

Metal Pushing V-belt for Torque Converter-type CVT for 1.5-Liter Class Vehicles

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ABSTRACT

A metal pushing V-belt for use in a new 1.5 L class torque converter-type CVT (TC-CVT) has been developed.

Because torque is amplified by the torque converter, a TC-CVT places a greater load on the belt than a conventional starting clutch-type CVT (SC-CVT), and the new V-belt therefore had to be able to cope with this increased load.

In order to fit the developed belt for this more severe use environment, the shape of the elements was modified to increase strength, and the accuracy of the shape of the rings was increased by reducing the high order of curvature component, resulting in more stable dynamic behavior. In addition, the hardness of the surfaces of the rings was increased in order to enhance wear resistance.

A noteworthy feature of the developed metal pushing V-belt is the fact that specifications enabling use in a 1.5 L class TC-CVT were achieved using only nine layers of rings.

1. Introduction

In 2001, Honda became the first automaker to internally manufacture a metal pushing V-belt⁽¹⁾. As of March 2007, the company had produced a total of 1 million belts for 1.5 L class SC-CVTs.

The newly developed 1.5 L class TC-CVT employs a torque converter, increasing torque in comparison to the SC-CVT at take-off and when the engine stalls. The metal pushing V-belt should therefore transmit more torque. The clamping force necessary to achieve torque transmission without slipping at the contact surfaces between the belt and the pulleys will therefore be higher than it was in the case of the SC-CVT, necessitating the development of a belt able to tolerate the new load.

This paper will provide an overview of the developed metal pushing V-belt, and will discuss the main technologies that it employs.

2. Development Goals

An increase in the clamping force applied to the belt by the pulleys will affect the elements and rings that make up the belt. The distortion of the elements when the belt is clamped by the pulley will increase, and the tensile

stress on the rings will increase. Tensile stress can be reduced by increasing the number of layers of rings, but this would increase costs. Twelve layers of rings is currently standard, but it was considered that cost competitiveness would be increased if the 1.5 L class TC-CVT could be developed using nine layers of rings.

This consideration led to the development of a metal pushing V-belt using nine layers of rings for the 1.5 L class TC-CVT being set as the development goal.

3. Configuration and Specifications of Metal Pushing V-belt

Metal pushing V-belts are made up of several hundred elements and two sets of layered rings. Figure 1 shows a photograph of the developed belt and Table 1 compares the main specifications of the current and the developed belts. The width of the developed belt is 24 mm, the standard width for a 1.5 L class CVT.

The names of the components making up the belt are shown in Fig. 2. The areas shaded over in Fig. 2 represent changes that have been made to the shape of the current SC-CVT element to increase strength and reduce surface pressure.

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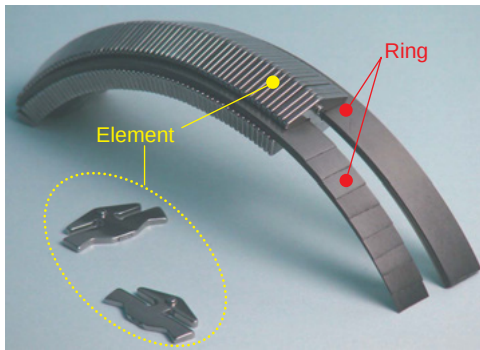


Fig. 1 Newly developed metal pushing V-belt

Table 1 Steel belt specifications

		Current	Developed
CVT type		SC-CVT	TC-CVT
Shaft distance (mm)		143	156
Ring	Width (mm)	a	9.15
	Thickness (mm)	b	0.184
	Diameter (mm)	c	191.7
	Number of rings	9 /Each side	9 /Each side
Element	Rocking edge width (mm)	d	24
	Thickness (mm)	e	1.5
	Body height (mm)	f	5.75
	Mass (g)	1.79	1.97

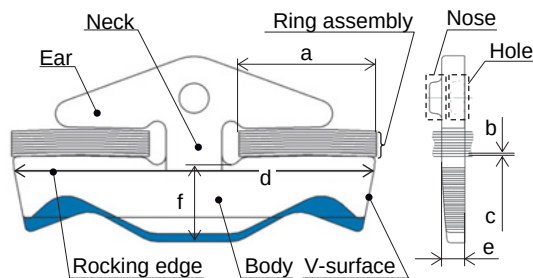


Fig. 2 Configuration of elements and ring assembly

4. Element Strength

The increase in the clamping force in the new belt would generate increased stress due to element distortion and would cause a decline in the wear characteristic of the belt due to increased pressure on the contact surfaces between the pulleys and the elements. These factors had to be taken into consideration. A reduction of 30% in stress was achieved by increasing the height of the element bodies in order to give them a larger cross-sectional shape (Fig. 3).

