

Development of Metal Pushing V-Belt for Continuously Variable Transmission

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ABSTRACT

Metal pushing V-belt is the core technology of CVT. Up to the present, only Van Doorne's Transmissie b. v. has engaged in the mass production of this component. As a result of knowledge obtained from ongoing analysis of the power transmission mechanism, newly conducted measurements of block compression force for slack string and numerical analysis, Honda is the first automotive manufacturer to have independently developed the metal pushing V-belt for mass production. This newly developed metal pushing V-belt features reduced pitch diameter and increased power transmission, to achieve compactness of the CVT and a wider ratio range.

1. Introduction

Numerous companies have spent years in research on metal pushing V-belts, but to date Van Doorne's Transmissie, b.v., is the only company to have engaged in the mass production of this component. Several factors lie behind this: despite the fact that CVT has received attention as an ideal automotive transmission technology, numerous issues in the transmission capacity and efficiency, start-up performance and mass producibility of metal pushing V-belt CVT have retarded the spread of the technology⁽¹⁾; in addition, the almost complete absence of papers on metal pushing V-belt development has meant that no clear overview of all aspects of the technology is available⁽²⁾, and VDT's strong patent rights⁽³⁾ have discouraged other contenders in the field. Honda has successfully applied the knowledge accumulated over years of analysis of transmissions (joint research with Doshisha University)⁽⁴⁾⁻⁽⁶⁾ and newly conducted measurements of clearance between elements and numerical analysis⁽⁷⁾ to the development of an original metal pushing V-belt. This paper discusses the specifications of this belt, and gives an outline of the development process.

2. Development Concept

To achieve compactness, ensure start-up drive power, and improve fuel economy in CVT, the ratio range must be enlarged. For compactness, it is necessary to decrease the distance between shafts; when doing this, the minimum pitch radius must be decreased to maintain or increase the ratio range. However, decreasing the minimum pitch radius while transmitting the same amount of torque increases the necessary pressure of the pulley on the metal belt, increasing the average tension of the rings in operation and the amplitude of ring stress caused by bending when the belt winds around the pulley. These factors make a high degree of strength essential. The development concept for this project was therefore established as follows:

The metal belt would be configured so as to make it possible to decrease the minimum pitch radius, and at the same time to reduce the load on the rings and increase durability.

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3. Structure of the Metal Belt / Component Specifications / Outline of Improvements

3.1. Structure of the Metal Belt

The metal belt is composed of several hundred elements and two rows of multiple rings (see Fig. 1).

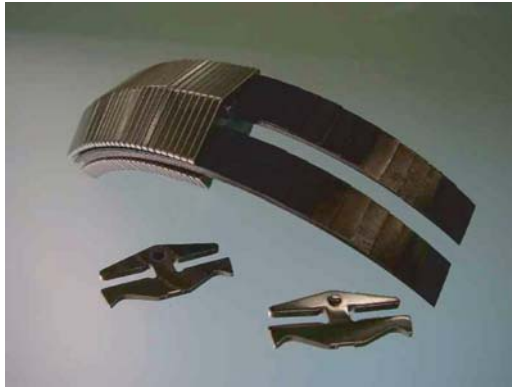


Fig. 1 Metal pushing v-belt

3.2. Elements

The elements are movable blocks that run between the pulleys and support thrust. The elements transmit torque from the drive pulley to the driven pulley by pushing against each other along with the right and left rows of rings. Fig. 2 shows the structure of the elements and the names of each section.

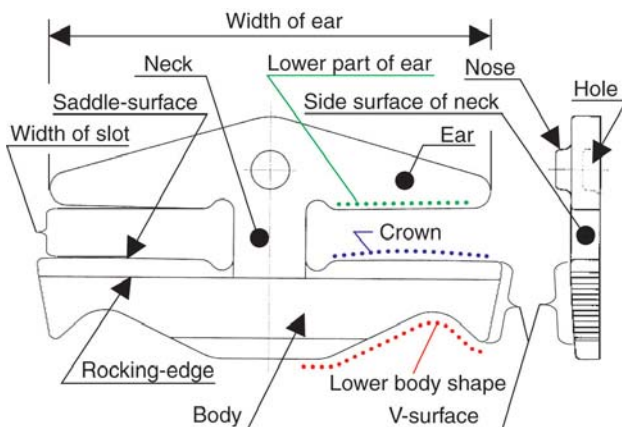


Fig. 2 Configuration of elements

3.2.1. V-surface length

When pulleys of the same shaft diameter are at minimum pitch, the lower sections of the V-surfaces of the elements of the former metal belt manufactured by other companies (termed "former elements" below) are brought into a position in which interference with the pulley shaft can easily occur. The V-surface in the newly developed elements is shorter than the lower section of the body, preventing interference between the V-surface and the pulley shaft, and enabling a reduction of diameter at minimum pitch. As a result, ratio range is 10% wider for the same distance between shafts and the same pulleys. Fig. 3 shows the relationship between

pulley and element position at minimum pitch in the formerly used metal belt manufactured by other companies (termed "former belt" below) and the newly developed belt.

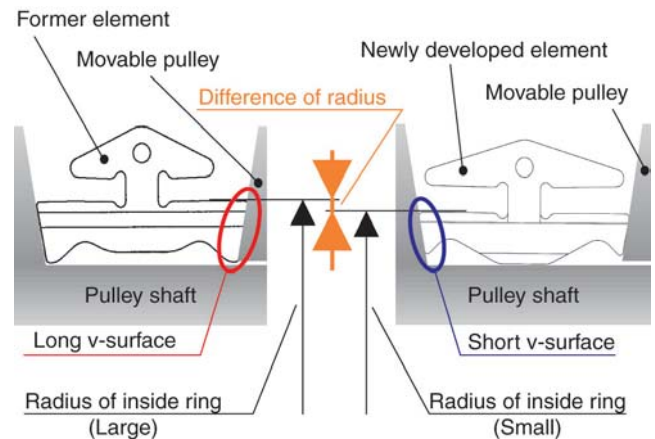


Fig. 3 Achievement of wider ratio

3.2.2. V-surface rigidity

The lower body shape was determined by element strength and V-surface friction characteristics, to ensure good friction characteristics by parallel displacement of the element V-surface and the pulley V-surface.

