

Development of Double-arm Chain-tensioner System

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ABSTRACT

Research was conducted with a focus on chain-tensioner systems in order to enhance the functions of chain systems. A double-arm chain-tensioner system was developed that differs from a conventional system in adding a sub-tensioner arm (“sub-arm” below) to make use of a lever ratio effect.

As a result, cost and weight have been reduced to levels below those of a conventional system, and chain friction and chain tension have been reduced across the entire operating range. In addition, the rate of chain elongation has been reduced compared to that of a conventional system.

1. Introduction

Among engine cam drive systems, chain drive systems are both more durable and more compact than belt drive systems, and are therefore used in the majority of engines. However, chain drive systems also present the disadvantage of greater friction and elongation due to wear compared to belt drive systems. Chain drive systems use chain guides and tensioner arms, which are not found in belt drive systems. As the chain slides against the chain guide and tensioner arm, resistance is generated. It has been reported that this sliding resistance with the chain guide and tensioner arm represents 90% or more of chain friction⁽¹⁾. Given this, the reduction of sliding resistance would be an effective means of reducing chain friction. Figure 1 shows friction in a cam drive system against engine displacement at an engine speed of 1500 rpm. The chain drive system displays approximately twice the friction loss of the belt

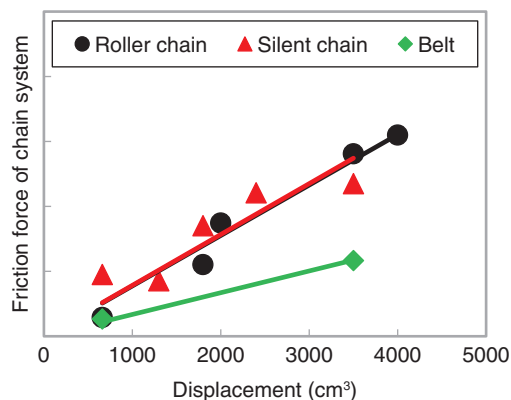


Fig. 1 Friction force of camshaft drive system

drive system. Friction resistance reduction methods such as the application of surface treatments to sliding parts are available to reduce sliding resistance in chain drive systems, but significant friction reductions cannot be expected using these methods. The reduction of average chain tension and the amplitude of chain tension, the sources of sliding resistance, are therefore important considerations in the reduction of chain friction.

Figure 2 shows a chain drive system using a hydraulic chain tensioner (termed a “chain tensioner” below). Chain drive systems use tensioner arms and chain tensioners positioned on the chain-unmeshing side of the crank sprocket in order to control chain vibration produced by factors such as torque fluctuations when the engine is in operation. In addition, a spring is situated inside the chain tensioner in order to apply a load to the chain. The chain tensioner controls the amplitude of chain tension by drawing engine oil into the interior of a plunger when the chain is slack and the plunger is extended, and attenuating the load exerted on the plunger when the chain is under

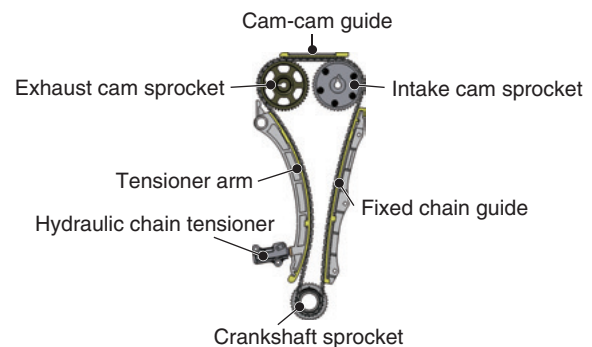


Fig. 2 Camshaft drive chain system

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tension. With the repetition of engine operation, the chain becomes worn and elongated. When the chain becomes elongated, the chain-tensioner plunger extends further to follow the chain. When the plunger extends further, the load placed on the chain by the spring in the chain tensioner is reduced. If the load becomes too low, the behavior of the chain becomes unstable, resulting in functional issues such as poor meshing between the chain and the sprocket. Because of this, it is essential to set the spring load such that the necessary load can be applied even when the chain becomes elongated. However, if the spring load is set too high, friction increases at the initial stage of chain life, before it has become elongated. As this indicates, the chain-tensioner system significantly affects the average chain tension due to the load placed on the chain by the spring inside the tensioner and the amplitude of chain tension during engine operation.

Consideration of chain-tensioner systems indicates that if it were possible to reduce the level of extension of the plunger following the chain elongation, and to reduce the rate of chain elongation itself, it would be possible to reduce the average tension on the chain by reducing the setting of the load placed on the chain by the spring inside the chain tensioner when the chain is in its initial state, before it has become elongated. In addition, if it were possible to reduce the amplitude of chain tension, chain friction would be reduced and the level of fatigue strength demanded from the chain would also be reduced, making it possible to reduce the cost and weight of the chain by reducing the number of plates.