In addition, the length of the element V-surfaces was increased in order to reduce contact pressure. CAE strength analyses were conducted to design the bottom of the element bodies to allow the contact pressure on the V-surfaces generated by the clamping force to be evenly

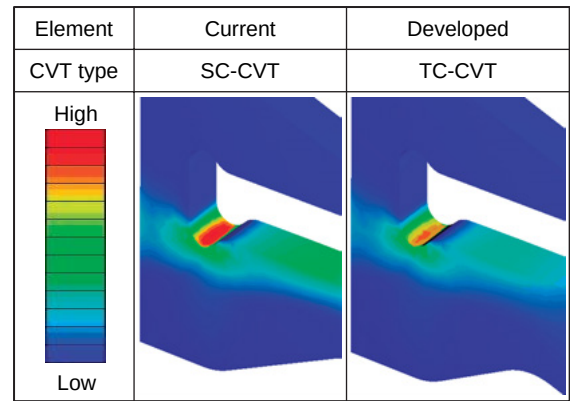


Fig. 3 Stress on element

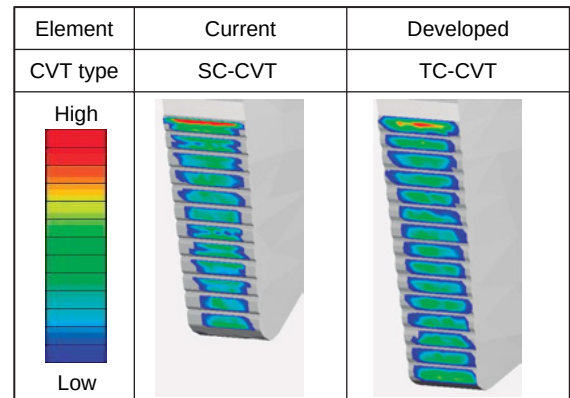


Fig. 4 Contact pressure at V-surface

distributed despite the high rigidity achieved by increasing the height of the bodies and the length of the V-surfaces. This enabled the achievement of a maximum level of contact pressure on the V-surfaces during operation equivalent to or lower than that recorded in the SC-CVT (Fig. 4), and minimized the increase in mass.

5. Wear Resistance of Rings

In the range in which torque is amplified by the torque converter in the TC-CVT, the tensile stress on the rings becomes greater than the tensile stress on the rings in the SC-CVT belt. In order to stabilize the dynamic behavior of the rings when this greater stress is generated, it was necessary to increase the accuracy of the shape of the rings. If the dynamic behavior of the rings became unstable, there would be interference with the sides of the element necks, and the edges of the rings would be subject to wear.

In order to increase the friction resistance of the rings, the development discussed here conducted measurements of the dynamic behavior of the rings, evaluated the accuracy of their shape, and optimized the difference in surface hardness of the rings and the sides of the element necks.

5.1. Measurement of Ring Dynamic behavior

Figure 5(a) shows the string between the drive and the driven pulleys where measurements of ring dynamic behavior were conducted at LOW ratio. Figure 5(b) shows a schematic of the sensor used in the measurements.

Figure 6 shows the results of measurements of ring displacement in the direction of width during operation based on signals from this sensor. In the current rings, right-left displacement of the rings in the string in which measurements were taken increased with increasing tensile stress. The developed rings, by contrast, demonstrated stable dynamic behavior, with no increase in left-right displacement despite increased tensile stress.

5.2. High Order of Curvature of Rings

Conventionally, when the accuracy of the shape of the rings is evaluated, the shape shown in Fig. 7(a) is termed “curve.” A measurement method that does not involve cutting of the ring is used in mass production to enable production control⁽²⁾.

It was shown that in the rings in which displacement in a left-right direction increased in the string used for measurements as tensile stress increased, a curved form of the type shown in Fig. 7(b), on the microscopic level

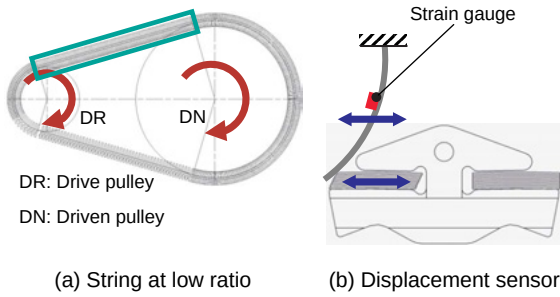


Fig. 5 Measurement of ring displacement

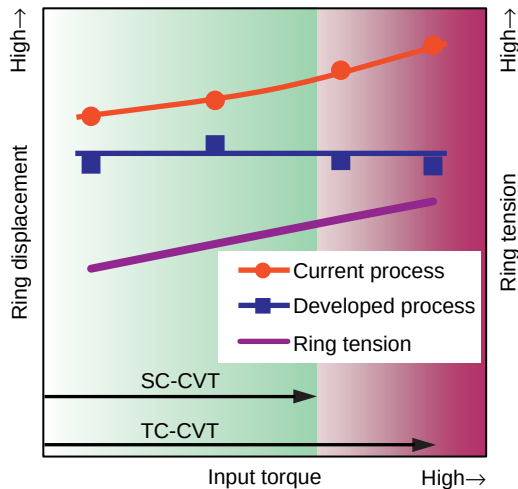


Fig. 6 Comparison of ring displacement

of micrometers and possessing a high degree of periodicity, also exists in addition to the curved form made up of low-order components shown in Fig. 7(a).

