1. Introduction

Recently, regulations on vehicle fuel efficiency and gas emissions have been intensified considering the impact on the global environment, with further regulatory developments planned globally in the coming years. Therefore, development of electrified technologies, including hybrid technology, is actively pursued in the automotive industry. More efficient internal combustion engines are also being pursued.

NTN develops and manufactures auto tensioners used for timing belt systems and timing chain systems, which transmit the rotation of the crankshaft of internal combustion engines (hereafter, “engines”) synchronously to the cam shafts and accessory belt systems for driving accessory devices.\(^1\)

The role of an auto tensioner is to appropriately maintain the tension of the belts and chains to reduce the system noise and extend operating life. It also contributes to low fuel consumption by reducing system friction through selecting the optimum specifications to fit particular engines.

NTN has developed a “Fuel-efficient Compact Chain Tensioner” (hereafter, “Chain Tensioner”) (Fig. 1) as a product to contribute to lower fuel consumption from timing chain systems.

In general, the chain tensioner used in vehicle engines employs a damping mechanism using engine oil supplied from the engine. The aim of NTN’s development was to reduce the energy loss and fuel consumption by significantly reducing the amount of engine oil used by the chain tensioner so that the load of the oil pump, which supplies engine oil to the entire engine, is reduced.

In addition, this development included simplification of the internal structure of the tensioner itself for reducing its size and weight to address the market demand for cost reduction. In this article, the structure and features of NTN’s developed chain tensioner are introduced.

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2. Structure

Simplified diagrams of the structure of the developed product and the conventional product are shown in Fig. 2 and 3. The developed product uses a newly adopted oil circulating structure and oil storage structure, described later in section three. Adoption of an oil storage structure helped eliminate the anti-backlash mechanism shown in Fig. 3 to simplify the structure. Also, modification of the return spring to a conical spring helped reduce the total length and achieve a more compact size. In case the plunger thrust power is insufficient in certain applications, an assist spring, also shown in Fig. 3, can be added for additional power.

3. Features

The features of NTN’s chain tensioner are listed below, compared to our conventional chain tensioner:

1. Reduction of the oil amount used by adoption of oil circulating structure: 1/10 or less
2. Activation of damping force from the initial stage by adoption of oil storage structure: elimination of anti-backlash mechanism
3. Compactness by modification of internal structure (Fig. 4): reduction of total length by 18%, reduction of weight by 10% or more

3.1 Contribution to Low Fuel Consumption by Adoption of Oil Circulating Structure

Conventionally, the oil supplied to the chain tensioner is released from the tensioner through the gap between the outer diameter of the plunger and the cylinder bore (leak gap) when damping force is generated. The released oil is stored in the oil pan below the engine to be re-supplied to various parts of the engine by the oil pump. The oil pump is required to have the supply capacity to also return the oil released from the tensioner.

In contrast, the developed product can significantly reduce the amount of oil released out of the tensioner by returning the oil that leaks out through the leak gap (when damping force is generated) back inside the plunger through a side hole on the outer circumference of the plunger (Fig. 5). This enables a significant reduction of the necessary amount of supplied oil while maintaining high reliability and durability as the conventional product. The reduction of the amount of oil used reduces the load the pump is required to drive, which can reduce the size of the oil pump, leading to lower fuel consumption from the engine.
Fuel-efficient Compact Chain Tensioner

3.2 Structure benefit from oil storage

A hydraulic chain tensioner generates the required damping force for adjusting the chain tension using oil supplied from the oil pump. However, as mentioned later, when the engine stops, the oil pump also stops supplying oil, which causes a delay of oil supply to the chain tensioner when the engine restarts. Conventionally, a mechanical anti-backlash mechanism was required to suppress abnormal noise generated due to insufficient tension from the above-mentioned delay for a few seconds after the engine starts.

The developed product adopts a structure to store oil inside the plunger to eliminate the anti-backlash mechanism. By adopting this structure, this stored oil is used until oil is supplied from the oil pump to the chain tensioner after the engine starts to compensate the delay of oil supply, producing appropriate damping force immediately after the engine starts (Fig. 6). Therefore, undesirable noise can be mitigated even when the anti-backlash mechanism is eliminated.

3.3 Compactness/lightweight Design

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2) Streamlined cylinder
Eliminating the anti-backlash mechanism also eliminated the need for the register ring and multiple grooves on the outer diameter of the plunger. The groove to accommodate the register ring on the cylinder bore is not required any more, making it possible to streamline the cylinder outer diameter.