3.2.3. Groove on element V-surface (channel width/pitch)

To maintain actual contact length while shortening the V-surface length in the newly developed belt, the ratio of the channel on the V-surface was changed from 75% in the former belt to 45%, while maintaining the friction coefficient, lubrication performance, and wear resistance of the former belt.

3.2.4. Ear width

The ear width has been increased against the former element, to allow contact of the lower section of the ear from the ring crowning center to the pulley in order to reduce ring stress caused by contact with the outermost ring.

3.2.5. Slot width

Clearance between the lower section of the ear and the saddle surface has been increased in comparison to the former elements. In this configuration, the nose and hole of the element always make contact before the contact between the ring and the lower section of the ear, reducing contact stress with the ring.

3.2.6. Nose height

To prevent the nose leaving the hole and maintain alignment despite increases in total clearance between the elements (see 3.4.1) due to declining durability, the nose is higher and the hole is deeper in the newly developed belt than in the former elements.

3.2.7. Position and diameter of nose and hole

The center of the ear has been positioned to facilitate ease of formation creating a structure in which element nose and hole contact occurs before contact between the lower section of the ear and the rings. The diameter of the nose and hole has been increased and their fillet profile (radius and taper angle) at the base has been changed, increasing their strength.

3.2.8. Element contact surface

When power is transmitted by the elements aligned in strings, the points at which any element is in contact with the element in front and behind are limited to both sides of the ears and from the lower section of the neck to the center of the rocking edge. This configuration makes it possible to maintain good alignment of the elements in strings, and to stabilize belt behavior. Furthermore, press processing has made it easy to control thickness and die quality.

3.2.9. Element thickness used to regulate clearance

Elements of 1.6 mm thickness are used to regulate clearance, as against the 1.4 mm elements used in the former belt. This has increased element strength while maintaining the ability to adjust clearance between elements (see 3.4.1) found in the former belt.

3.3. Rings

The ring assembly features two rows of multiple rings in layers. In the section of the belt wrapped around the pulley, these rings push the elements against the pulleys, and control the element path between the two pulleys (strings). Fig. 4 shows the structure of the rings and the ring assembly, and gives the names of the various parts.

3.3.1. Width

It is well known that when pulleys are rendered movable, misalignment generally occurs.⁽²⁾ The ring width has therefore been reduced to absorb the increased misalignment

between the pulleys generated by increasing the speed ratio range. The amount of overhang with the element saddle has been set within a range that prevents a negative effect on durability.

3.3.2. Edge shape

To reduce the load on the rings when the ring edge is in contact with the side surface of the element neck or the pulley V-surface, the ring edges have been given a fully rounded shape.

3.3.3. Mesh shape

The mesh shape has been set at an even pitch to maintain the oil film between the rings, ensure centering and ease of manufacture of assembly.

3.3.4. Crowning shape

Offsetting the ring and element crowning centers has achieved stable behavior of the power directed towards the pulley V-surface by the layers of rings when the metal pushing V-belt is in operation. This means that the rings always approach the pulley V-surface, which is smoother than the element necks. Because of this, the frequency of ring edge contact with the element neck (a non-continuous surface) has been minimized, preventing ring edge wear and damage.

3.3.5. Curvature

When the rings are set up in the assembly after curving and shaping in the production process, sections of the ring edges contact the pulley V-surface and the edge of the element neck, affecting the durability of the belt. Because the crowning center of a ring in the assembly does not correspond with those of other rings above and below, centering becomes unsuitable, and abnormal wear can easily occur to inner and outer surfaces, or ring edges. To prevent this, a new ring curvature measurement method was developed, and the bending of the ring in production is controlled within a specified range.

3.3.6. Layer clearance

To increase ring durability and maintain lubrication, an optimum range was set for clearance between rings.

3.4. Belt Assembly

The metal pushing V-belt is composed of several hundred elements and two rows of rings, and the accuracy of the total assembly is considered to be the sum of the accuracy of each element and ring assembled.

3.4.1. Total clearance between elements

If the total clearance between elements is large, the range of slip and the slip velocity of the elements in the drive-side pulley increase, causing wear of the pulley V-surface (see 4.1.2, Fig. 7).

On the other hand, if the clearance is too small it exerts a negative effect on efficiency, and therefore the optimum range was set. The space in which the thickness gauge is inserted in Fig. 5 is the total clearance between elements.

3.4.2. Difference between left and right total clearance between elements

When there is a large difference between left and right total clearance between elements, it causes abnormal contact between the pulley V-surface and the element V-surface, leading to wear. To prevent this, the difference has been controlled within a specified value.

