

A Configuration Evaluation Technique for CVT Metal Belt Rings

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ABSTRACT

A method for divided measurement of the lateral curvature of rings was developed for use in helping assure the quality of metal pushing V-belts for continuously variable transmissions (CVT). The method measures the lateral curvature without cutting the ring by dividing the full circumference into several partial segments that are measured separately. The data for the overlapping portions are cross-checked and the data starting point is then shifted over to calculate the peak-to-trough height automatically. The maximum quantity is taken as the lateral curvature for evaluation. The conventional method of lateral curvature measurement by cutting and expanding had shortcomings because that method could not be used for measurement prior to testing on actual transmissions and the lateral curvature varied depending on the point of cutting when measuring rings with points of curvature change. The present approach has resolved those issues.

1. Introduction

In 2001, Honda utilized original technologies to develop and mass-produce a metal belt for CVT. Details of the process of development and the specifications of this belt formed the subject of a previous paper in the *Honda R&D Technical Review*⁽¹⁾.

As shown in Fig. 1, the new metal belt is composed of elements and rings. The accuracy required in the production of these components is extremely high, even when compared to other automotive components, necessitating the development of new measurement methods to verify configuration. This paper provides an overview of the development of a new method for divided measurement of the lateral curvature of the rings utilized in these belts.

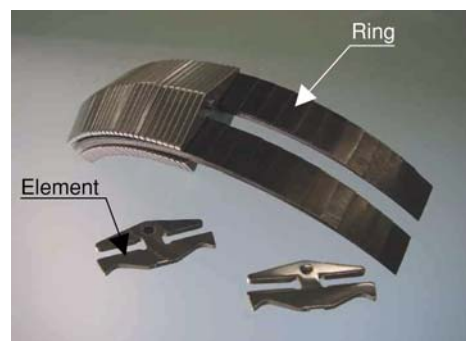


Fig. 1 Metal pushing V-belt

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2. Development Aims

2.1. Directional Lateral Curvature of Ring Circumference

An example of the rings used in the CVT metal belt is shown in Fig. 2. Each ring is constructed from a thin cylindrical metal plate and is 0.18 mm thick.



Fig. 2 Ring

In the finished belt the rings are assembled in two layers of multiple rings. The rings guide the elements onto the pulley in the sections of the belt wrapped around the pulleys and control the trajectory of the elements between the drive and driven pulleys. Figure 3 shows a cross-section of the ring and element assembly when wrapped around a pulley. When the belt is in operation the ring assembly is normally centered on the saddle surface from the innermost to the outermost rings maintaining the ring edges in approximate alignment. This ensures that multiple ring edges make contact simultaneously if contact occurs with the elements and the pulley V-surfaces reducing the load on each individual ring.

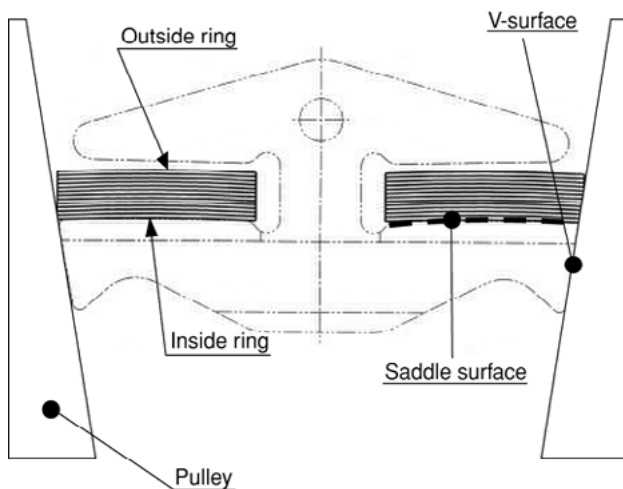


Fig. 3 Structure of V-belt assembly

However, as Fig. 4 shows, if deformed rings are included in the belt assembly the edges fall out of alignment with those of the cylindrical rings and protrude against the elements or the side of the pulley V-surface. When the metal belt is operated under these conditions the edges of the

deformed rings make contact more easily with the elements and the pulley V-surfaces than those of the circular rings. This causes strong sectional loads in the ring assembly and can lead to early breakdown of the belt. It is therefore essential to control the degree of deformation of the rings within prescribed limits in the production process.

