1. Introduction

Currently, all motor vehicles are being required to address a number of environment protection and resource saving concerns. An increased number of vehicles are being equipped with an idling stop mechanism as one of the means for improving fuel economy of the conventional internal combustion engine vehicle (Fig. 1). This trend is expected to continue, and the method of restarting the engine is shifting to the integrated starter generator (ISG). This is a belt driven method where the crankshaft is driven by the accessory belt from the alternator. This engine restarting method is characterized by quick engine restarting time and quiet operation, compared with using the traditional starter motor.

For the accessory drive belt system of most vehicles (Fig. 2), an auto tensioner is used to maintain an adequate belt tension. This prolongs the life of the belt and accessory systems and also prevents vibration and noise due to belt slippage. To effectively reduce vibration of belt, the auto tensioner is usually placed at the lower tensioned area of the belt when the engine is operating, namely, after the crank pulley (driving side). However, when using the ISG method for idle stop, the auto tensioner must be set at the area where the belt is in high tension when the engine restarts, namely, before the ISG pulley. Since the areas of high tension and low tension switch between steady driving and engine restarting, auto tensioners used with ISG systems are required to have new functions.

In order to respond to these requirements, NTN has developed a new “variable damper auto tensioner for ISG-equipped engines” for the accessory drive belts of vehicles with this feature.

It is necessary to set the belt tension rather higher than usual to prevent the belt from slipping at the time of the engine restarting when we applied a conventional auto tensioner to the accessory drive belt of the engine equipping with ISG and it causes harm for millage improvement.

This paper introduces the new developed variable damper auto tensioner which contributes to the mileage improvement of the ISG-equipped car.

---

*Hiroo MORIMOTO*

**Yuta MOCHIZUKI**

---

---

*Automotive Product Design Dept. Automotive Business HQ
**Functional Experiment Dept. Automotive Business HQ
2. Characteristics of engines adopting the belt driven ISG method

Fig. 3 shows a diagram of a typical accessory system layout of a vehicle engine. Fig. 3 (a) shows the system status under steady driving conditions. During this state, the crank pulley is the driving pulley. Since the crank rotation speed changes due to the combustion process of each cylinder, the belt tension fluctuates at the frequency of engine rotation x (1/2) x number of cylinders. By minimizing the reaction force generated with this fluctuation of the belt tension (hereinafter, tensioner reaction force), we can reduce the average belt tension, increasing the life of the belt and accessory systems, as well as, improving fuel economy by reduction of friction losses. In other words, the smaller the tensioner reaction force to the belt, the more desirable.

On the other hand, Fig. 3 (b) shows the system status when the engine is restarting (hereinafter, ISG restarting). The ISG pulley acts as the driving pulley to turn the stopped crank pulley through the belt. At the moment of ISG restart, the belt tension between the ISG pulley and the crank pulley suddenly increases. As a result, the auto tensioner is deeply pushed in, creating lower tension. Therefore, the tensioner reaction force must typically be set at a higher set value to avoid belt slippage.

It seems then, that auto tensioners in engines equipped with an ISG are required to provide conflicting functions; low tensioner reaction force during steady driving and sufficient tensioner reaction force to avoid slip during ISG restarting.

3. Variable damper auto tensioner for ISG equipped engines

3.1 Structure

Fig. 4 and 5 show the cross-sections of the conventional product and the new variable damper auto tensioner for ISG equipped engines (hereinafter, developed product), respectively. The main feature of the developed product is the ability to switch the tensioner reaction force according to driving conditions with a simple mechanism and without use of electrical control, etc.

The conventional product creates a pressure chamber and leak gap with the valve sleeve and rod. Along with the extension/compression of the auto tensioner, the rod is pushed in/out against the valve sleeve.

For the conventional product, the hydraulic tensioner reaction force is generated by elastic deformation of oil in the pressure chamber and flow resistance as oil passes this leak gap.

The developed product has a pressure chamber and two leak gaps created by the valve sleeve, plunger and rod. We can describe the radial gap between the outer diameter of the rod and the inner diameter of the plunger as the first leak gap. The radial gap between the outer diameter of the plunger and the inner diameter of the valve sleeve is the second leak gap. In addition, a second check valve is formed by the rod, plunger, retaining ring and switch spring. The second check valve is open when the pressure in the pressure chamber is low, since the plunger is pushed toward the pressure chamber by the switch spring. The tensioner reaction force generated is adjusted by the opening/closing and the size of two leak gaps.
3.2 Operation principle

Fig. 6-8 illustrate the relationship between the change in length of the auto tensioner and the resulting tensioner reaction force when the developed product is extended/shrunk at an amplitude equivalent to that of ISG restarting conditions. The graphs shown in the right side of each diagram are called Lissajous patterns. The Lissajous patterns of the developed product can be divided into three regions according to the operational conditions. The following is the description of the internal operation of the auto tensioner for each region:

(1) Region where the auto tensioner shrinks and the reaction force increases (Fig. 6)

In this region, the auto tensioner starts shrinking from its most extended condition. As the auto tensioner shrinks, the rod and plunger move into the valve sleeve. As the plunger is pushed by the switch spring, it is fixed to the tip of the rod contacting the retaining ring, moving with the rod. The pressure of the pressure chamber increases as the oil in the pressure chamber is compressed, and the oil leaks from the pressure chamber via the first leak gap between the outer diameter of the rod and the inner diameter of plunger, and through the second check valve. The second check valve remains open as the pressure in the pressure chamber is still lower than the force of the switch spring pushing the plunger.