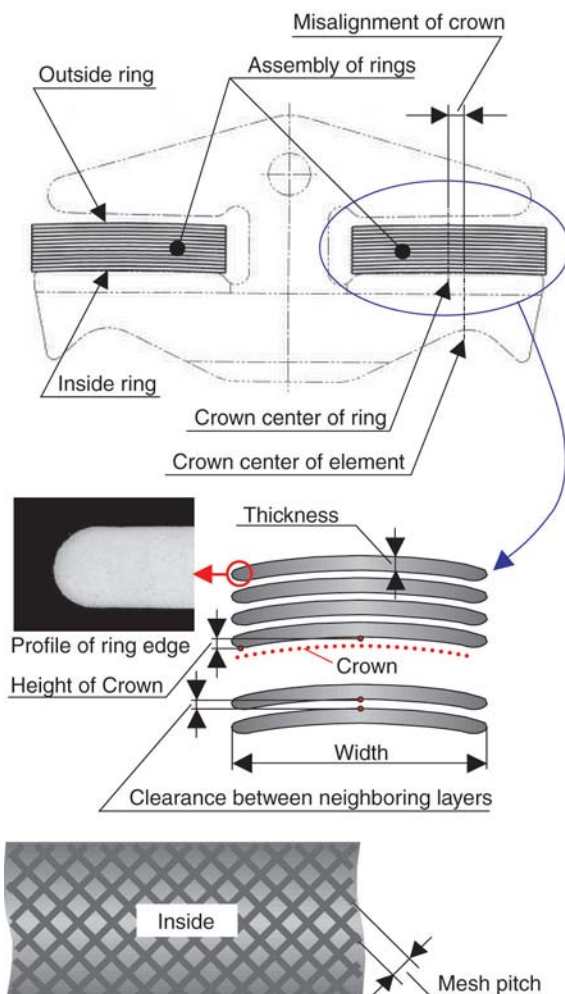


Fig. 4 Structure of rings and ring assembly



Fig. 5 Total clearance of elements

3.4.3. Difference between inner length of left and right rings

If the inner circumferences of the left and right rings differ, one side of the ring is put under excessive tension, with a negative effect on durability. Differences in circumference have been controlled within a specified limit to prevent this phenomenon.

3.4.4. Average difference of thickness between elements

When vertical variations occur in the thickness of elements, the saddle surface pushes the rings up, placing an excessive strain on them. This causes the outermost ring and the lower section of the ear to come into contact and their behavior to become unstable, which negatively affects the life cycle of the belt. Horizontal variations cause the side surface of the element neck and the ring edge to come into contact, leading to the possibility that high surface pressure will be exerted on sections of the ring edge. To prevent these occurrences, the average difference of thickness has been controlled within a specified range.

4. Kinematic Analysis of Element

Measurements of clearances between elements in slack strings were taken to analyze the structure of the metal pushing V-belt, and an appropriate total clearance between elements was established on this basis.

4.1. Establishing Total Clearance Between Elements

4.1.1. Changes in clearance between elements in operation

Fig. 6 shows a graph representing changes in behavior with different settings for total clearance between elements. The vertical axis represents clearance between elements

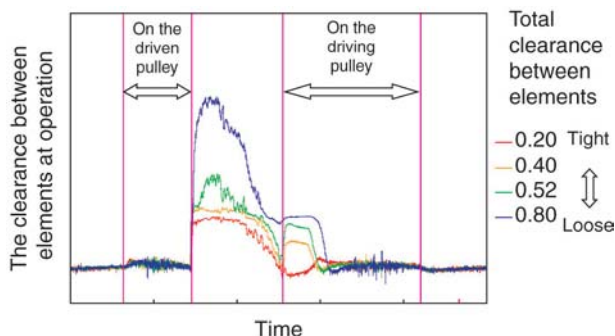


Fig. 6 Clearance between elements at operation

during operation, and the horizontal axis represents time. The clearance between elements during operation achieves its maximum value in the string running from the driven pulley to the drive pulley, and then suddenly decreases at the entrance to the drive pulley. It increases over the drive pulley again, and then suddenly decreases and reaches zero in the middle of the drive pulley. Element clearance during operation shows a tendency to increase with increases in total element clearance.

4.1.2. Relative slip velocity between belt and pulley

Fig. 7 is a graph showing calculation results for relative slip velocity of the belt and the pulley when the clearance between elements suddenly reaches zero in the middle of the drive pulley during operation.

The vertical axis shows the relative slip velocity between belt and pulley, and the horizontal axis shows total clearance between elements. The relative slip velocity between belt and pulley is around zero until point p for total clearance between elements, then increases after point q, with the distance between points p and q representing the border for slip velocity increase. In the newly designed belt, after point q the slip velocity of the belt relative to the pulley increases, causing wear of the element and pulley V-surfaces to occur more easily. To take this into account, an appropriate range was established for the total clearance between elements in the belt assembly.

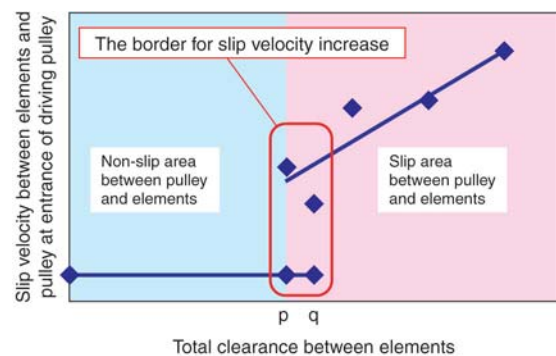


Fig. 7 Slip velocity between elements and pulley on driving pulley

5. Durability and Reliability

To enable belt strength to be increased, various durability tests were conducted, followed by stress simulations using the same conditions. In addition, a new method for evaluation of inclusions in materials was developed.

5.1. Belt Behavior/Stress Simulations

The simulation method has been described in a previous paper⁽⁷⁾, and details will therefore be omitted here.

5.1.1. Belt strength and durability

Fig. 8 shows an S-N diagram for the metal pushing V-belt. The vertical axis represents the amplitude of stress on the innermost ring, and the horizontal axis represents the number of bending cycles for the belt. Stress in the newly designed belt was analyzed against the former belt under two standard loads. Results show lower stress in the newly designed belt.