The high-order component of this curvature was highlighted by the application of Fourier analysis following the removal of low-order components from the automatically measured curvature data. Because this method can quantify the periodicity of specific orders across the entire length of the rings, it is able to identify the causes of curvature in the production process.

Figure 8 shows the results of Fourier analysis of measurements taken using 18 layers of rings, with Fig. 8(a) showing results for the current rings, and Fig. 8(b) showing results for the developed rings.

The amplitude of the sixth-order component is conspicuous in the results for the current rings. A procedure related to the sixth order component was therefore sought in the production process of the rings. It was found that the outer diameter of the roller used in the rolling process was approximately one-sixth the diameter of the rings, and that the accuracy of this roller was affecting the curvature of the rings. The accuracy of the

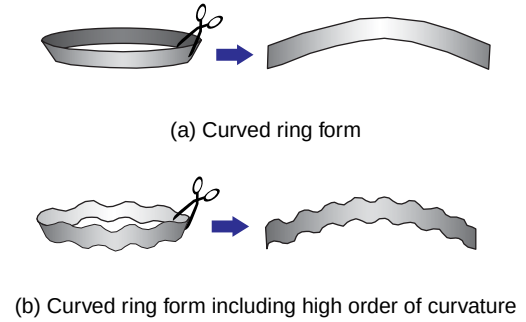
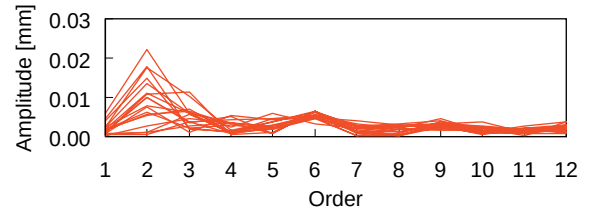
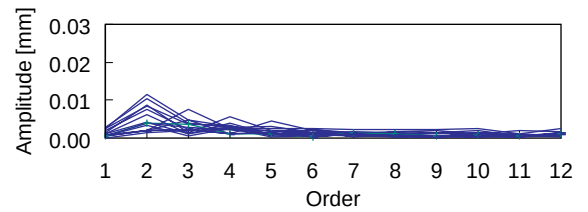


Fig. 7 Schematic of curved ring form



(a) Current



(b) Developed

Fig. 8 Comparison of frequency component

roller was increased, resulting in a reduction in the amplitude of all orders, in particular the sixth-order component.

5.3. Optimization of Difference in Surface Hardness

In order to help prevent wear from progressing through temporary contact between the rings and the sides of the element necks, the surface hardness of the developed rings was increased to a higher level than the surface hardness of the sides of the element necks.

5.3.1. Comparison of surface hardness of rings and sides of element necks

Figure 9 shows the hardness of the developed rings and element necks in the direction of depth from the surface.

The hardness of the surface of the rings is higher than that of the sides of the element necks, and the gradients for the element necks show that they become harder from the upper section to the lower section. This allows the edges of the rings on the outer circumference side, where the change in dynamic behavior is greater in the layered rings, even if they make contact with the sides of the element necks, to have the high degree of difference in surface hardness that will help prevent wear from progressing in the rings.

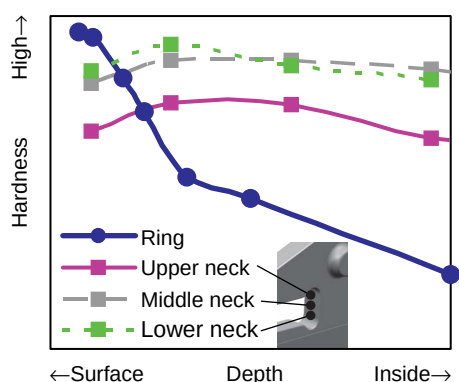


Fig. 9 Hardness of element neck and ring

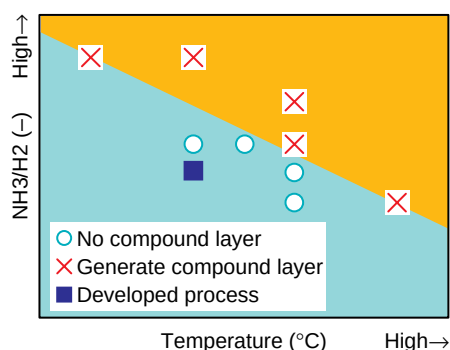


Fig. 10 Compound layer generation at nitriding

5.3.2. Ring hardness

Figure 10 shows whether a compound layer was or was not generated on the surfaces of the rings when the temperature and the ratio of the gases were varied during the nitriding process. Hardness increases as the nitrogen gas ratio increases, but if a compound layer forms, durability can decline.

