

Development of Electronically Controlled Hydraulic Steering Damper for Motorcycles

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ABSTRACT

The world's first electronically controlled hydraulic steering damper for motorcycles, HESD (Honda Electronic Steering Damper), has been developed. The HESD gives optimum damping characteristics during running. Handling characteristics and the "Kickback" phenomenon were analyzed using a motorcycle with and without a steering damper. The steering damper with optimum damping characteristics according to the speed and acceleration of the vehicle reduced the "Kickback" phenomenon. An electronically controlled linear solenoid is applied to alter flow resistance of the damper. The HESD reduced kickbacks while maintaining sporty handling at low speed running.

1. Introduction

Kickback is a vibration phenomenon (vehicle behavior) arising in motorcycles running at high speed. Kickback is a sharp change in the steering angle which occurs as the vehicle passes over bumpy road surfaces. This can lead to rider discomfort and fatigue.

Typical measures employed to reduce kickback include setting adjustments to the tires, suspension characteristics and vehicle alignment. However, another device for reducing kickback is a steering damper. A steering damper adds a damping torque to the steering axis and suppresses any sudden movement to the handlebar. Hydraulic types have been the main types of damper control used to date. The issue with steering dampers is that when the damping torque required to reduce kickback is applied it can affect the handling when the vehicle is running at low speed. Consequentially, such steering dampers have only been applied to racing motorcycles and some commercial motorcycles.

An analysis of the handling characteristics and kickback phenomenon was conducted and the damping characteristic requirements for these were observed. This paper describes the development of a new technology with the application of



Fig. 1 Appearance of the HESD

an electronically controlled rotary steering damper that applies variable damping characteristic. This new technology successfully reduces kickback phenomenon without deterioration of the light handling when the vehicle runs at low speed.

Figure 1 shows the newly developed Honda Electronic Steering Damper (HESD) system and Fig. 2 shows the 2004 CBR1000RR model with the new steering damper system.

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Fig. 2 Appearance of the CBR1000RR

2. Development Goals

In order to apply the system to mass-production motorcycles, development goals were set up as follows.

- (1) To reduce the magnitude of kickback without deterioration of light handling when running at low speed.
- (2) Design the system to be light and compact.

3. Kickback Phenomenon

The Japanese Automobile Standard Organization, JASO, has defined kickback as the sudden change in the steering angle of a motorcycle caused when passing over bumpy road surfaces⁽¹⁾. Kickback can affect handling and stability.

Figure 3 shows a graph of the steering angle and front suspension behavior when the kickback phenomenon occurs. When a front wheel of the motorcycle passes over a bumpy road surface, a load is exerted to the vehicle's forward direction. If the direction of the front wheel and direction of the force to that wheel are not the same, a torque is exerted on the steering axis according to the steering angle, the bump height on the road surface, and the contact load to the front wheel. As the steering system turns, the rider's steady state steer force and tire's self aligning torque cause the steering direction to shift back to the direction prior to the load impact. When the torque is excessive, however, the steering is forced in the opposite direction. This repetition increases the steering amplitude. The operational frequency of the steering angle is 5-10 Hz and is believed to be determined by such factors as vehicle weight and alignment. The operational

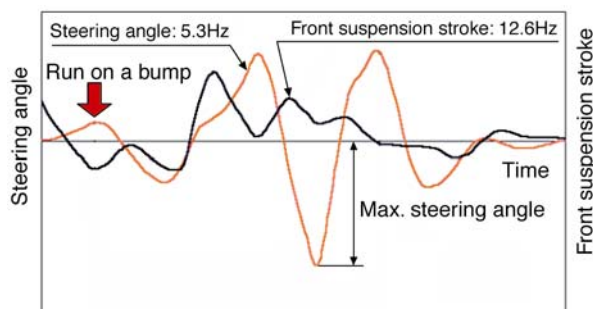


Fig. 3 Explanation for "Kickback" phenomenon

frequency of the front suspension when kickback occurs is approximately twice that of the steering angle.

The load exerted to the motorcycle's forward direction, which is input to the steering system, increases along with greater road surface irregularities and higher running speeds. This consequentially leads to greater kickback occurrence. Even as the direct contact load to the front wheel decreases, for example, as the speed is accelerated, the steering angle increases in reaction to the exerted load and also greater kickback occurs. The excessive kickback transmits greater force on the rider's arms such that the rider can have discomfort and fatigue.