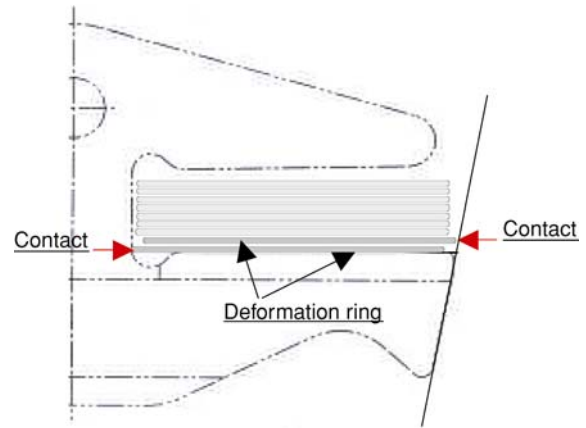


Fig. 4 Partial contact of ring assembly

Figure 5 shows the forms of normal and deformed rings and the shapes produced when they are cut and expanded. In Fig. 5, h , the degree of deviation from the straight line along the edge of an expanded circular ring, represents the lateral curvature of the ring. Figure 5(1) shows a ring with no deformation and therefore without lateral curvature. A ring that has a tapered deformation is shown in Fig. 5(2). When cut and expanded, this ring forms a U-shape. The ring shown in Fig. 5(3) has a parallel quadrilateral deformation producing an S-shape when cut and expanded.

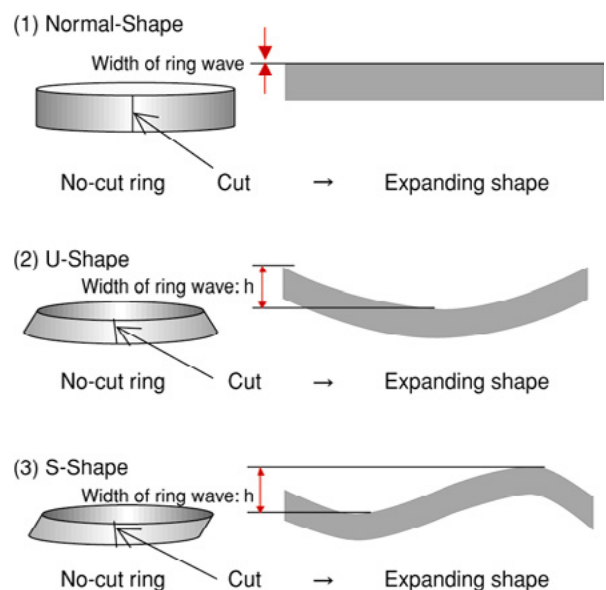


Fig. 5 Ring-wave

2.2. Conventional Measurement Method

Cutting and expanding the ring, as described above, is the conventional method for measurement of lateral curvature.

In this method, the rings are cut at an arbitrary point and expanded; the form of the resulting ring edge is measured, and the lateral curvature is found from the maximum deviation of the edge from a base point. Figure 6 shows an outline of the method.

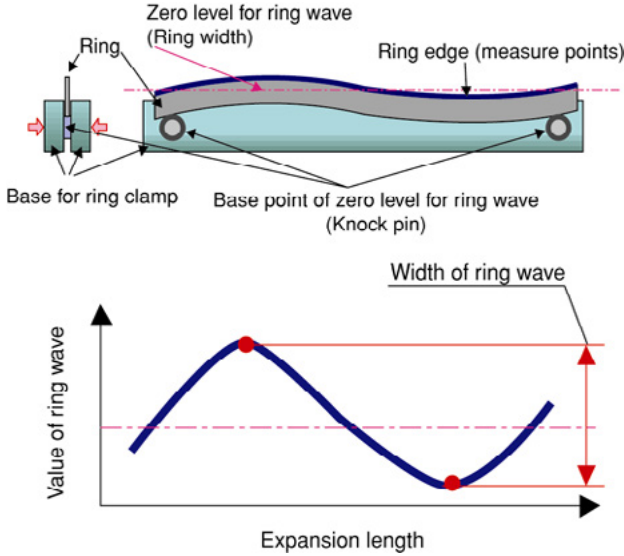


Fig. 6 Method for measurement of ring wave

The ring, after being cut and expanded is fixed in a ring clamp composed of two plates of approximately the same length as the circumference of the ring. When the ring is being fixed in the clamp, knock pins are put in place to hold the lower edge of the expanded ring on the base line for measurement. A cylindrical measuring probe is then used to trace the ring edge set in the clamp. The degree of wave of the ring edge is measured at fixed intervals and the values obtained at these points are plotted to reproduce the wave. Next, the amount of deviation of the reproduced wave from a straight line is determined over a fixed length and taken as the lateral curvature of the ring. However, because this method necessarily involves the destruction of the ring, it cannot, for example, be utilized to determine lateral curvature before a strength test. In addition, when the degree of lateral curvature of the ring changes at various points, measurements of lateral curvature differ with different starting points for measurement (the point at which the ring is cut).

