, they can hardly stabilize the center of gravity, making the motorcycle unstable, as shown in Fig. 3. For the controlled case, "KADS" can automatically maintain the center of gravity to stabilize the motorcycle, and riders can easily feel the tire adhesion. This is called the riding skill support.

To realize the concept described in this section, we developed the products introduced in the following chapter.

3 ECU

The unique control system developed by KYB can detect the motorcycle condition in real time with information from multiple sensors mounted on the motorcycle and automatically adjust the damping force of the suspensions to an appropriate level according to the riding situation (running, cornering or braking). To provide optimal control based on the system concept, KYB newly developed HW and SW of the ECU.

3.1 Appearance and Structure

The appearance of the ECU is shown in Photo 1. A chip-mounted board is installed in the resin enclosure. The inside of the resin enclosure is filled with potting material to provide sealing and fixing to ensure resistance to vibration, water and dust (Photo 2).

Photo 1 Appearance of ECU

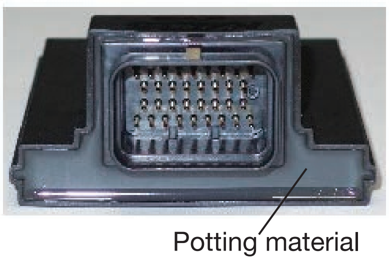


Photo 2 Filled with potting material

3.2 Interfaces

The ECU has connections to components, as shown in Fig. 4. The ECU provides interfaces with a Controller Area Network (hereinafter "CAN") and six analog input ports, enabling it to accept many different types of input. With these inputs, the ECU can control up to four solenoids. The ECU's highly flexible HW makes it possible to support a variety of interface requirements just by customizing the SW to the specifications of target motorcycle models.

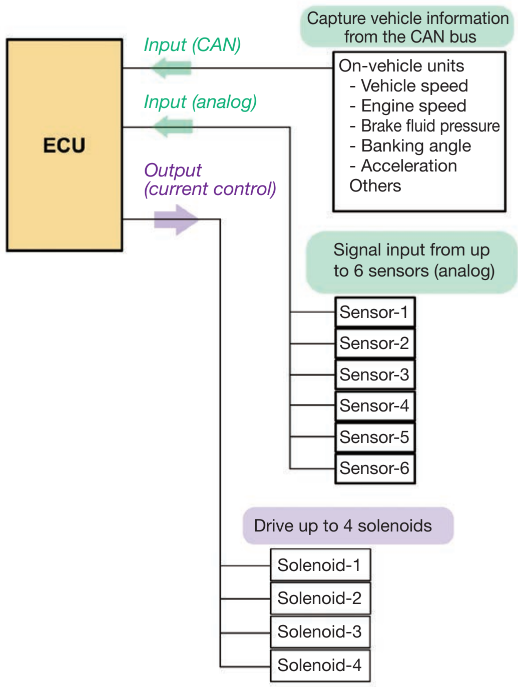


Fig. 4 Connections between ECU and components

Fig. 5 is a functional block diagram showing the general configuration of the ECU. This battery-powered ECU captures various input signals to perform calculation of damping force control. Its output section has a control switch and a current detection function, and puts out a desired current based on the results of calculation. The control switch is driven by pulse width modulation (PWM).

The ECU also has a safety mechanism that can detect and process anomalies. Should an anomaly occur, the mechanism works to initiate appropriate processing, causing the system to go to a safe state.

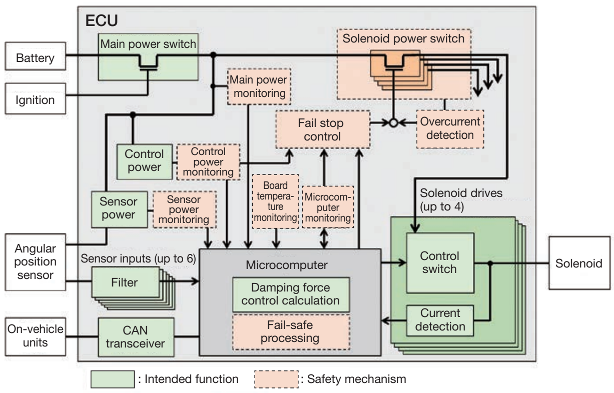


Fig. 5 ECU functional block diagram

3.2.1 Input to ECU

The ECU communicates with on-vehicle units via the

CAN bus to capture vehicle signals, including vehicle speed, engine speed, brake fluid pressure, banking angle and acceleration. It acquires sensor signals via the analog input port to detect the vehicle behavior. For "KADS," the angular position sensor described in Chapter 4 is mounted on the vehicle to detect the angle of oscillation of the rear swing arm. This sensor signal is captured via the analog input port.