4. Evaluation Method of Running Test

A large super sport motorcycle was used in all running tests of this research. Table 1 shows the major specifications of the test motorcycle. The following test method was used to evaluate light handling (steering effort) and kickback.

4.1. Evaluation of Steering Effort at Low Speed

As shown in Fig. 4, the test motorcycle goes into the test course with straight running at a constant speed of 30 km/h. From point "A", the motorcycle changes lanes to the right or left by two meters and then reverts to its straight running. The steering torque fluctuation in this lane change test mode at the change in steering angle was defined as "low speed steering torque fluctuation" and was evaluated. See Fig. 5. The test rider also rated the steering effort according to the sensory test. Figure 6 shows the rating scale of the test

Table 1 Major specifications

Item	Specifications	
Engine type	Liquid cooled 4-stroke DOHC 4-cylinder	
Engine displacement (cm ³)	998	
Transmission	6 speed constant mesh	
Vehicle dimension (mm)	2025 × 720 × 1120	
Wheel base (mm)	1410	
Vehicle mass (kg)	179	
Tire size	Front	120/70-17
	Rear	190/50-17
Suspension	Front	Telescopic
	Rear	Swing arm

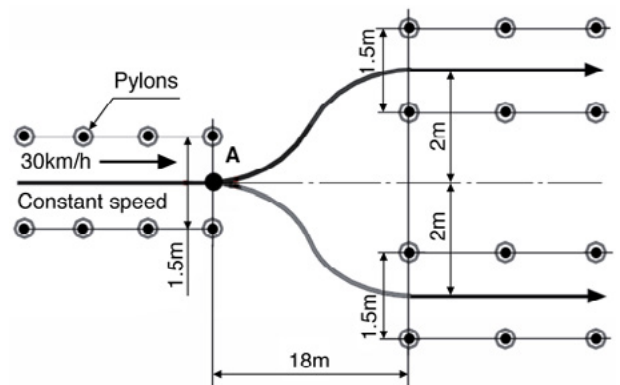


Fig. 4 Test condition of lane change at low speed

rider's sensory evaluation. The above-mentioned test method has been defined as the "low speed lane change test."

4.2. Evaluation Method of Kickback

As shown in Fig. 7, the motorcycle enters the test course with straight running at a constant speed of 120 km/h using sixth gear. From point "A," the motorcycle enters a bumpy road surface at full throttle condition. The greatest steering angle that occurs in the test was defined as the "maximum kickback steering angle," and then evaluated as shown in Fig. 3. The test rider also conducts sensory evaluation. The same criteria for evaluating the ride sensation used in the low-speed lane change test as shown in Fig. 6 are also used in this test. This test has been defined as the "kickback test." The demanding conditions were used in the testing to generate the kickback phenomenon.

5. Target Damping Characteristics

A running test was conducted to determine the target damping characteristics. Tests were conducted by using a steering damper with manual control damping characteristic.

5.1. Target Minimum Damping Characteristics

Light handling can be achieved by decreasing the damping torque generated by a steering damper. The low speed lane change test was repeated while gradually increasing the damping torque of the steering damper. The sensory evaluation was also conducted. If the increase in steering torque fluctuation at low speed is less than 10%, it was confirmed that there was no change in the rider's

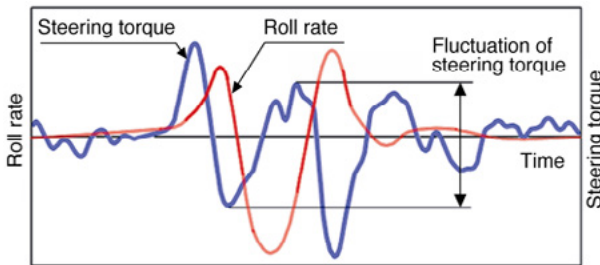


Fig. 5 Definition of steering torque fluctuation at low speed

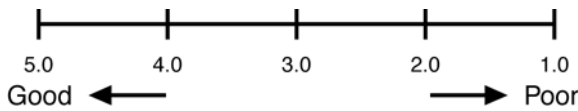


Fig. 6 Rating scale

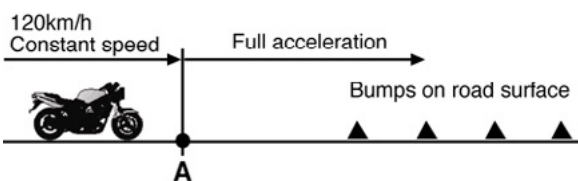


Fig. 7 Condition of Kickback test

evaluation of steering effort as shown in Fig. 8. As shown in Fig. 9, this test verified that the fluctuation in steering torque at low speed increased proportionally for damping torque applied in almost maximum steering angular velocity. From the results of these analyses, the target value for the steering torque fluctuation at low speed was determined within 10% of the test motorcycle without steering damper system. It was also verified that the damping characteristics to achieve the target is characteristic of line 1 shown in Fig. 10. This was defined as the target minimum damping characteristic.