Figure 7 shows a comparison of measurements of lateral curvature obtained from rings with various points of curvature change cut at different points. Figure 7 demonstrates that when rings are cut and expanded from the arbitrary points A-D around the circumference, the position of the points of curvature change differ. In addition, given this difference, the lateral curvatures h_1 , h_2 , h_3 and h_4 as measured over a fixed length also differ.

The aims for the development of a new measurement method for lateral curvature of CVT belt rings were therefore established as follows.

The measurement method should enable:

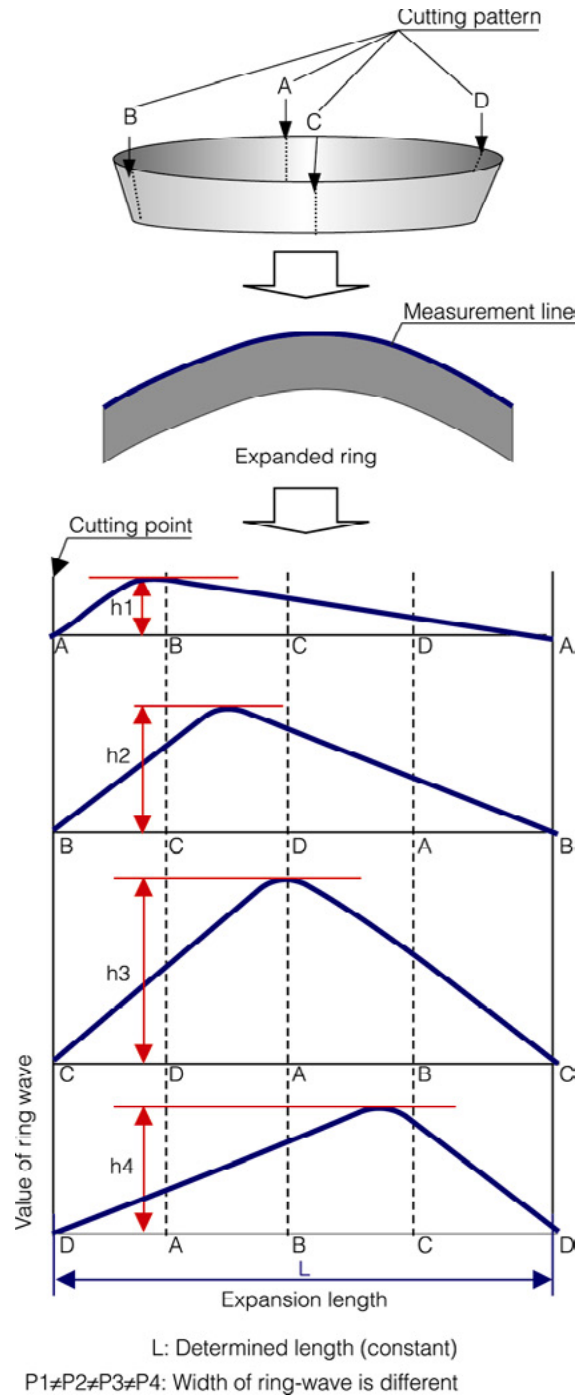


Fig. 7 Rings with points of extreme curvature change

- (1) Measurement of any type of lateral curvature without cutting; and
- (2) Accurate measurement of lateral curvature of rings with points of curvature change.

3. New Measurement Method

3.1. Divided Measurement of Lateral Curvature

Figure 8 shows a schematic of the new method and gives an outline of the basic principles used to solve the drawbacks of the conventional cutting and expansion method.