3.2.2 Output from ECU

The output is connected to the solenoids integrated in the suspensions described in Chapter 5. Based on the calculation of damping force control, the current flowing through the solenoids is controlled. For "KADS," the damping force control covers three components: the left damper of FF, the right damper of FF, and RCU. The damping forces of these components can be independently controlled.

Table 2 Control logic list

Control name	Description
Pitching-based control	Adjusts the damping force according to the acceleration in the longitudinal direction of the vehicle. Suppresses nosedive.
Road surface condition-based control	Adjusts the damping force by determining the road surface condition based on the acceleration in the vertical direction of the vehicle.
Banking angle-based control	Adjusts the damping force according to the banking angle. Stabilizes the vehicle's attitude during cornering.
Vehicle speed response control	Adjusts the damping force according to the vehicle speed.
Engine speed-based control	Adjusts the damping force according to the engine speed. Suppresses the abrupt changes in attitude of the motorcycle caused by the engine speed fluctuation.
Jump-based control	Adjusts the damping force by detecting vehicle jumps. Alleviates the impact on the motorcycle during landing.
Brake fluid pressure-based control	Adjusts the damping force according to the brake fluid pressure. Stabilizes the motorcycle during braking.
Stroke speed-based control	Adjusts the damping force according to the suspension stroke speed. Adjusts the basic characteristics to improve the ride quality.
Bottoming control	Adjusts the damping force to suppress bottoming of the suspensions.
Damping force correction control	Corrects the damping force by identifying the type of riding: solo, tandem, load.
Mode selection control	Enables the rider control such that the rider can freely select running modes.

3.3 Damping Force Control

To realize the "Ground-Hook" system concept, we built/integrated the 11 control logics listed in Table 2 to develop KYB's proprietary damping force control.

The ECU calculates the damping force control settings at a rate of 1/1,000 seconds in response to the signal inputs stated in section 3.2.1. With this high-speed processing, smooth control of the damping force has been realized. Parameters used for the control calculation can be flexibly set using a dedicated tuning tool according to the target motorcycle models.

3.4 Tuning Tool

KYB originally developed a tuning tool for setting parameters to control the damping force. Fig. 6 shows a conceptual illustration of the parameter settings. The use of the tuning tool allows the user to set in detail the damping force control characteristics for each input signal. To ensure usability, KYB provides vehicle manufacturers with this tuning tool as an application program that can be operated visually and intuitively. The tool makes it possible to adjust parameters efficiently in the actual vehicle evaluation, contributing to the shorter time of tuning of damping force in the development evaluation phase.

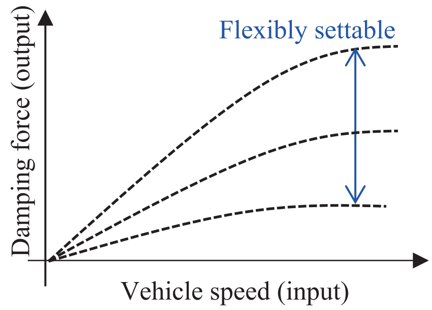


Fig. 6 Conceptual illustration of damping force control parameter settings

4 Angular Position Sensor

To achieve a sensor to detect the angle of oscillation of the rear swing arm, we adapted an existing product to develop a new angular position sensor.

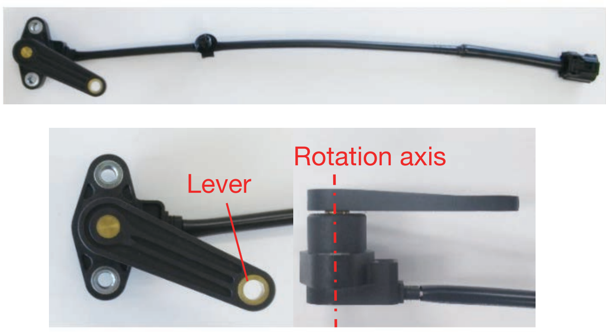


Photo 3 Appearance of angular position sensor

4.1 Appearance and Structure

The appearance of the angular position sensor is shown in Photo 3. The new sensor has a lever that is suitable for detecting the angle of oscillation of the rear swing arm. The sensor can be connected to the vehicle body via a rod installed at the tip of the lever so as to synchronize with the oscillating rear swing arm. The angle (angle of oscillation) is detected by the lever rotation.