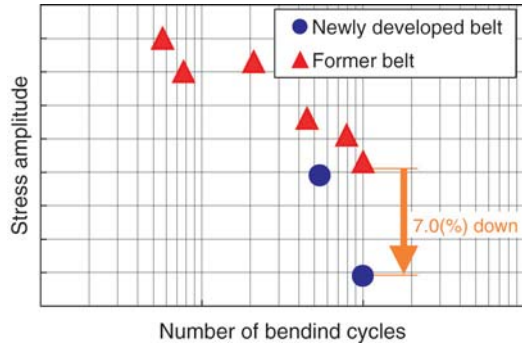


Fig. 8 S-N diagram of CVT belt

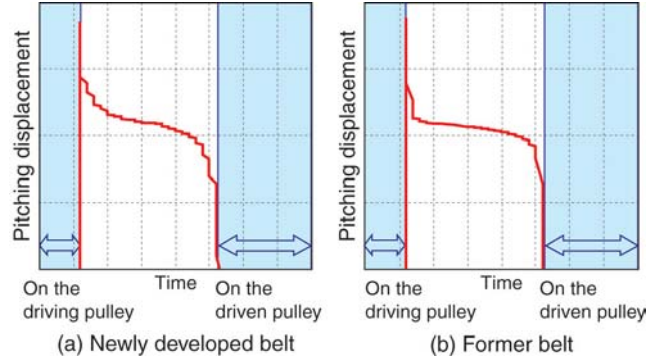


Fig. 10 Element pitching behavior

5.1.2. Causes of difference in ring stress

Fig. 9 compares ring stress waveforms for the innermost rings of the former and the newly designed belt under identical conditions. The difference in the stress waveforms at points e and f is conspicuous, which represent the change in stress in the section wrapped around the driven pulley. The waveform for the newly designed belt changes smoothly at the entrance and exit of the pulley. If we compare the rate of change of element pitching behavior, we see that the change in the angle of pitching displacement around the entrance and exit of the pulley is smaller in the newly designed belt (points g and h in Fig. 9). Fig. 10 shows change in the angle of pitching displacement in the section running between the exit of the drive pulley and the entrance of the driven pulley.

The rings receive a reactive force from the change in the angle of pitching displacement, and because of this the operating load of the rings is smaller in the newly developed belt, and ring stress is therefore reduced. This is because the shorter V-surface length has brought the distance between the rocking edge and the middle point on V-surface closer.

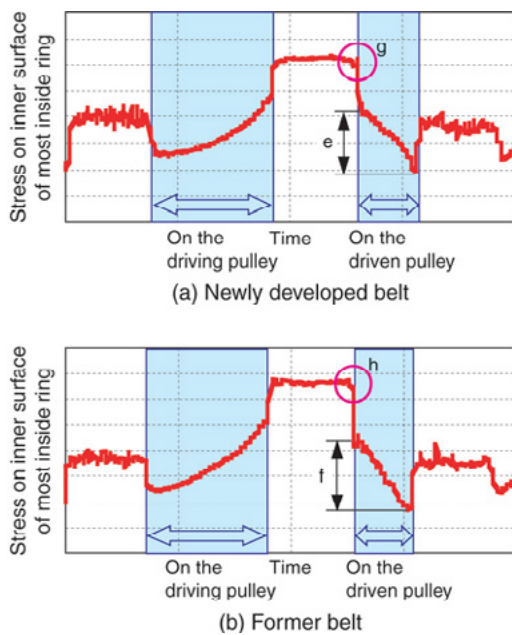


Fig. 9 Ring stresses

5.1.3. Element nose strength

The role of the nose is to maintain good alignment during operation, but excess load can cause damage to this section. The limit loads which produced damage had already been clarified in the element tests to be described below. Because of this, it was known that estimation of the nose load during operation was an important factor in judging belt durability. This load is affected by the clearance between nose and hole, and by the width of the slot. Fig. 11 shows operating loads on the nose and hole during belt operation. Nose-hole contact was observed in the string on the side on which pushing force between the elements was not generated. The maximum load on the nose occurs around the pulley entrance and exit.

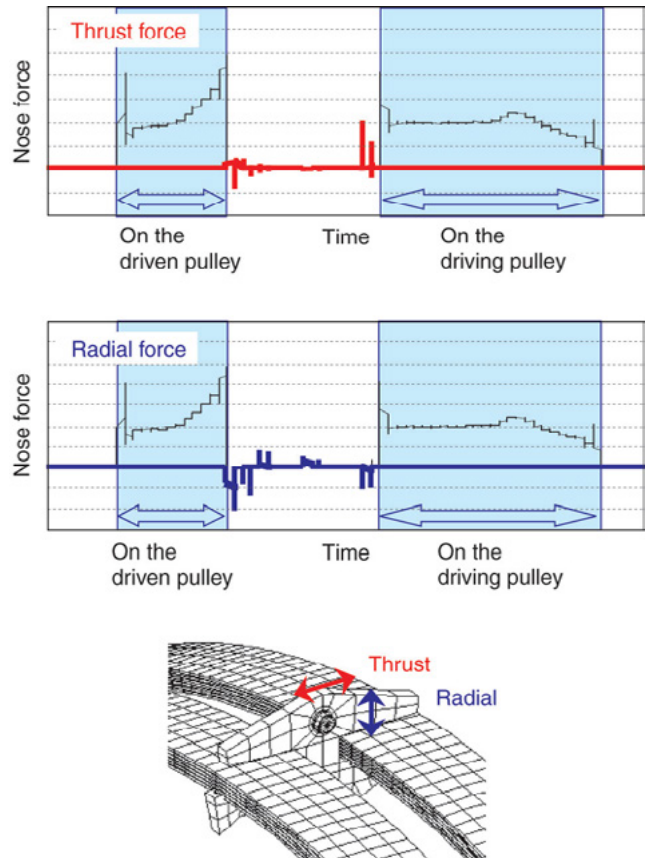


Fig. 11 Nose-hole contact

Fig. 12 shows the maximum load on the nose when the clearance between nose and hole is varied. These results show that when clearance exceeds a specific value, the load on the nose suddenly increases. This demonstrates that increasing clearance has a negative effect on belt alignment. The influence of slot width on nose load is shown in Fig. 13. These results show that when slot width exceeds a specific figure, nose load increases, but ring stress decreases.