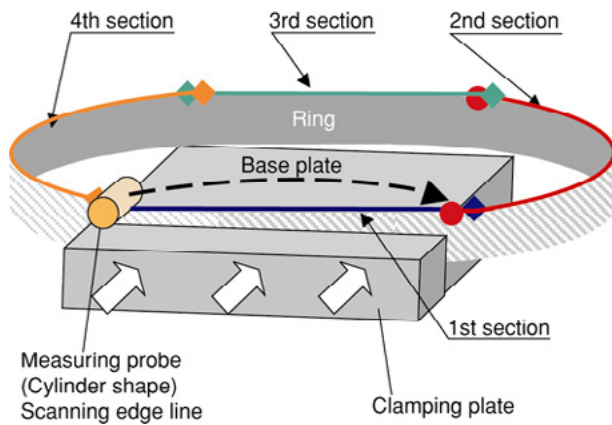


Fig. 8 Improved method (requires no cutting)

The ring clamp utilized in the divided measurement method is shorter than that used in the conventional method making it possible to position the clamp base plate against the inner circumference of the ring. The ring is fixed in the clamp at a specified clamping force. When the ring is clamped, the lower edge is placed against knock pins set at the base line for measurement. Next, a cylindrical measurement probe traces the ring edge fixed in the clamp and the amount of deviation from the base line is measured at fixed intervals along the circumference. The ring is then released from the clamp and moved enabling deviation from the base line to be measured in another segment. The starting point for measurement in this section is a point at approximately four-fifths the length of the first section, meaning that measurements overlap. Measurement proceeds in this way by dividing the overall circumference of the ring into several overlapping segments. The data for the overlapping sections is then cross-checked and a straight line drawn between the starting and finishing points. The maximum deviation occurring at a right angle to this line is taken as the lateral curvature for evaluation. Figure 9 shows a model of the procedure of cross-checking data for the overlapping sections in the divided measurement method.

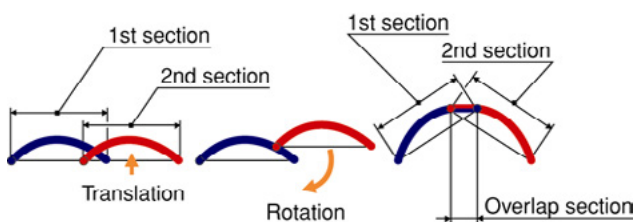


Fig. 9 Method for data overlapping

As previously discussed, measurements of lateral curvature taken using the cutting and expansion method differed depending on the point at which the ring was cut. This effect does not occur in the newly developed method because the starting point for evaluation of the combined data is shifted at fixed intervals over the circumference of the ring and the maximum deviation from the baseline that is calculated from this data is taken as the lateral curvature of the ring.

Figure 10 shows an image of this method.

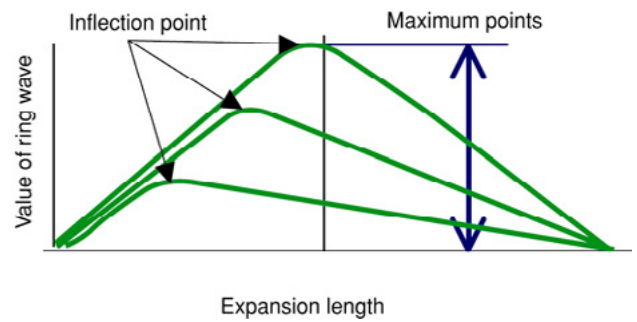


Fig. 10 Method for defining curvature

3.2. Verification of Reliability

Tests were conducted to determine the reliability of the results obtained for degree and form of lateral curvature by the combination of data obtained in various segments using the new method against the results obtained using the cutting and expansion method. These tests were conducted on a sample of 50 rings and involved comparison of measurement results obtained from both methods when identical starting points were used for measurements.

Figure 11 shows the results of these reliability tests as a scatter diagram.

The vertical axis shows results obtained using the divided measurement method and the horizontal axis shows results from the cutting and expansion method. The new method shows high reliability with a coefficient of correlation of 0.974.

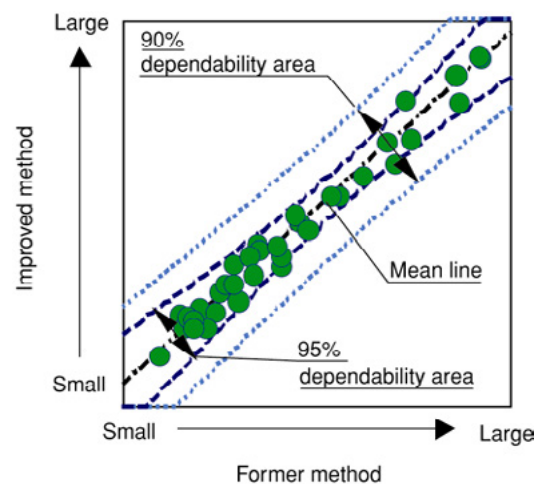


Fig. 11 Scatter diagram comparing measurement methods

Figure 12 shows a comparison of the configurations of curves obtained using the two methods.