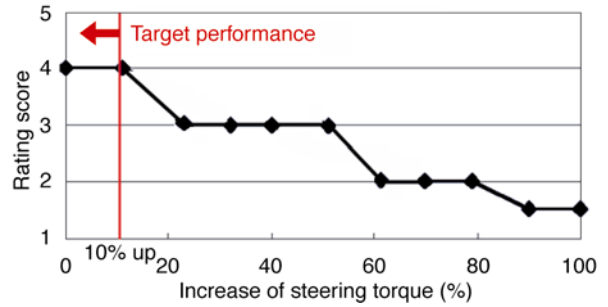


Fig. 8 Rating of handling heaviness

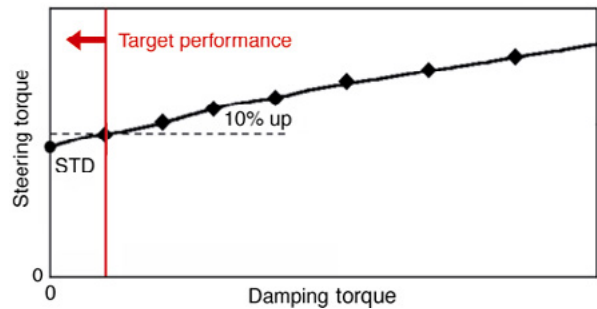


Fig. 9 Relationship between steering torque and damping torque

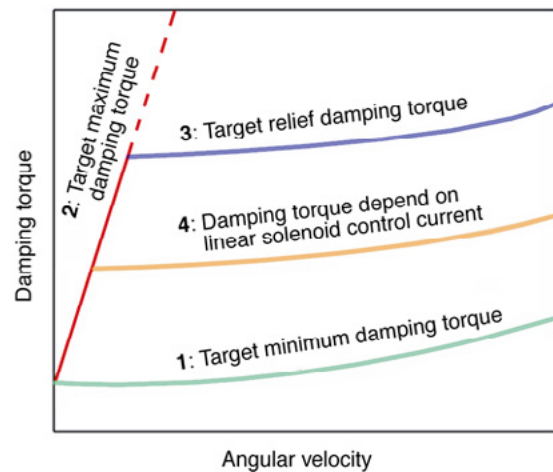


Fig. 10 Target characteristics on relationship between damping torque and angular velocity

5.2. Target Maximum Damping Characteristics

A steering damper that can exert a large damping torque will help reduce the level of kickback. The kickback test was repeated while gradually increasing the damping torque on the steering damper. Test rider evaluation of the kickback feeling showed a 4-point rating increase when the maximum kickback steering angle was reduced by 75% or more compared to without a steering damper. This reduction of 75% was set as the target value. Figure 11 shows the target performance. It was also confirmed that the maximum kickback steering angle tended to converge as the damping torque increases as shown in Fig. 12.

It was also found that exerting a larger damping torque at lesser steering angles and steering angular velocity is effective for reducing the kickback.

However, test results also showed that applying an excessive damping torque at low steering angular velocity affects the straight line running stability. When a motorcycle leans to the right or left, the front wheel turns to that leaning direction to maintain stability. Turning of the front wheel is delayed when the damping torque is greatly increased.

The maximum damping torque characteristic without affecting the straight running stability was obtained from the above-mentioned test results. Line 2 shown in Fig. 10 was determined as the target maximum damping characteristic.