Using a 2.4 L engine with a chain drive system, the research discussed in this paper set out to reduce friction by 50% in order to achieve friction loss equivalent to a belt drive system, while realizing a cost and weight equivalent to or lower than in a conventional chain drive system. In order to realize these goals, the project developed a double-arm chain-tensioner system making it possible to reduce the average chain tension, the amplitude of chain tension, and the rate of chain elongation.

2. Double-arm Chain-tensioner System

Figure 3 shows an overview of the double-arm chain-tensioner system. The system differs from a conventional system in positioning a sub-arm between the tensioner arm and the chain tensioner. The positioning of the sub-arm produces lever ratios at the points of contact between the sub-arm and the tensioner arm and between the sub-arm and the chain tensioner due to the difference in their distance from the sub-arm support point. The effect of these lever ratios results in the following main differences between the double-arm chain-tensioner system and a conventional system:

- (1) The degree of movement of the plunger in relation to the degree of movement of the tensioner arm due to the chain elongation is reduced.

- (2) The stroke and the speed of variation of the amplitude of the plunger in relation to the oscillation of the tensioner arm due to the amplitude of chain tension are reduced.
- (3) The load input to the plunger due to the amplitude of chain tension is increased.
- (4) The load applied to the chain by the chain-tensioner spring is reduced.

In addition, the positioning of the tensioner has the following effects:

- (5) The positioning of the chain-tensioner plunger facing upward enhances air-venting performance.
- (6) The positioning of the chain-tensioner plunger facing upwards helps to prevent oil leakage when the engine is stopped.

Making use of these effects, the following goals were set for functional enhancements in the development of a double-arm chain-tensioner system:

Friction: Based on the effect described in (1), reduction of friction by means of the reduction of the degree of movement of the plunger in response to the chain elongation.

Amplitude of chain tension: Based on the effect described in (2), reduction of the amplitude of chain tension with the increased ability of the tensioner to follow the chain at high engine speeds.

Reduction of chain elongation: Based on the effects described in (1) and (2), reduction of chain elongation by means of reduction of the surface pressure between the pins and the plates of the chain.

Cost and weight: Reduction of cost and weight through reduction of the number of chain plates by means of reduction of the amplitude of chain tension and chain elongation.

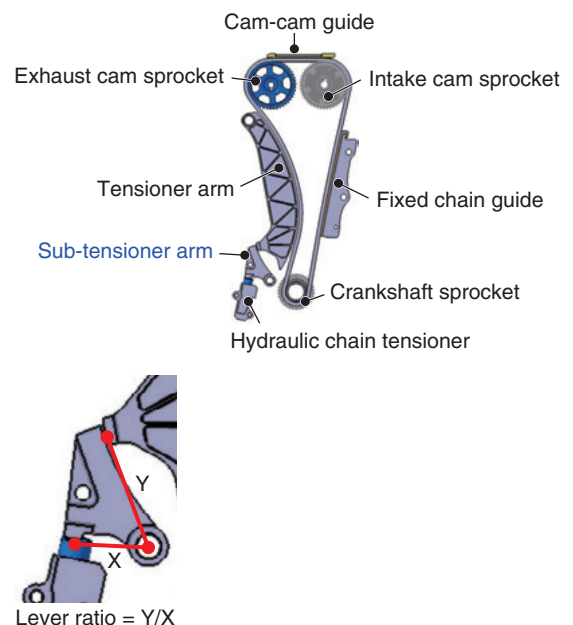


Fig. 3 Double-arm chain-tensioner system

Figure 4 shows changes in the load applied to the chain by the chain-tensioner spring due to chain elongation for a conventional chain-tensioner system and the double-arm chain-tensioner system. The load applied to the chain by the double-arm chain-tensioner system was set in order to make the load at the maximum chain elongation rate equivalent to that of a conventional system. It was possible to set the load on the chain in its initial state prior to elongation at a lower level in the double-arm chain-tensioner system as compared to the conventional system, and the changes in load in response to chain elongation are also less pronounced in the double-arm system. In addition to the fact that the degree of movement of the chain-tensioner plunger in relation to the degree of movement of the tensioner arm due to the chain elongation is lower in the double-arm system, this is also a result of the fact that the load setting took into consideration factors including changes in the lever ratios and changes in the efficiency of load transmission from the plunger spring to the chain due to chain elongation.