The results described above made it possible to reduce ring stress by setting optimum values for clearance between the nose and hole and the slot width.

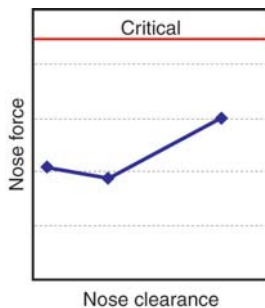


Fig. 12 Nose-Hole reaction forces by the clearance

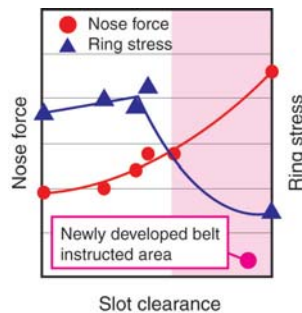


Fig. 13 Nose-hole reaction force and ring stress by element slot clearance

5.2. Element Strength

The hyper-eutectic steel used for the elements is quenched and tempered to obtain the required tenacity and fatigue strength, but the heat treatment conditions necessary to obtaining these characteristics had been insufficiently studied. The test model shown in Fig. 14 was therefore used to conduct strength and fatigue tests on the nose in isolation, enabling evaluation of effects of heat treatment and molding accuracy on fatigue strength.

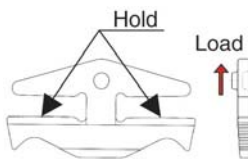


Fig. 14 Test mode

Fig. 15 shows the effect of varying quench time, and demonstrates that fatigue strength drops with increased quench time.

The cause of this is thought to be the growth of crystal grains and the precipitation pieces shown in Fig. 16. These precipitation pieces were assayed as cementite (Fe_3C). Fig. 17 shows a photograph of the fracture surface after fatigue tests, demonstrating that a long quench time causes a grain fracture surface. Fig. 18 demonstrates the effect of nose shaping accuracy and fatigue strength.

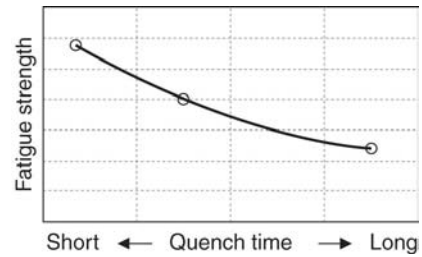


Fig. 15 Relationship between quench time and fatigue strength

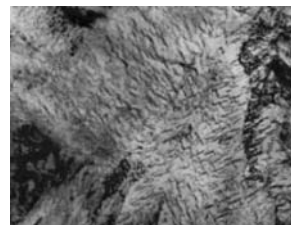


Fig. 16 Precipitation pieces in a phase

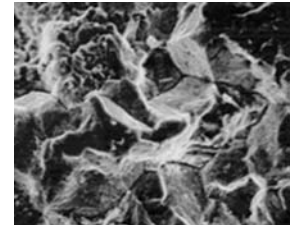


Fig. 17 Fatigue fracture surface for long quench time

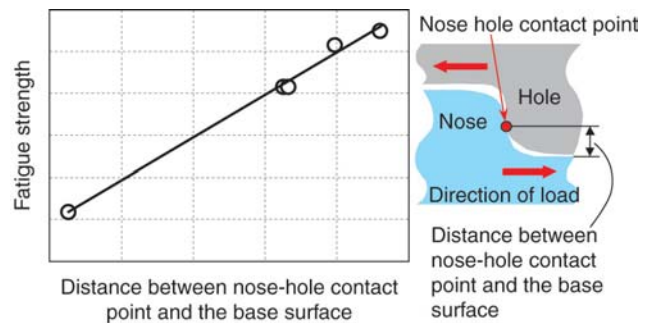


Fig. 18 Relationship between distance between nose-hole contact point and the base surface and fatigue strength

Strength is mainly affected by the position of contact between nose and hole, and when target accuracy is not achieved, fatigue strength drops. These results enabled designers to establish the optimum heat treatment conditions and the required level of accuracy in forming the nose, and assisted in deciding on the final specifications of the elements. Fig. 19 shows the results of durability tests on the belt assembly, and these show a good correlation with the results of tests of element fatigue strength. The final specifications necessary to ensuring fatigue strength in the nose were established on the basis of these results.

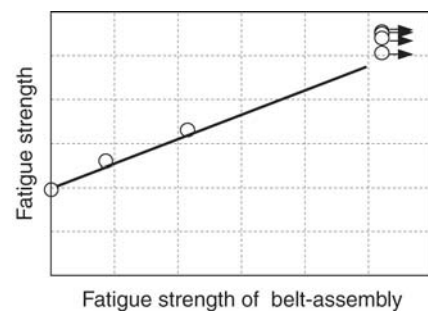


Fig. 19 Relationship between fatigue strength of belt-assembly and fatigue strength of elements

5.3. Ring Strength

The rings in the newly developed belt are 0.18 mm thick. This is to ensure pliable bending in the rings so that there will be no resistance when the belt wraps around the pulleys, or put another way, to minimize the bending stress when the belt wraps around the pulley. High strength to prevent failure under tension and high fatigue strength to resist continuous bending is required from these extremely thin rings. Taking these requirements into consideration, 18Ni maraging steel was selected as the material for manufacture of the rings because it is one of the highest strength materials available. To further increase the superior characteristics of 18Ni maraging steel in the newly developed belt, the non-metallic inclusions in the material were reduced in size, and the heat treatment conditions were improved. This has significantly increased fatigue strength.