Solid lines represent results obtained from the cutting and expansion method, and broken lines results from the divided measurement method. Both methods reproduce extremely similar configurations of curvature demonstrating the ability of the method of overlapping and combining data to provide an accurate rendering of the configuration.

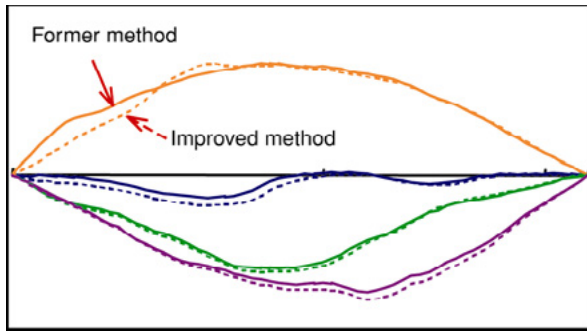


Fig. 12 Comparison of configurations generated by different measurement methods

4. Use in Mass Production

Figure 13 shows a machine for high-speed automatic measurement of the lateral curvature of rings that applies the principles discussed in this paper.

As Fig. 14 shows, when a ring is placed in this machine it undergoes the following operations:

- Operation 1: Clamping
- Operation 2: Measurement
- Operation 3: Unclamping
- Operation 4: Moving
- Operation 5: Reclamping.

Figure 15 shows the procedures the system automatically applies to the data obtained from measurements:

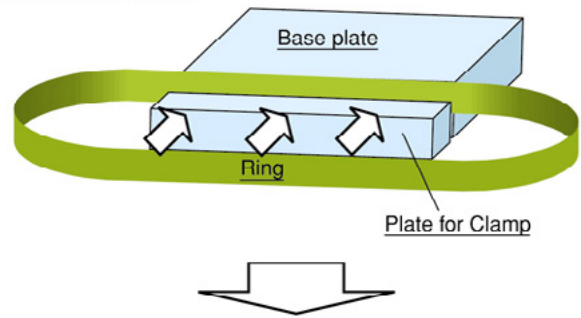
- Procedure 1: Collation of divided measurement data
- Procedure 2: Combination of data obtained from over-lapping sections to reproduce configuration of lateral curvature
- Procedure 3: Shift of starting point to calculate degree of lateral curvature.

The significant reduction in the number of procedures involved in measurement achieved by this system has enabled it to be utilized in mass production quality control.

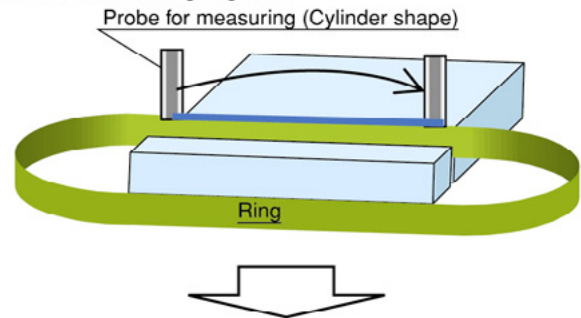


Fig. 13 Machine for automatic ring curvature measurement
[Made by: Honda Engineering CO., LTD.]