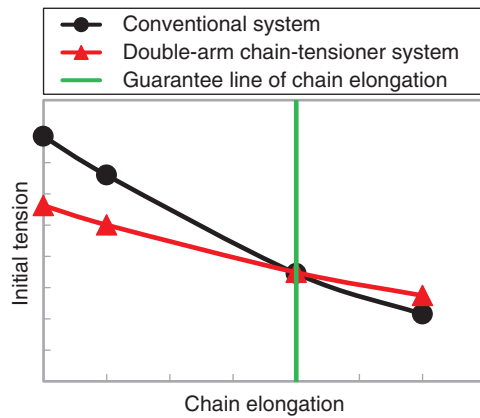


Fig. 4 Relation between chain elongation and initial tension

3. Basic Performance of Double-arm Chain-tensioner System

In order to verify the basic performance of the double-arm chain-tensioner system, the double-arm system and a conventional system were tested in engines of the same specifications; only the chain drive systems were changed. Table 1 provides an overview of the engine specifications. Figure 5 shows a comparison of measurements of chain tension during engine operation for the conventional system and the double-arm chain-tensioner system. Chain tension measurements were conducted by turning the crank sprocket into a load cell. Tension was regarded as positive on the fixed-guide side and negative on the tensioner-arm side. Figure 5 indicates that the amplitude of chain tension is lower for the double-arm chain-tensioner system across the entire range of engine operation. At high engine speeds, the

Table 1 Engine specifications

Cylinder configuration	Inline 4
Bore × Stroke (mm)	87.0 × 99.0
Displacement (cm ³)	2354
Compression ratio	10.5
Chain type	Silent chain
Chain pitch (mm)	6.35
Number of link plates	4/3
Number of links	176
Tensioner type	Hydraulic tensioner
Number of sprocket teeth	Crankshaft sprocket : 23 Camshaft sprocket : 46

increase in the ability of the chain tensioner to follow the chain due to the reduction of the amplitude of chain tension has resulted in a reduction of chain tension of approximately 35%. In addition, the results indicate that the reduction in the amplitude of chain tension would make it possible for this specification to satisfy fatigue strength demands even if the number of plates in the chain was reduced.

Figure 6 shows a comparison of the results of measurements of friction in the chain systems. The

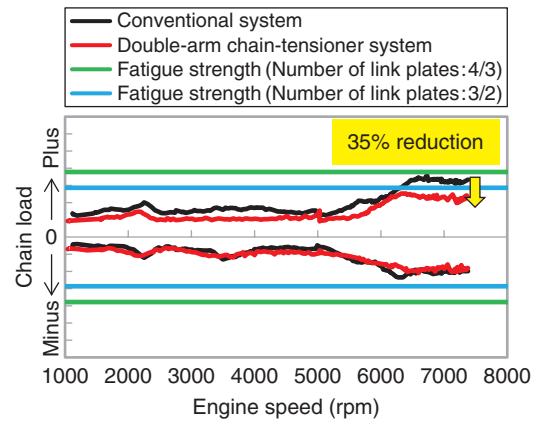


Fig. 5 Comparison of chain load

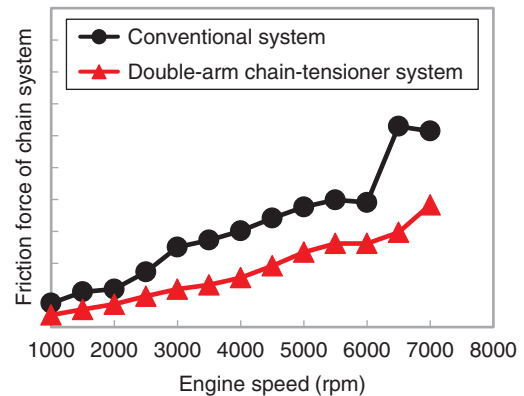


Fig. 6 Comparison of chain friction force

reduction of the amplitude of chain tension and average chain tension realized through the use of the double-arm chain-tensioner system reduces friction across the entire engine operating range. In addition, friction is reduced by 50% in the range up to 4000 rpm.