5.3.1. Inclusions

The rings in metal pushing V-belts require strength at ultra-high cycles. Research to the present has demonstrated that at high cycles below 10^7 , the surface is the initiation point of fractures in high-strength steel, while at ultra-high cycles above 10^7 , inclusions in the material are the sources of fatigue fractures⁽⁹⁾⁻⁽¹⁰⁾. In maraging steel, Ti (C, N) inclusions are the point of origin of fractures, and fatigue fractures at 10^6 have been reported⁽¹⁰⁾. However, the fatigue behavior of maraging steel at ultra-high cycles has not been sufficiently clarified. For this reason it was judged necessary first to test the fatigue behavior of the material at ultra-high cycles. The upper limit for conventional fatigue tests using rotational bending and stretching pressure is approximately 50 Hz. For this reason, twenty days is required to reach 10^8 cycles, and time restrictions make evaluations in this ultra-long longevity area extremely difficult. However, it has recently become possible to evaluate ultra-high cycle fatigue using ultrasonic fatigue tests^{(11), (12)}. This method was used in the development of the new belt to clarify the fatigue behavior of maraging steel at ultra-high cycles. The results of these tests established a limit value for the diameter of inclusions, below which they would not negatively affect fatigue at ultra-high cycles. Because the bending stress on the ring is dispersed around the entire circumference, as stated above there is a possibility of fractures originating in the inclusions, and therefore evaluation of the inclusions adds another level of reliability. Inclusions are normally evaluated by optic microscopy of the fracture surface^{(13), (14)}, but this method is limited in its powers of resolution. Ability to detect inclusions was therefore increased using the dissolution method. The solvent used was a 10% methanol bromide solution. 5 g of the material for evaluation was dissolved, and the inclusions trapped in the mesh after filtering were observed with an Scanning Electric Microscope (SEM). Fig. 20 shows an SEM photograph of an inclusion.

Depending on the size of the inclusion, the area of the projection surface affects fatigue, and the square root of the surface is generally utilized as a parameter in evaluating inclusions⁽¹⁰⁾. This development utilized the following equation to find d^* , the diameter of a circle with the same projection surface area, and used this as a parameter.

$$d^* = 2 \sqrt{\frac{ab}{\pi}} \quad (1)$$

Where a and b are the lengths of the long side and the short side of the inclusion respectively.

The filtered inclusions were all subjected to image processing and d^* was found for each. Fig. 21 is an extreme value statistical graph with plots of inclusion diameter d^* found through the dissolution-filtration method described above for steel K (the ring material used in the former belt) and steel L (the ring material used in the newly developed belt).

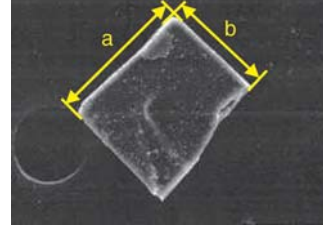


Fig. 20 SEM photograph of Ti (C, N) inclusion

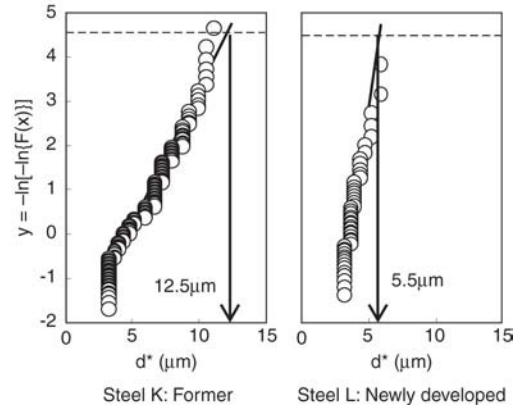


Fig. 21 Diameter distribution of non-metallic inclusions

As this graph shows, it is possible to predict the maximum diameter of the inclusions occurring in steel K and steel L using the bilateral exponential distribution⁽¹⁵⁾. To predict the maximum diameters it is necessary to establish the recurring section for the extreme value statistics, and given that the aim here was 99% certainty, the recurring section was set at $y = 4.6$. Reading the values at $y = 4.6$ from the graph, we find predictions of $12.5 \mu\text{m}$ and $5.5 \mu\text{m}$ for maximum diameter of inclusions in steel K and steel L respectively. By means of this sequential processing, it is possible to predict the maximum diameter of inclusions to a high degree of accuracy. Fatigue tests for these steels were conducted using ultrasonic fatigue test equipment. Stress during the tests was calculated using the results of measurements of displacement of one edge of the test piece using a whirlpool-type displacement meter⁽¹¹⁾. Fig. 22 shows an S-N diagram of test results. High-strength steels normally generate S-N diagrams with no fatigue limit in the ultra-high longevity area⁽⁹⁾⁻⁽¹¹⁾, and these test results demonstrate the same tendency. The results show that steel L has superior fatigue strength to steel K at 10^9 cycles. Furthermore, the results of SEM observation of the fatigue fracture surfaces show that all fractures in steel K are initiated at inclusions. Fig. 23 shows representative photographs.