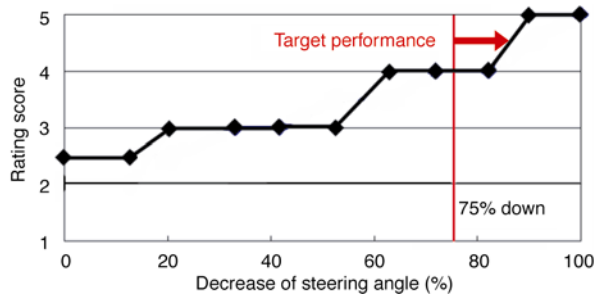


Fig. 11 Rating of kickback performance

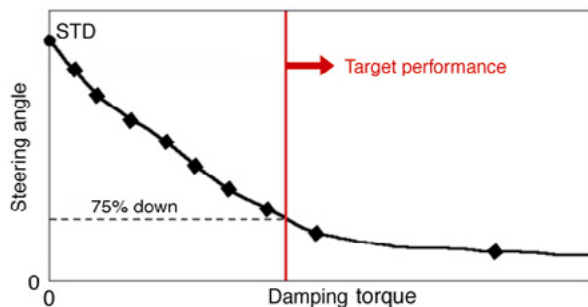


Fig. 12 Relationship between steering angle at kickback test and damping torque

5.3. Relief Valve System

In the targeted maximum damping torque characteristic described in the section 5.2., damping torque is raised in conjunction with increasing steering angular velocity and the higher strength is required for the damper body because the damper pressure is greatly increased. As a result, the body becomes large and heavy. If a suitable damping torque can be applied in low steering angular velocity, the kickback can be sufficiently reduced by a minimal damping torque. By fitting an adjustable relief valve, increasing damping torque was controlled by releasing more than certain specific pressure.

The working pressure characteristics of relief valve satisfying the target of kickback reduction were obtained from the test results. The characteristics are represented in line 3 shown in Fig. 10 and it was defined as the target relief valve characteristics. The optimum damper body size and specifications were determined by applying these characteristics.

6. Damping Characteristic Control with Vehicle Speed and Acceleration

6.1. Requirements of Controlling Mechanism

From the above-mentioned test results, it was found that the damping characteristic of the steering damper needs to change according to the required performance. Some steering dampers currently available on the market have an adjustable damping characteristic with manual operation. The newly developed system is fitted with an automatic controlling device that electronically controls the damping characteristic to generate the optimum damping characteristics according to running conditions.

6.2. Control Parameters

The conventional steering damper creates a substantial heaviness of steering effort during low speed operation. As the operation speed decreases, the rider controls the motorcycle largely by adjusting the steering angle. This increases the steering angular velocity as shown in Fig. 13. The kickback occurs more readily when running at high speed where the steering system receives larger impact loads, when accelerating where the contact load of the front tire decreases.

Speed and acceleration have been applied to the controlling parameter for the damping characteristics. The conditions for controlling are as follows:

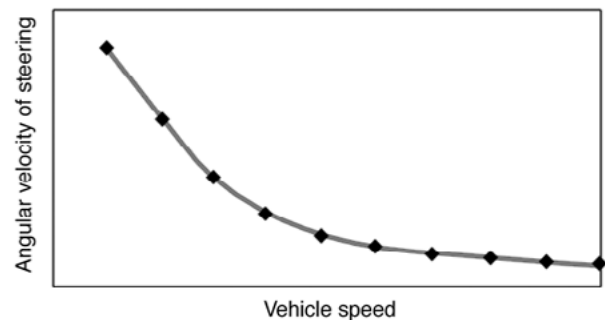


Fig. 13 Characteristics of angular velocity of steering

- Damping torque is reduced to enable light handling when running at low speed.
- Damping torque is increased to reduce kickback when running at high speeds and accelerating.

7. System and Control

7.1. Damper System

There are generally three types of steering damping systems; friction type dampers, hydraulic type dampers and electromagnetic type dampers. Table 2 shows the characteristics for each damper system and the verified results on each type. As a result, the hydraulic system was selected for this development. Hydraulic type dampers provide a damping mechanism with fluid resistance of the hydraulic oil and can generate a damping torque according to the actuation speed of the dampers.

Hydraulic steering dampers are classified into a linear actuation type and a rotary actuation type. The rotary type adopted in this development has the following advantages:

- There is no reciprocating part between the hydraulic oil chamber and the outside, so little oil is consumed by raking out.

- Steering axis and damper rotational axis are set on the same axis to provide a working damping angle in proportion to the steering angle.