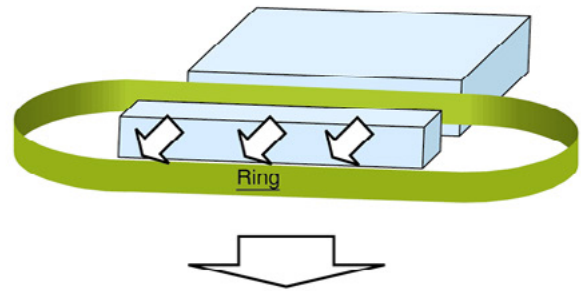
Operation 1: Clamping



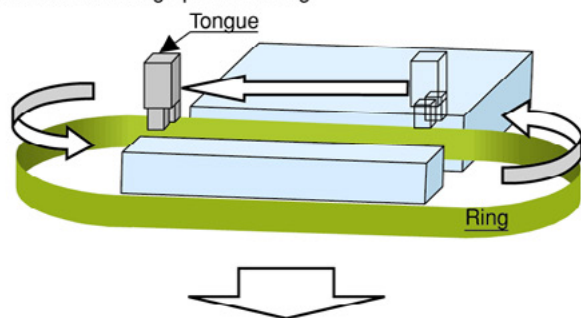
Operation 2: Measuring edge line



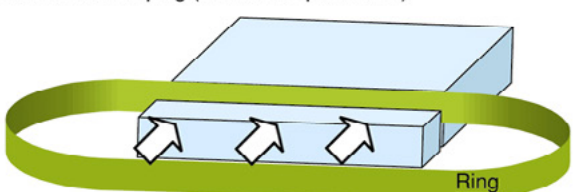
Operation 3: Disengaging from clamp



Operation 4: Picking up and moving



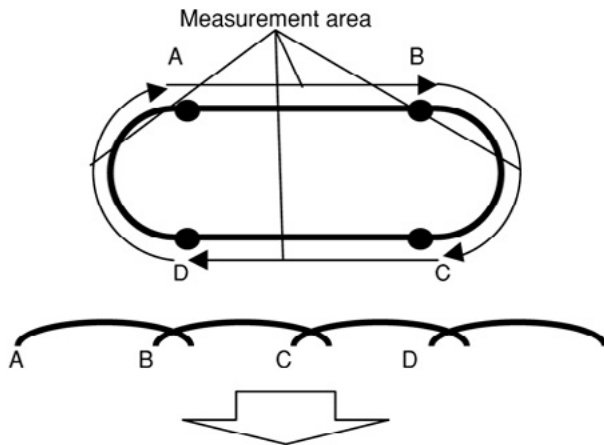
Operation 5: Clamping (Return to operation 1)



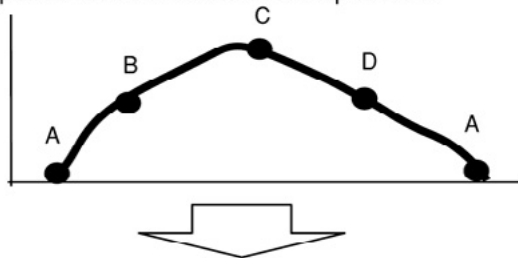
* One process is from operation 1 to 5, and it is performed several times.

Fig. 14 Conceptual image of operation machine for automatic curvature measurement

Computation 1: Configuration data of measurement result



Computation 2: Combination of overlap sections



Computation 3: Defining maximum width of ring wave

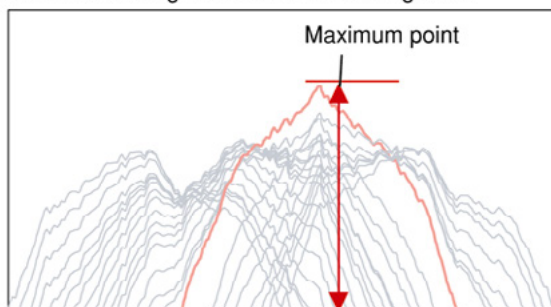


Fig. 15 Image of automatic machine process of computation

5. Conclusion

Honda R&D has developed a method for more accurately measuring the lateral curvature of rings utilized in metal pushing belts for CVT, a factor directly affecting the durability and life of these belts. The salient characteristics of this method are as follows:

1. The method enables measurement over the entire circumference of the ring without cutting, by dividing the circumference into overlapping segments. This makes it possible to apply this method before strength tests.
2. In the conventional cutting and expansion measurement method, values obtained for curvature differ for the same ring depending on the relative positions of the starting point for measurement and points of curvature change making accurate evaluation less possible. Calculations in the newly developed divided measurement method are made on the basis of new starting points for each measurement segment and the maximum value for curvature over the entire circumference is taken as the measured lateral curvature enabling a more accurate evaluation.

6. Afterword

Deformation of components affects the performance of the metal pushing belts utilized in CVT. To provide more accurate measurement of the form of these components, in addition to the ring curvature measurement method discussed in this paper, Honda R&D has developed an original technique for the evaluation of deformation in belt elements.

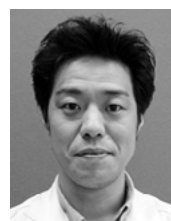
Research into the ideal form of components and the ability to evaluate production consistency in relation to that ideal is important to the future evolution of metal pushing belts for CVT. The authors will continue their efforts to advance technologies for evaluation of components and enhancing their performance.

In closing, the authors would like to offer their sincere thanks to all who contributed to the success of this development project.

7. References

- (1) Yagasaki, T., et al.: Development of Metal Pushing V-Belt for Continuously Variable Transmission, Honda R&D Technical Review, Vol. 14, No. 1, pp. 181-190 (2002)
- (2) Patent Application 2000-70230: Method and equipment for measurement of curvature of thin metal rings and method of production

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