4.2 Functions and Characteristics

This sensor includes a magnet and a Hall device to convert the mechanical rotation angle of the lever into an electric analog signal.

The effective range and output characteristics of this sensor are shown in Figs. 7 and 8, respectively. Over the effective range, the output characteristics are linear against the rotation angle of the lever, and the output voltage level is proportional to the power voltage supplied by the ECU. Thus, the sensor has a sufficient effective range and an adequate accuracy for detecting the angle of oscillation of the rear swing arm. This signal is also recognized by the ECU as one of the vehicle behaviors and is used as input for calculation of the damping force control.

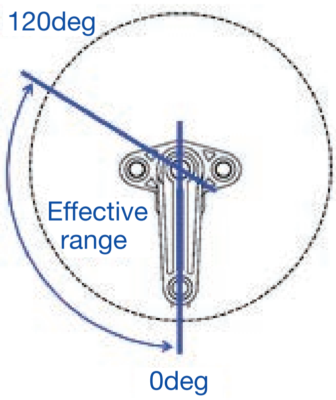


Fig. 7 Effective range

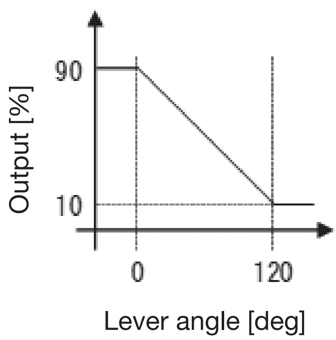


Fig. 8 Output characteristics

5 Suspensions

This new suspension uses a solenoid valve to offer a high reaction rate and generate a wider range of damping force than the conventional counterpart, thereby enabling a high degree of both handling stability and riding comfort simultaneously. To achieve an optimal damping force based on the system concept, we newly developed an FF, an RCU and a built-in solenoid.

For a higher reaction rate, the new suspension uses a proportional solenoid to convert electric energy into mechanical (linear) motion by means of an electromagnetic force.

5.1 FF

5.1.1 Basic Structure

Photo 4 shows the appearance of the new FF. This FF with a built-in solenoid has a solenoid valve installed within the damper and has an input current connector mounted outside the damper.

For the conventional suspension, several measures have been taken to improve the damping force or reaction rate, for example, the use of larger cylinders or pressurization of the hydraulic fluid.

For the new suspension, the use of larger cylinders is also applied. In addition, the right damper is equipped with a mechanism to produce an expansion damping force while the left damper has another to produce a contraction damping force. The use of these independent damping mechanisms eliminates the delay in response in generating a damping force during switch-over between expansion and contraction.

Photo 4 Appearance of new FF

5.1.2 Damping Force Characteristics

Fig. 9 shows the damping force characteristics for various methods of controlling the damping force. The method using a bypass oil passage with a needle valve can offer natural ride quality by making use of the valve characteristics, but only has a narrow range of damping force adjustability due to its structure.

For the relief pressure regulation method, it is possible to ensure an adequate range of damping force adjustability. However, it is unavoidable for the relief valve pressure regulation to start generating the damping force at a lower speed than the aforementioned needle valve method, making it difficult to ensure riding comfort of the motorcycle.

The new product further adopts a bypass oil passage method using a spool valve. This damping force generation mechanism consisting of a bypass oil passage based on the conventional type and a ganged valve can simultaneously provide both natural ride quality and a wide range of damping force adjustability equivalent to those of the conventional suspension.

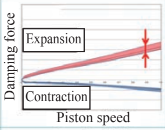
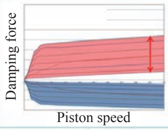
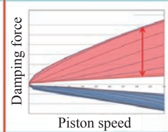
Method	Bypass oil passage with needle valve	Relief pressure regulation	New product Bypass oil passage with spool valve
Damping force characteristics			
Damping force adjustability	×	○	○
Ride quality of actual vehicle (evaluation results)	○	×	○

Fig. 9 Damping force characteristics

5.1.3 Solenoid Valve Structure

Fig. 10 shows, as an example, the structure of the solenoid valve in the expansion damping force generation mechanism (the right damper). The solenoid valve consists of a solenoid section, shown on the left-hand side of the figure, and a spool valve section, shown on the right-hand side.

