Reduction of Kickback by Attaching a Check Valve to Hydraulic Power Steering

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In recent years rapid improvements have been made in automotive technology, and customers are demanding increasingly low levels of vibration and noise in steering systems. We have succeeded in reducing kickback, a main cause of steering system vibration and noise, by attaching a check valve to the hydraulic power steering gear. An explanation of this improvement and related research results are given herein.

***Key Words**: hydraulic power steering, kickback, vibration, noise*

1. Introduction

In recent years striking improvements have been made in virtually all types of automotive technologies, starting with those related to the basic functions of moving, turning and stopping. Given such an atmosphere of improvement, automakers are demanding increasingly severe levels of noise and vibration, and demands being made of steering makers are no exception to this trend.

Kickback, or vibration created when input from the road is transmitted to the steering wheel as the vehicle travels over bumpy roads, is one phenomenon responsible for steering system vibration. The suspension system is another main cause of vehicle vibration. A report is given herein on how kickback has been reduced without changing the vehicle design by attaching a check valve to a rack & pinion type power steering gear.

2. Mechanism of Kickback Occurrence

Vibration is created when input from the road is transmitted through the vehicle's suspension system and steering system to the steering wheel as the vehicle travels over bumpy roads[1). This phenomenon is referred to as kickback. For the purposes of this paper, attention is focused on steering system vibration transmission characteristics.

An example of kickback occurrence in the steering system is shown in **Fig. 1**. In this case, data was taken as a front tire fell into an indentation in the road while the vehicle was being turned to the left.

(1) First, the tire falls into the indentation in the road.
(2) For an instant the load between the tire and road surface is released and the tie rod axial force is reduced (point A).
(3) Next, as the tire reaches the other side of the indentation, the contact load between the tire and road surface is restored, increasing tie rod axial force.
(4) The increase in tie rod axial force pushes hydraulic fluid out from the cylinder and into the pressure port. As a result, insufficient hydraulic fluid is supplied to the assist-side cylinder and input from the tie rod is transmitted to the steering wheel, which is felt as kickback (point B).

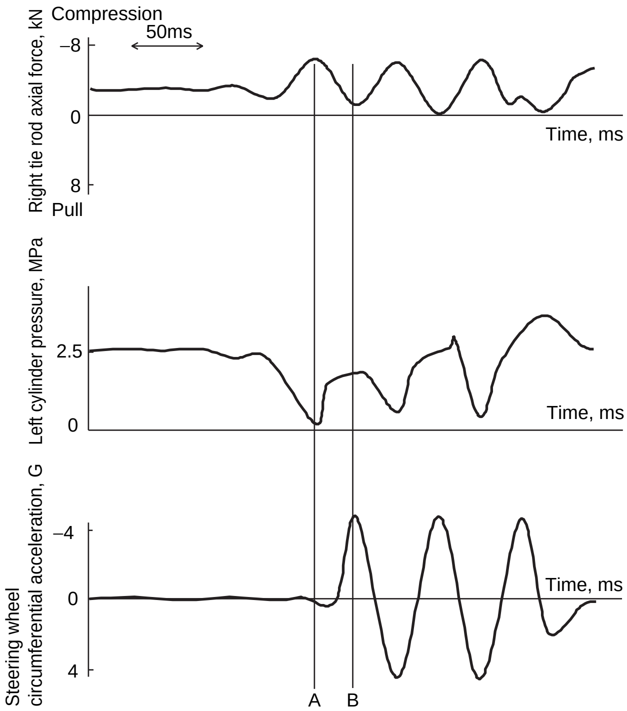

Fig. 1 Data on actual vehicle at kickback occurrence (steering wheel is turned to the left)

The rigidity of rack & pinion type steering gears is higher than that of ball screw type systems, and therefore rack & pinion type systems are more sensitive to input from the road and inferior in regard to kickback.

3. Cause of Kickback Occurrence

Kickback is created when changes in the tire-to-road-surface load occur as the vehicle travels over a bumpy road, and this kickback is transmitted from the tires to the steering gear to the steering wheel.