7.2. System and Damper Configuration

Figure 14 shows the system configuration of the newly developed HESD. The ECU of the controller segment determines the control current value for the linear solenoid housed in the damper based on information from a vehicle speed sensor. The linear solenoid is attached to the main valve and adjusts the pushing force according to the control current value calculated by the ECU. The reason for using a linear solenoid is to achieve an actuation response at sudden acceleration and deceleration, and a linear change in damping characteristics according to the change in current value.

Figure 15 shows the internal structure of the HESD. The damper body consists of an oil chamber divided into right and left by the vane and oil lines for controls. The hydraulic oil fills the oil chamber. The damper body is fixed on the motorcycle body frame. The vane is located in the oil chamber and is connected to the steering system via a link. Both the steering system and vane share the same rotational axis and rotate on a 1:1 ratio. When the vane rotates, the hydraulic oil begins to flow between the right and left oil

Table 2 Investigation of types

Types Items	Friction Type Use of mechanical friction	Hydraulic Type Use of fluid resistance	Electromagnetic Type Use of magnets and coils
Damping characteristics	Unsuitable	Suitable	Suitable
Generated damping force	Small	Large	Medium
Controllability	Low	Medium	High
Size	Small	Small	Large
Cost	Low	Medium	High

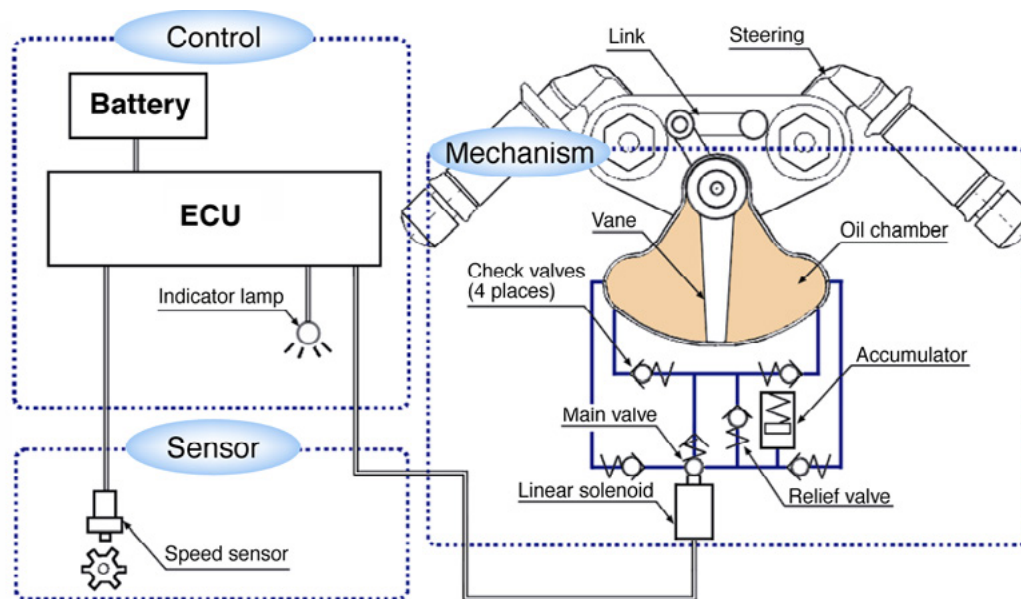


Fig. 14 System diagram of the HESD

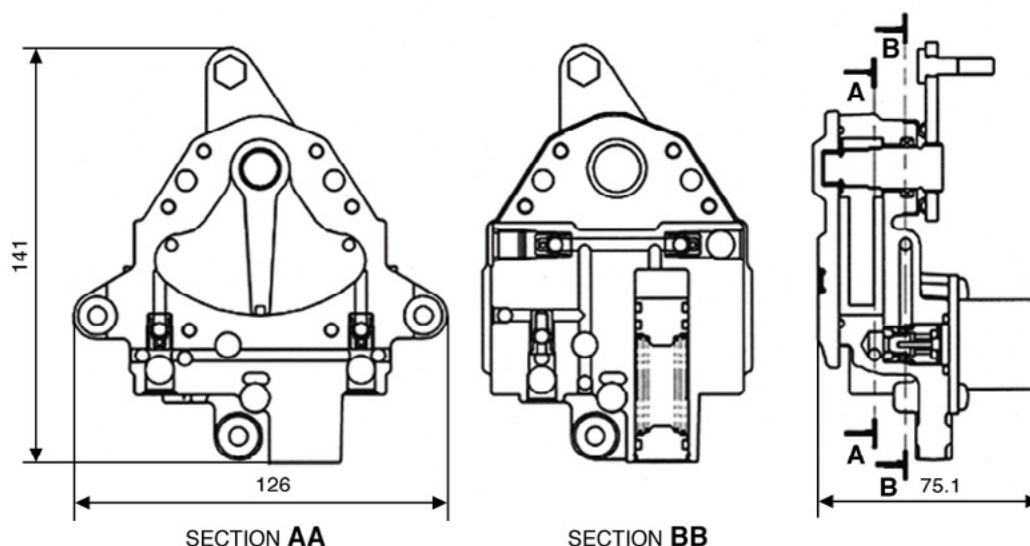


Fig. 15 Inner structure of the HESD

chambers. At the same time, the fluid resistance and the friction inside of the damper is transmitted to the steering system as a damping torque around the common rotational axis. The controlling oil lines were designed as three-dimensional piping with excellent space efficiency to achieve a light weight and compactness. The main valve, check valves, a relief valve and an accumulator are placed in the controlling oil lines. The functions of each component are described below.

The main valve regulates the magnitude of fluid resistance according to the valve opening conditions. The check valves ensure a one-way flow of the hydraulic oil to the main valve. The relief valve is located in the oil line parallel to the main valve and limits the maximum generating damping torque. The accumulator serves to stabilize the damper inner pressure though the volume of the hydraulic oil changes according to the operational temperature.

7.3. Control of Damping Characteristics

The fluid resistance varies according to the angular velocity of the vane and the opening area of the main valve. The opening area of the main valve is set according to the balance between the pushing force by the linear solenoid and the return force of the pressure adjusted by the main valve.