The operating principle is that when the coil in the solenoid section is non-energized, the spool is pressed by the spring against the left-hand side, closing the soft passage to the holder. The total volume of the fluid flows into the hard passage of the hard valve, generating a high damping force.

When the coil is energized, a magnetic field exists around the coil, generating a force to attract the plunger to the base (an attraction force). This attraction force appears as a stroke of the plunger. The spool position is adjusted according to the input current to the solenoid, and the degree of opening of the soft passage is adjusted accordingly. This flow rate control can expand to switching over to the hard passage, offering a wider range of damping force adjustability. In other words, seamless switching from the soft passage to the hard passage and vice versa according to the input current value allows quick adjustment of damping force from low to high levels.

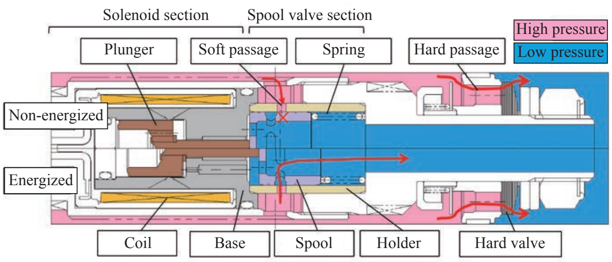


Fig. 10 Solenoid valve structure

5.1.4 Initial Spring Adjuster

Many FFs for sporty motorcycles have an initial spring adjusting mechanism. For semi-active FFs, the initial spring adjuster is generally located above the central axis of the dampers along with electric wiring, jeopardizing the ease of use. In this new product, an initial spring adjuster is located close to each of the dampers, not over the central axis, offering ease of use equivalent to that of the conventional suspension (Photo 5).

Photo 5 Appearance of initial spring adjuster

5.2 RCU

5.2.1 Basic Structure

Photo 6 shows the appearance of the RCU. Like the FF, the RCU has an internal solenoid: a solenoid valve is installed in the damper, and an input current connector is provided outside the damper. This double damper consists of an outer shell and a cylinder to guide the oil to the solenoid valve. In terms of damping force control, the bypass oil passage method using a spool valve is used as in the case of the FFs.

Photo 6 Appearance of RCU

5.2.2 Solenoid Valve Structure

The solenoid valve basically has the same structure as that of the FF. Fig. 11 shows the structure of the solenoid valve of the RCU.

For the RCU, only the expansion damping force can be adjusted. It uses a double-valve system that employs a soft passage with an internal soft valve. The damping force characteristics of the RCU focus on the low-piston-speed region to ensure high tire adhesion and suppress the attitude change of the vehicle during acceleration. The use of the soft valve helps compensate for the damping force in the low-speed region, achieving a smooth, luxurious and natural ride quality.

The operating principle is that when the solenoid is non-energized, the spool will not move to the right-hand side, closing the soft passage, as in the case of the FF. The total volume of the fluid flows into the hard valve provided on the damper side, generating a high damping force.

When the solenoid is energized, the spool moves to the right-hand side. The degree of opening of the soft passage is adjusted according to the input current to the solenoid. This regulates the flow into the soft valve, adjusting the damping force.

6 In Closing

KYB has completed the development and mass production of the new suspension product integrating different systems, which is the first time for the company to release for motorcycles. This makes it possible to deploy the suspension system to other categories of vehicles in a short time.

Mass production of this product has been launched in 2021 for use in TRACER9 GT ABS of Yamaha Motor Co., Ltd. It is under consideration to introduce the product into many other models of motorcycles. KYB is working on the application development.

Finally, we would like to take this opportunity to sincerely thank Yamaha Motor Co., Ltd., related partner manufacturers that gave us their cooperation for the development of this product, and all those concerned from related internal functions.

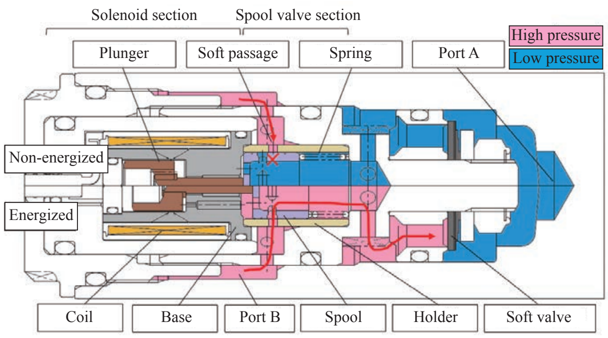


Fig. 11 Solenoid valve structure

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