4. Evaluation of Reliability

In order to evaluate the reliability of the double-arm chain-tensioner system, the system was subjected to chain system durability tests and chain elongation evaluation tests using conditions in which the loading on the sub-arm support points would be at its maximum. Figure 7 shows a comparison of the surface pressure between the chain pins and plates calculated from the results of chain tension measurements. Figure 8 shows the results of the chain elongation evaluation tests. Figure 5 indicated that the

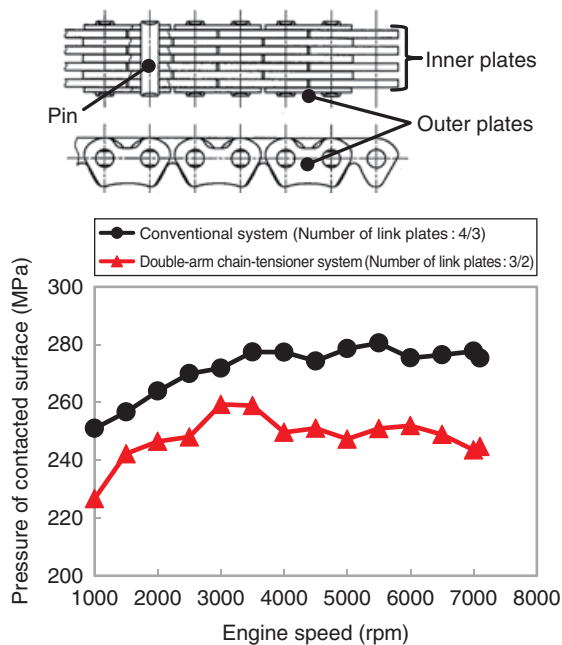


Fig. 7 Comparison of pressure of contacted surface

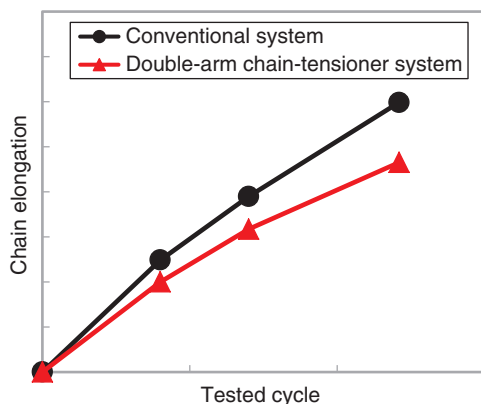


Fig. 8 Comparison of chain elongation

reduction of the amplitude of chain tension in the double-arm chain-tensioner system would make it possible for the system to satisfy fatigue strength demands despite the reduction of the number of plates in the chain. Figure 7 indicates that as a result of the reduction of average chain tension and the amplitude of chain tension, the surface pressure between the chain pins and plates would be lower in the double-arm chain-tensioner system than the conventional system even if the number of plates in the chain was reduced. Given that these results demonstrate that the use of the double-arm chain-tensioner system increases reliability, tests for the evaluation of reliability were performed on a specification in which the number of plates was reduced against the conventional system. Figure 8 indicates that despite the reduction in the number of plates, the effect of the reduction in surface pressure reduces the chain elongation rate by 30% in the double-arm chain-tensioner system as compared to the conventional system. In addition, the results of durability tests using maximum loading on the sub-arm showed that no malfunctions occurred under these conditions.

5. Cost and Weight

Figure 9 shows a comparison of the cost and weight of a conventional system and the double-arm chain-tensioner system. The reduction of the number of plates in the double-arm chain-tensioner system reduces cost by 2.5% and weight by 0.8% against the conventional system.

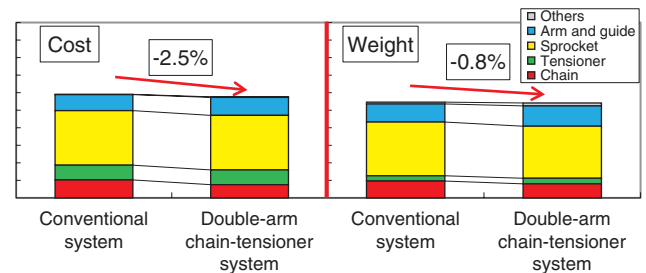


Fig. 9 Cost and weight

6. Conclusion

The following results were achieved in the development of a double-arm chain-tensioner system.

- (1) Friction in the system has been reduced across the entire range of engine operation. In particular, friction has been reduced by 50% in the range up to 4000 rpm.
- (2) The amplitude of chain tension has been reduced across the entire range of engine operation. In particular, the amplitude of chain tension has been reduced by a maximum of 35% in the high-speed range.
- (3) The reduction of the average chain tension and the amplitude of chain tension made it possible to reduce

the number of plates in the chain. This has reduced cost by 2.5% and weight by 0.8% against a conventional system. In addition, despite the reduction in the number of plates, the chain elongation rate has been reduced by 30%.

Reference

- (1) Sakaguchi, M., Yamada, S., Seki, M., Koiwa, Y., Wakabayashi, T., Yamauchi, T.: Prediction of Friction in Timing Chain Using Multi-body Dynamics Simulation, 2011 JSAE Annual Congress Proceedings, No. 154-11, p. 1-6, No. 20115527

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