7.3.1. Damping characteristics under de-energized

The damping characteristic of line 1 shown in Fig.10 was realized by a fully opened main valve actuating the spring in the main valve under de-energized. The fluid resistance of the hydraulic oil is generated mostly in the main valve and increases according to the steering angular velocity.

7.3.2. Damping characteristics under energized

At low steering angular velocity, the pressure generated from the pushing force initiated by the linear solenoid is larger than a return force by the generated pressure, which allows the main valve to stay closed. When the main valve is closed, the hydraulic oil does not flow into the control oil line, but flows into the gap between the oil chamber and vane. The target maximum damping torque of line 2 shown in Fig. 10 was achieved. As the steering angular velocity increases and the return force due to the pressure exceeds the

pushing force of the linear solenoid, the main valve opens. Damping characteristics change from line 2 to line 4 based upon the control current value as shown in Fig. 10.

7.4. Electronic Control

An electronic control system has been adopted to achieve excellent damper control functionality with high accuracy and high actuation response. The ECU calculates vehicle speed and acceleration by using signals of vehicle speed and determines the control current value for the linear solenoid by a three-dimensional map. As the control current value increases, the damping characteristics change continuously from line 1 to line 3, as shown in Fig. 10. Figure 16 shows the control map. The control current of the linear solenoid is dropped at low speeds and increases according to an increase in the vehicle speed. When the vehicle accelerates, the control current value increases according to the acceleration. During deceleration, the control current value is set equal to that of the constant speed.

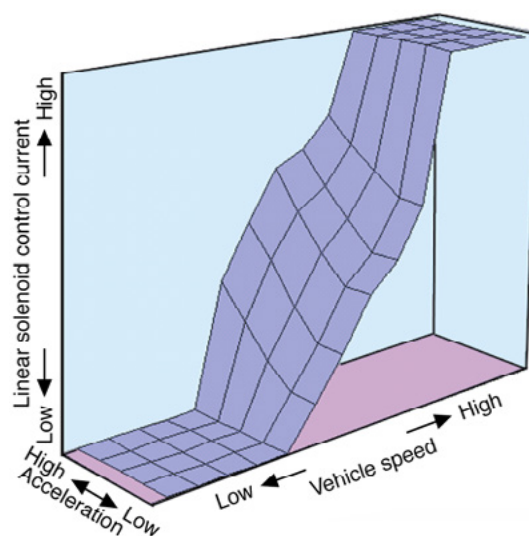


Fig. 16 Control mapping

8. Results of Effect Verification

The following test was conducted with an HESD fitted vehicle to verify the efficiency of the system configuration and specifications described herein. A vehicle without a steering damper and a vehicle with a conventional steering damper were used in the comparative testing. Two types of conventional steering dampers with the target specification of this development were used. One has the characteristic of fluctuation in the low speed steering torque increased by approximately 10% (conventional specification 1). The other has the maximum kickback steering angle reduced by approximately 75% (conventional specification 2).