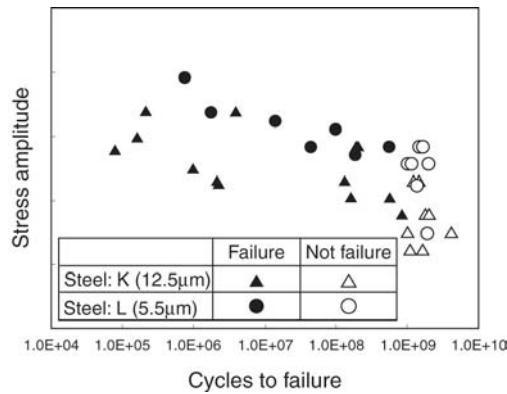
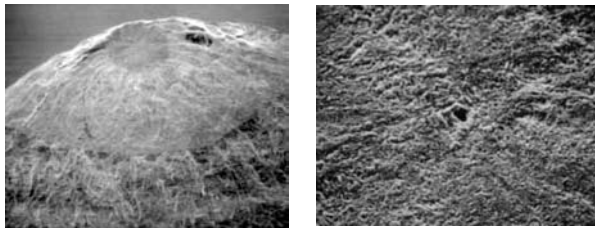


Fig. 22 S-N diagram by ultrasonic fatigue test



(a) Fracture face (b) Ti (C,N) at crack initiate point

Fig. 23 SEM photograph of fracture face

Analysis has confirmed the presence of Ti, and it has been demonstrated that the crystals are rectangular, so it is clear that Ti (N, C) inclusions initiate fractures. Observing the fatigue fracture surfaces for steel L with an SEM indicates that fractures originating on the surface and fractures initiated by inclusions both occur in this material. Whichever the initiate point, the S-N diagram shows the same longevity. It is clear, therefore, that if predictions of maximum inclusion diameter using extreme value statistics are 5.5 μm or less, as for steel L, it does not negatively affect fatigue longevity. Production process control was therefore initiated to control the diameter of inclusions in ring materials.

5.3.2. Heat treatment

After the ring materials have been welded into cylindrical shapes, they are cut and rolled into rings. The materials then go through solution heat treatment to achieve homogeneity of structure when rolled, correction processing (to supplement the circumference), and finally aging and nitriding to produce the finished ring. Conditions for solution heat treatment and aging have been considered optimum to produce the maximum hardness and stretching strength after final processing. However, because the most important characteristic for the rings used in metal pushing V-belts is fatigue strength under constant bending, it is necessary to optimize processing conditions from this perspective. High hardness is an important factor in fatigue characteristics, but the residual compression stress produced on the surface of the material by nitriding is more effective. Therefore conditions were optimized on the basis of the results of tests on the relationship between the residual surface stress produced by nitriding and heat treatment conditions. Residual surface stress was measured using X-ray analysis. The

relationship between the temperature for solution treatment directly after rolling and the residual stress on the surface of the material was investigated, and Charpy V-notch testing were used to determine the effect of solution temperature on tenacity. The results are shown in Fig. 24.

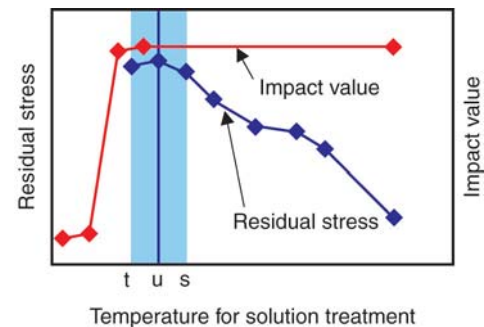


Fig. 24 Relationship between solution treatment condition and residual stress or Charpy impact value

It is clear from these results that residual stress varies with solution conditions, and that the maximum value of residual compression stress occurs below the temperature represented by point s on the diagram. The results of Charpy V-notch testing show that when solution temperature is low, residual work hardening causes tenacity to drop, with impact value dropping suddenly below the temperature represented by point t on the diagram. These results led to the temperature shown at point u in the diagram being selected as the solution heat treatment temperature allowing residual surface stress and tenacity to be balanced.

The newly developed rings and the former rings were put through fatigue tests using the rotational bending fatigue test apparatus shown in Fig. 25. Results are shown in Fig. 26, with tension as the load parameter for the vertical axis.

An example of a former ring which fractured at 10^4 – 10^5 cycles is shown in Fig. 27. As the Figure shows, a Ti (C, N) inclusion was the initiate point of the fracture. The newly developed rings, by contrast, did not fracture from inclusions, and demonstrated a 30% improvement in fatigue strength over the former rings in the 10^8 cycle ultra-high longevity area.

The results discussed above demonstrate that controlling the diameter of inclusions below the point at which they begin to affect fatigue longevity and optimizing heat treatment conditions has significantly increased fatigue strength.