The suspension system and steering system each have separate factors contributing to vibration. In the case of the suspension system, the effectiveness of countermeasures is normally measured by the degree to which input from the tires to the tie rods can be reduced, and in the case of the steering system, the degree to which input from the tie rods can be absorbed by the steering gear.

The following methods are generally employed to reduce kickback.

(1) Countermeasures for suspension system kickback
- Optimization of kingpin inclination angle
- Reduction of kingpin offset amount
- Optimization of caster angle
- Reduction of suspension transverse stiffness

(2) Countermeasures for steering system kickback
- Increase of pump flow
- Optimization of valve characteristics
- Reduction of hose expansion
- Reduction of steering system stiffness

However, most of the above countermeasures require major modification of the vehicle or steering system design and adversely affect the stability of vehicle control.

Accordingly, as a means of reducing kickback while minimizing modification of current vehicles and steering systems, we focused our attention on attaching a check valve to the hydraulic power steering.

4. Description and Effect of Check Valve Attachment

4. 1 Check Valve Structure and Operating Principle

As shown in **Fig. 2**, the check valve attached to the steering gear as a countermeasure for kickback contains four parts: the sheet, poppet, coil spring, and case.

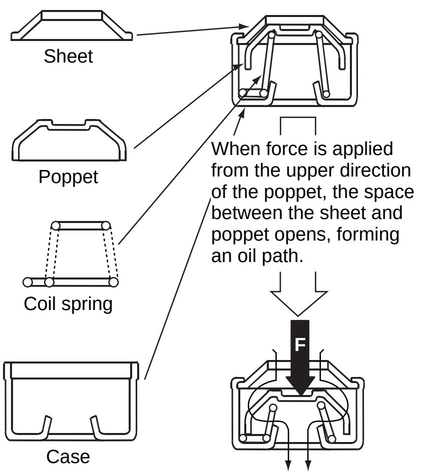

Fig. 2 Check valve components

Normally, the poppet of the check valve, which is attached to the pressure port, is caused by the force of hydraulic fluid flow to push the coil spring, and hydraulic fluid flows from the pump to the cylinder without resistance. When kickback occurs, the hydraulic fluid pushed out of the cylinder tries to flow back from the pressure port, but the check valve closes and prevents it from flowing back. The hydraulic fluid trapped in the cylinder acts as a damper to reduce kickback.

The flow of hydraulic fluid when a check valve has been attached is shown in **Fig. 3**.

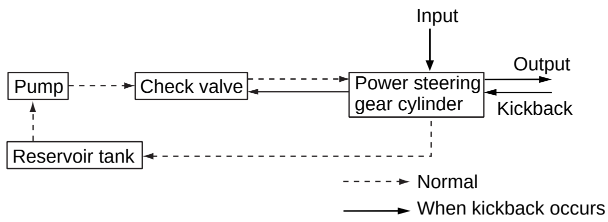

Fig. 3 Flow of hydraulic oil

4. 2 Method of Attaching Check Valve

Regarding the attachment method, the check valve is pressed into the valve housing pressure port, as shown in **Fig. 4**. With this method, attachment can be accomplished merely by performing additional machining of the area where the check valve is attached to the valve housing; no major design change is necessary.

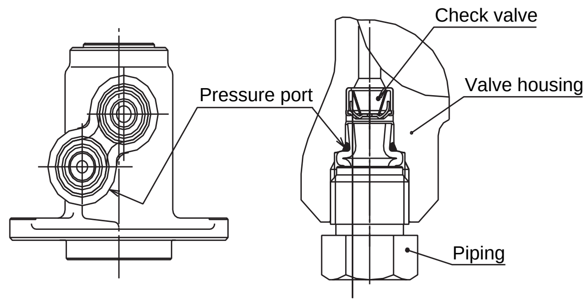

Fig. 4 Mounting method of a check valve

4. 3 Reduction of Kickback on a Test Car

A steering system with a check valve was installed on a test car and testing performed. Measurement results are shown in **Fig. 5**. Test conditions were the same as those described in section 2 hereof (vehicle traveled over a road indentation while being turned to the left).

(1) First, the tire falls into the indentation, just as in the case of the vehicle with no check valve.

(2) For an instant the contact load between the tire and road surface is released and tie rod axial force is reduced (point A).