Optimization of conditions during nitriding of the developed rings has increased the concentration of nitrogen on the surface, resulting in increased surface hardness. In addition, the internal hardness of the rings does not reduce the toughness that is a characteristic of the maraging steel used in the rings.

5.3.3. Hardness of element neck

Compressive residual stress is conventionally imparted to the surface of the sides of the neck section by means of water jet peening, in order to increase strength. New conditions were set for the developed elements so as to allow the surface hardness of the sides of the element necks not to exceed that of the rings, while still imparting sufficient compressive residual stress to help prevent a decline in strength.

6. Strength and Durability

6.1. Element Strength

To verify the strength of the developed elements, their performance in unit fatigue strength tests was compared with that of the current elements (Fig. 11). The results of strength tests and strength calculations correspond almost exactly, with both showing a strength increase of 30% in the developed elements.

6.2. Wear Resistance of Rings

The current belt and the developed belt were subjected to a durability test using a high level of tensile stress, as would be generated at take-off in a TC-CVT. Wear at the edges of the rings was reduced by 64% in the developed belt in comparison to the current belt.

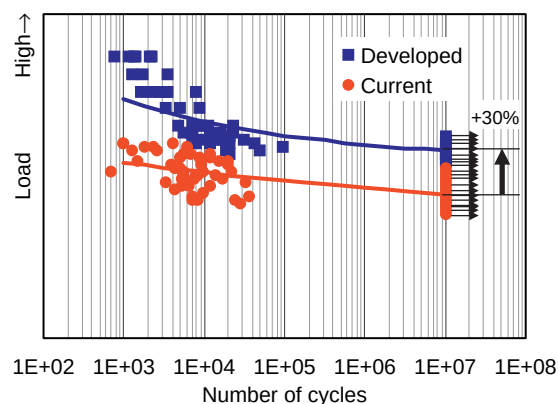


Fig. 11 Fatigue strength properties of simple element

7. Maximum Transmitted Power

Figure 12 shows a comparison of the maximum transmitted power and the maximum allowable torque of the current belt and the developed belt. The new metal pushing V-belt is able to cope with the increased torque produced by the use of a torque converter in addition to the higher levels of power and torque resulting from the evolution of the engine, with only nine layers of rings.

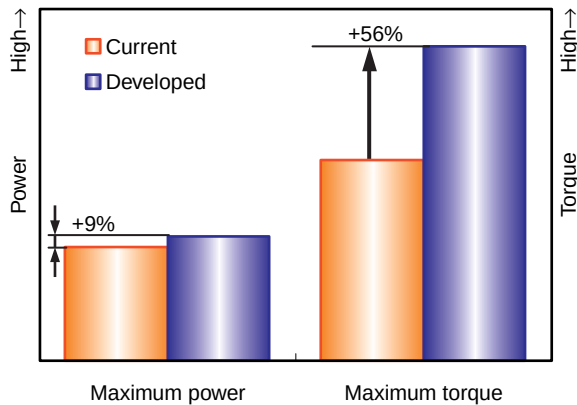


Fig. 12 Potential of newly developed V-belt

8. Conclusion

A metal pushing V-belt using nine layers of rings that can be employed in a TC-CVT has been developed. The major points of this development are as follows:

- (1) The height of the element bodies and the length of the element V-surfaces were increased, resulting in increased strength and an enhanced wear characteristic.
- (2) The high order of curvature component of the rings was reduced and the accuracy of the shape of the rings was increased, resulting in more stable ring dynamic behavior.
- (3) The hardness of the surface of the rings was increased and the difference in hardness between the surface of the rings and the surface of the sides of the element necks was optimized, increasing the wear resistance of the rings.

9. Afterword

The development of a metal pushing V-belt for a TC-CVT discussed in this paper can be characterized as a project focusing on small details. In seeking further performance enhancements even from a specification that had been considered completed, such a focus on details involves identifying further points that can be modified and ceaselessly making modifications in order to achieve further evolution.

Guided by Mies van der Rohe's phrase "God is in the details," Honda will seek to achieve further evolution of

the parts discussed in this paper in future through theoretical study of form and the development of innovative production technologies, while maintaining a close focus on the details.

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