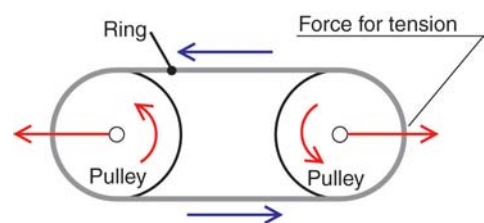


Fig. 25 Illustration of the ring fatigue test

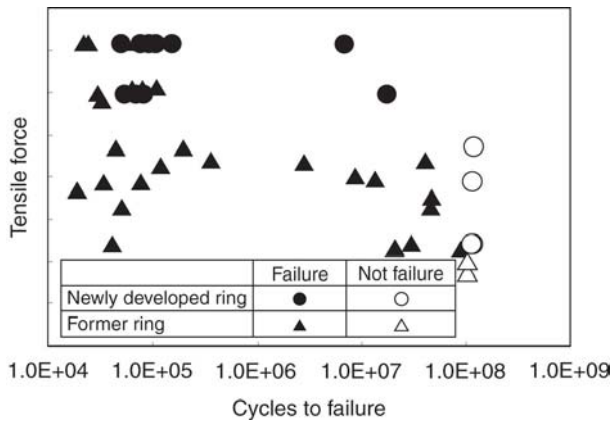


Fig. 26 Comparison of fatigue behavior in former and newly developed rings

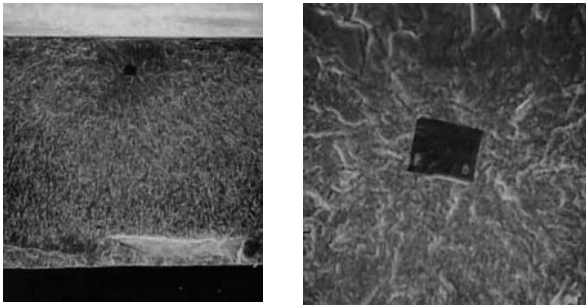


Fig. 27 SEM photograph of fracture face

6. Conclusion

Honda has developed and successfully mass-produced an original metal pushing V-belt for CVT. This development has made possible the reduction of minimum pitch radius for pulleys, reduced the load on the rings and increased fatigue strength. The newly developed metal pushing V-belt has the following characteristics:

- (1) Total clearance between elements has been fixed below a specified value. If total clearance between elements is too large, element and pulley slip velocity in the drive-side pulley suddenly increases, causing wear to the pulley V-surface.
- (2) The element V-surface has been shortened to increase the speed ratio range. The shorter V-surface has resulted in a reduction in pitching moment and stress on the rings in the pulley contact area.
- (3) Increased slot width and the establishment of an optimum range for nose-hole clearance has ensured that the nose and hole will make contact before the lower section of the ear and the ring, resulting in a reduction of stress operating on the ring.
- (4) Taking into account the significant effect of heat treatment of the elements (mainly quench time) and accuracy in formation of the nose and hole (mainly nose-hole contact position) on the fatigue strength of the nose and hole, treatment and formation have been optimized.
- (5) Dissolution in solution and extreme value statistical

analysis were combined as a method of evaluating inclusions in ring materials, enabling high-accuracy prediction of the maximum diameter of inclusions. Fatigue strength in the newly developed rings has been significantly increased by controlling the maximum diameter of inclusions to a size at which they do not affect fatigue strength.

- (6) The finding that residual compression stress on the surface of the ring changes with variations in solution conditions enabled the establishment of heat treatment conditions balanced with tenacity, leading to increased fatigue strength in the rings.

7. Afterword

The success of this development was based on research guidelines obtained from studying the existing belt mass-produced by Van Doorne's Transmissie, b.v. Theoretical studies of shape and further research in production technologies will be important factors in future evolution.

In conclusion, the authors would like to express their deep debt of gratitude to the many people who provided assistance in the course of this project, and to Van Doorne's Transmissie, b.v., for their understanding of Honda's intention to mass produce its own metal pushing V-belt.

References

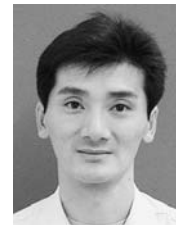
- (1) Osono, K., Aoki, T.: "Development of a Metal Pushing V-belt for an All-electronically-controlled CVT," HONDA R&D Technical Review, Vol. 8, pp. 21–33 (1996)
- (2) Hendriks, E., et al.: Aspects of a Metal Pushing V-Belt for Automotive Cut Application
- (3) Van Doorne's Transmissie, b.v.: Catalog
- (4) Kanehara, S., et al.: "Research on Pushing Block-type Metal Belt Transmission Mechanisms," HONDA R&D Technical Review, Vol. 7, pp. 49–67 (1995)
- (5) Yoshida, H.: "A Study of Forces Acting on Rings for Metal Pushing V-Belt Type CVT," SAE Paper 970686
- (6) Fujii, T., et al.: "Research on CVT Utilizing Metal Pushing V-Belt," JSAE Pre-publication Collection, No. 975, pp. 269–272 (October, 1997)
- (7) Saito, T., et al.: "Development of Stress Simulation Techniques for CVT Metal Pushing V-Belts," HONDA R&D Technical Review, Vol. 13, No. 1, pp. 125–130 (2001)
- (8) Emura, H., et al.: "Fatigue Strength Characteristics of High-strength Steel," Transactions of Japan Society of Mechanical Engineers, Vol. 55, No. 509, A, pp. 45–50 (1989)
- (9) Abe, T., et al., "Surface and Internal Fatigue Fractures in High-strength Steel," Spring Technology Association, 1998 Spring Lecture Series Collection, pp. 17–20 (1998)
- (10) Murakami, Y., et al.: "The Effect of Minute Defects and Inclusions on the Fatigue Strength of Maraging Steel," Transactions of Japan Society of Mechanical Engineers, Vol. 53, No. 492, A, pp. 1482–1491 (1987)

- (11) Ishii, H., et al.: "Evaluation of Longevity and Fatigue Strength of Steel Alloys Used in Mechanical Structures Using Ultrasonic Fatigue Testing," Transactions of Japan Society of Mechanical Engineers, Materials Division Lecture Series, pp. 591–592 (1999)
- (12) Ishii, H., Yagasaki, T., Akagi, H.: "Evaluation of giga-cycle fatigue properties of some maraging steels by intermittent ultrasonic fatigue testing," Proceedings of the International Conference on Fatigue in the Very High Cycle Regime, pp. 89–96 (2001)
- (13) Microscopic Testing Method for the Non-metallic Inclusions in Steel, JIS G 0555
- (14) Standard Practice for Determining the Inclusion Content of Steel, ASTM E 45
- (15) Shibata, T.: "Development of Extreme Value Statistics and Application to Materials Problems," Sanyo Technical Report, Vol. 3, No. 1, pp. 8–16 (1996)

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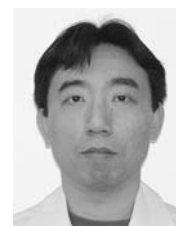
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