(Additional notes)

(1) Anti-backlash mechanism (conventional product)
A mechanism to suppress vibration of the timing chain due to no oil supply immediately after the engine starts even when no damping force is produced on the chain tensioner. NTN has two mechanisms: a buttress thread type, which uses the frictional force of the screw and has small backlash and quiet operation, and a register ring type, which has a simplified structure with a ring and stepped grooves.1, 2)

(2) Role of the check valve (Fig. 8)
- When the chain has tension, the plunger is pushed back and the pressure of the pressure chamber (a) becomes higher than the oil supply pressure (b), the check valve is closed and damping force is produced.
- When the chain loses tension, the plunger is extended and the pressure of the pressure chamber (a) becomes lower than the oil supply pressure (b), and the steel ball moves and oil flows into the pressure chamber.

(3) Delay of oil supply when the engine starts (Fig. 9)
In general, oil is supplied to the chain tensioner by the oil pump, which pumps out oil in the oil pan located at the bottom of the engine. Since rotation of the oil pump usually works together with rotation of the engine, oil is not supplied while the engine stops. Therefore, oil in the piping of the engine drops back into the oil pan a while after the engine stops. When the engine starts, oil is re-supplied to the chain tensioner through the piping, which causes a delay before the chain tensioner is supplied with oil again.

4. Functional Evaluation

4.1 Comparison of oil consumption
To evaluate the oil circulating structure, which is a feature of the developed product, operation with the actual product was simulated to measure the amount of oil released from the chain tensioner (oil consumed) under vibration and the result was compared with the conventional product. During the test, oil was supplied to the chain tensioner and the orientation of the sample was horizontal (Fig. 10). Below is an example of the evaluation conditions and the evaluation result. The comparison was made with the samples having an equivalent damping capacity (load generated when vibration was applied).

<Example of the evaluation conditions>
- Amplitude of applied vibration : ± 0.2mm
- Frequency of applied vibration : 100Hz
- Supply oil pressure : 0.2MPa
- Oil type : SAE 10W-30
- Oil temperature : 35°C, 100°C
- Measurement of oil amount : 30s
The developed product could reduce oil consumption to 1/10 or less compared with a conventional product with the equivalent damping capacity (Fig. 11).

**Fig. 11 Measurement result of used oil amount**

4.2 Evaluation at Start-up of the Engine

In order to verify the impact of eliminating the anti-backlash mechanism and verify the function of the oil storage structure, a test was conducted simulating the engine start-up using the actual engine. By verifying the displacement of the plunger and the input load, the effect of the aforementioned delay of oil supply at the engine start-up was determined. The following are some examples of the evaluation results.

When the plunger is quickly extended due to the start-up of the engine (the condition from (1) to (2) in Fig. 12) and no oil is supplied from the engine, damping force is produced by internal oil stored in the oil storage giving an appropriate tension to the chain, in an early stage, which suppressed the vibration of the chain (amplitude of the plunger displacement). The result verified that the anti-backlash mechanism can be eliminated.

**Fig. 12 Result of evaluation of behavior at start-up of the engine**

4.3 Oil Hydraulics Damping Property

A dynamic characteristics evaluation test was conducted to evaluate the dynamic reaction force of the chain tensioner when vibration is applied to index the basic damping force of the hydraulic chain tensioner. In the dynamic characteristics evaluation, the load generated by the applied vibration is verified while supplying oil to the chain tensioner; therefore, the impact of various parameters such as the leak gap, check valve load and spring load can be verified. The evaluation can be conducted on the platform simulating the operation with the engine. The following is an example of the evaluation conditions:
<Evaluation conditions>
- Amplitude of applied vibration: ± 0.2mm
- Frequency of applied vibration: -200Hz
- Supply oil pressure: 0.3MPa
- Oil type: SAE 10W-30
- Oil temperature: 35°C

Fig. 13 shows the comparison of the evaluation results of the developed and conventional product. The developed product shows load generation up to higher frequencies, similar to the conventional product, which verifies good followability and basic damping capacity. The maximum and minimum values in Fig. 13 are the results obtained from the Lissajous figure (Fig. 14 Amplitude-Generated Load) at various frequencies.

5. Conclusion

In this article, the Fuel-efficient Compact Chain Tensioner was introduced. The developed product achieved reduced oil consumption in the tensioner to 1/10 or less, compared to the conventional product. The functionality of the conventional product was maintained by adopting the structure to circulate oil in the tensioner, which contributes to lower fuel consumption of the engine by reducing the load to the oil pump. In addition, the developed product achieved a reduction in length by 18% and a reduction of weight by 10% by simplifying the structure and reducing the size of the tensioner.

We will devote ourselves to further development and promote product development for higher functionality.

References