(2) Region where the auto tensioner shrinks, yet the reaction force remains mostly unchanged (Fig. 7)

In this region, the force of the switch spring pushing the plunger is balanced with the pressure in the pressure chamber. Therefore, only the rod moves, into the valve sleeve as the auto tensioner shrinks, and the change in the pressure chamber volume is smaller. As the pressure continues to increase, the switch spring gradually shrinks, maintaining the balanced condition. When the compression of the switch spring reaches the stroke of the second check valve, the second check valves closes.
(3) Region where the auto tensioner shrinks and the reaction force increases again (Fig. 8)

In this region, the pressure in the pressure chamber exceeds the force of the switch spring pushing the plunger. Therefore, the second check valve closes and the plunger moves into the valve sleeve with the rod. At the same time, the pressure of the pressure chamber is increasing and the oil leaks from the second leak gap formed by the outer diameter of the plunger and the inner diameter of the valve sleeve.

Fig. 8 Region where auto tensioner shrinks and reaction force increases again

4. Achieving the ideal damper property

4.1 Comparison of properties between the conventional and developed products

With the conventional product, the conflicting properties, that is, the reduction of belt tension during steady driving and addition of relatively large belt tension at ISG restarting, cannot be simultaneously achieved.

(1) Belt tension adjustment by the conventional product during the steady driving

Fig. 9 shows the Lissajous pattern considering steady driving conditions. During steady driving conditions, since the fluctuation of the belt tension is small, the extension range of the auto tensioner is also small. Therefore, the tensioner reaction force generated by the extension/shrinkage is small with the conventional product designed for low belt tension (low reaction force spec.). On the other hand, with the conventional product designed for high belt tension required for ISG restarting (high reaction force spec.), the tensioner reaction force becomes large even if the amplitude of the auto tensioner is small. Therefore, the belt tension becomes unnecessarily large, resulting in adverse fuel economy effects due to increased friction.

(2) Belt tension adjustment with the conventional product during ISG restart

Fig. 10 shows the Lissajous pattern considering the amplitude that occurs during ISG restarting. At ISG restart, since the belt tension instantly increases, a large tensioner reaction force is required.

The conventional product with high reaction force specifications can ensure the belt tension required for ISG restarting, not allowing any belt slippage. However, the conventional product with low reaction force spec. cannot ensure the belt tension required for ISG restart, as the tensioner reaction force is insufficient, likely leading to slippage between the belt and pulleys.

Fig. 9 Lissajous pattern during steady driving (conventional product)

Fig. 10 Lissajous pattern at ISG restarting (conventional product)
(3) Belt tension adjustment with the developed product

Fig. 11 shows the Lissajous pattern of the developed product. The tensioner reaction force can be maintained low during steady driving, similar to the conventional product with low reaction force spec. However, during ISG restarting, a large tensioner reaction force can be instantly generated similar to the conventional product with high reaction force spec.

4.2 Verification of the effect with the actual vehicle

NTN has installed the developed product on an actual vehicle and measured; (1) pulley rotation speed when restarting the engine with the ISG, and (2) tensioner reaction force during steady driving. As a comparison, the conventional product (high reaction force spec.) was also measured.

(1) Restarting the engine with the ISG

Fig. 12 (a) and (b) show the measurement results of the developed product and the conventional product (high reaction force spec.), respectively. We have defined the engine restarting point as the moment when the crank pulley rotation speed starts stabilizing, and we compared the time from the moment the ISG pulley rotation started until the engine restarting point.

From the test, the time until the engine restarting point was not later than the conventional product with high reaction force spec. and the correct ISG restarting was verified. During the measurement, no belt slippage occurred.

(2) Auto tensioner reaction force during steady driving

Fig. 13 shows an example of the auto tensioner reaction force measurement results at a certain rotation speed of the engine. Graph (a) shows the results of the developed product when installed on an actual vehicle and (b) shows the results of the conventional product (high reaction force spec.). The developed product reduced the maximum value of the tensioner reaction force by around 50% compared with the conventional product. From this, we can expect an improvement of fuel economy through reduction of tension on the accessory belt.
5. Conclusion

NTN has developed a variable damper auto tensioner for use on ISG equipped engines that can automatically adjust the accessory belt tension according to the driving conditions. NTN has verified the developed product’s effectiveness by testing it on an ISG equipped engine. When the developed product is installed, the starting time of the crank pulley is about the same as the conventional product with high reaction force spec. At the same time, the tension of the accessory belt can be reduced up to 50% during steady driving, with which an improvement of fuel economy can be expected.

As the requirement for improving fuel economy further increases, NTN aims to contribute to global environmental protection by marketing this developed product worldwide.

Reference
1) Seiji SATO, Technology Trends in Auto Tensioners, NTN TECHNICAL REVIEW, No. 79 (2011) 83-89
2) HIS Data (2014)