8.1. Low Speed Lane Change Test

This test verified whether the HESD made steering heavy when running at low speeds. Figure 17 shows the distribution of steering torque fluctuation during the low speed lane change test. The horizontal axis shows the maximum steering velocity. The average values for ten evaluations of each specification are shown with the horizontal line. Fluctuation in steering torque at low speed was increased by 8%, when comparing between the vehicles with the HESD and without a steering damper. This is a favorable result even in comparison with the conventional damper specification 1 configured with the target value. On the other hand, that was increased by 52% on the vehicle with conventional damper specification 2. Table 3 shows the sensory evaluation results. The vehicle fitted with the HESD was rated with the same score as the vehicle without a damper. It was further verified the HESD vehicle was ratable as the same level as that without a steering damper.

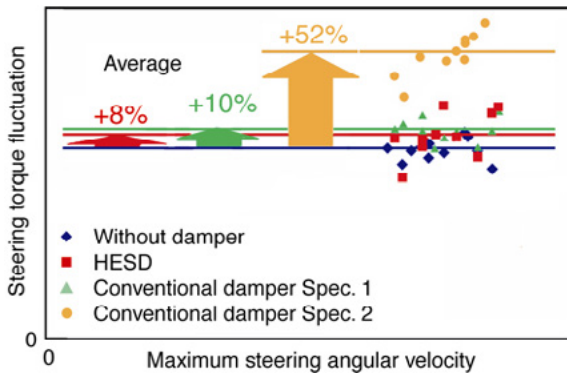


Fig. 17 Low speed lane change test results

Table 3 Steering heaviness evaluation result

	Rider A	Rider B	Rider C
Without damper	4.0	4.0	4.0
HESD	4.0	4.0	4.0
Conventional damper Spec. 1	4.0	4.0	4.0
Conventional damper Spec. 2	3.0	2.0	3.0

8.2. Kickback Test

Figure 18 shows the time-series change for the steering angle of tested vehicles as they passed over the tested road surfaces. The HESD has reduced the maximum steering angle by approximately 85%. This was a better result than that achieved by the target conventional damper specification 2. In contrast, conventional damper specification 1 achieved only a 19% reduction in steering angle. Table 4 shows the sensory evaluation results of kickback characteristic. The vehicle with the HESD received high ratings compared with that for the vehicle without a damper.

These test results have demonstrated that the HESD has suitable damping characteristics for riding conditions. Those provide light handling when running at low speeds while reducing kickback occurrences when running at high speeds, which is not possible on vehicles with conventional steering dampers.

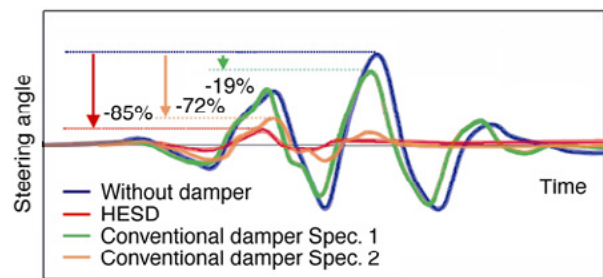


Fig. 18 Kickback test results

Table 4 Kickback performance evaluation result

	Rider A	Rider B	Rider C
Without damper	3.0	2.5	2.5
HESD	5.0	4.0	4.0
Conventional damper Spec. 1	3.0	2.5	3.0
Conventional damper Spec. 2	4.0	4.0	4.0

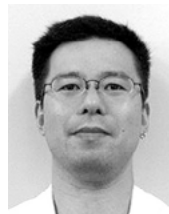
9. Conclusion

- (1) Handling characteristics and kickback phenomenon characteristics were analyzed. Optimal steering damping characteristics for speed and acceleration were found.
- (2) An electronically controlled linear solenoid was used to alter the internal damper fluid resistance. This reduced kickback occurrences while maintaining light handling at low speed running.
- (3) Maximum damping characteristics and oil line layout were optimized. A lightweight and compact electronically controlled steering damper for motorcycles was achieved.

References

- (1) Society of Automotive Engineers of Japan, Inc.: JASO T803-96, Glossary of terms relating to motorcycle and moped stability and controllability, p. 22 (1996)

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