(3) Next, as the tire reaches the other side of the indentation, the contact load between the tire and road surface is restored, increasing tie rod axial force. However, the check valve closes in response to input from the tie rod, and therefore cylinder pressure increases (point B).

(4) These results confirmed that the check valve was effective in causing the hydraulic fluid to be trapped in the cylinder. The load transmitted from the tire to the steering gear was received by the hydraulic pressure in the cylinder, which reduced kickback.

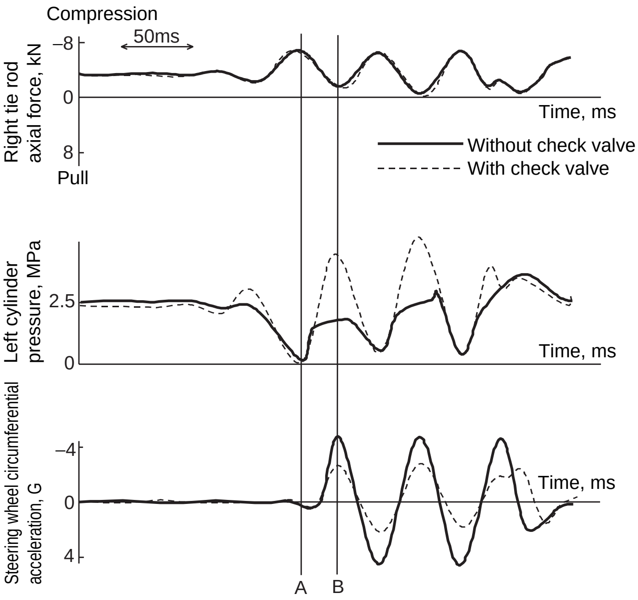

Fig. 5 Kickback reduction effect on actual vehicle

4. 4 Investigation of Kickback Reduction Effect by Bench Testing

Regarding the method of investigating the kickback reduction effect by bench testing, the steering gear input shaft was fixed in position and load from the tie rod placed repeatedly on the system, as shown in **Fig. 6**. At such time steering wheel holding torque, cylinder pressure, port pressure and load were measured.

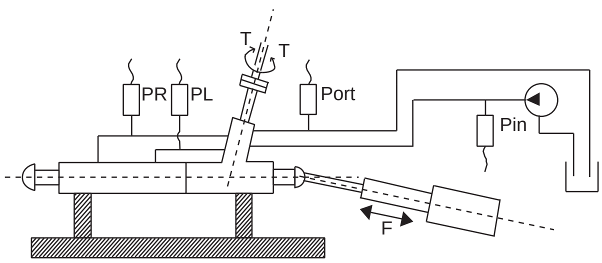

Fig. 6 Bench test method

Test conditions are shown in **Table 1**.

The steering gear oil flow and pressure were set at the same levels as those of an actual vehicle, and various tie rod oscillation frequencies were used. Input from the tie rod was repeatedly swung between 0 kN and 4 kN, or 2 kN (compression) ± 2 kN, to simulate the loads that occur during driving on bumpy roads.

Bench test results are shown in **Figs. 7, 8** and **9**.

Regarding the relationship between frequency and steering wheel holding torque, in the case of there being a check valve, steering wheel holding torque is constant when the oscillation frequency exceeds 5 Hz, but without the check valve, steering wheel torque rises along with frequency.

Concerning cylinder pressure, the cylinder pressure when tie rod oscillation frequency exceeds 5 Hz is higher in the case of there being a check valve than in the case of there being no check valve.

Table 1 Conditions of bench test

Item	Condition
Set flow, ℓ /min	5
Set pressure, MPa	8.3
Tie rod axial force, kN	2 ± 2 (compression)
Load waveform	Sine curve
Frequency, Hz	1, 5, 10, 15, 20
Tie rod angle, degrees	Actual vehicle equivalent

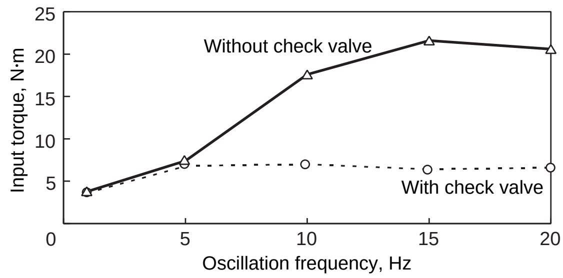

Fig. 7 Oscillation frequency and input torque

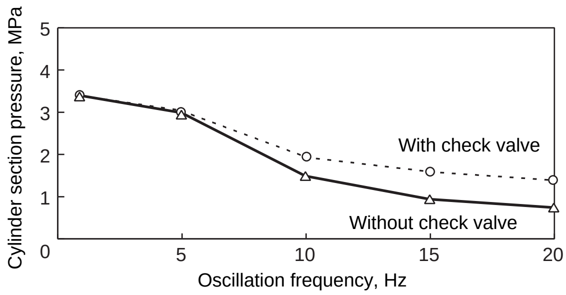

Fig. 8 Oscillation frequency and cylinder pressure

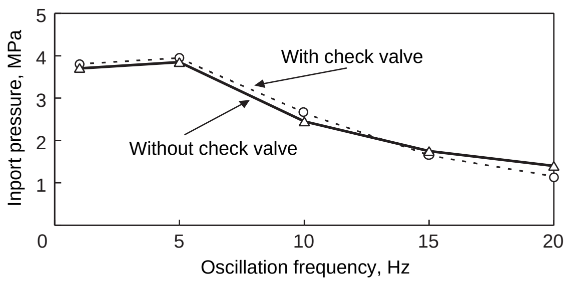

Fig. 9 Oscillation frequency and inport pressure

Concerning import pressure, the levels with and without a check valve are about the same.

In regard to the effect of check valve attachment, the above results confirm that when tie rod oscillation frequency exceeds 5 Hz, load from the tie rod tends to push hydraulic fluid out of the cylinder so that it flows back from the pressure port, but such reverse flow is prevented because the check valve closes. As a result, load from the tie rod can be absorbed by the cylinder's hydraulic pressure and steering wheel holding torque reduced, as was verified by the data taken during test-car measurements.

5. Problems Created by Check Valve Attachment and Countermeasures

Although the effect of attaching a check valve was confirmed by both bench and test-car investigations, problems created by such attachment must likewise be considered.

During curb-collision testing done using a test car equipped with a steering gear to which a check valve had been attached, because the hydraulic fluid in the cylinder could not escape, the input load from the tire was received by the cylinder, and tie rod axial force increased, which could lead to a problem with tie rod bending. As a countermeasure, an orifice was made on the poppet area of the check valve.

Bench testing was done to evaluate the check valve with orifice, but as shown in **Fig. 10**, a reciprocal relationship between kickback reduction ratio and tie rod axial force reduction ratio was obtained.

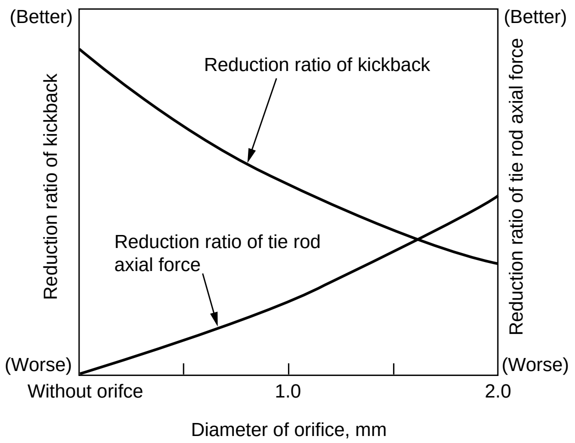

Fig. 10 Reduction ratio of kickback and diameter of orifice

Based on these results, evaluation on a test car was done and an orifice diameter (ϕ1.0) determined that balanced performance and strength.

6. Conclusions

The attachment of a check valve to the steering gear pressure port as a countermeasure against kickback was shown to be effective. This countermeasure is inexpensive and requires no major vehicle or steering system design changes.

Also, the provision of an orifice in the check valve eliminated the problem of tie rod axial force increase during collisions with curbs, and with this orifice, specifications optimal for the concerned vehicle can be set.

Reference

1) K. Kodaka, M. Minakawa : HONDA R&D Technical Review, **11**, 1 (1999).