

Application of Metal Pushing V-Belt Stress Simulation with CVT Pulley Stiffness

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ABSTRACT

A simulation method was developed allowing simultaneous evaluation of dynamic behavior and ring stress for the estimation of the durability of metal pushing V-belts for CVT's. The high rotational speed range of the CVT is simulated utilizing the finite element method used in crash analysis. This paper focuses on dynamic behavior of the pulley, and the simulation method, which was modified to allow the pulley stiffness to be reflected. The pulley stiffness values are found by applying static loading to the three-dimensional FEM model. As a result, it is found that the flexional stiffness affects the ring impact stress at the pulley entrance and exit. Furthermore, the mechanism of contact between the ring edge and pulley surface or the element due to the ring misalignment caused by the pulley flexion is clarified. For the first time, these results make it possible to obtain design guidelines for the pulley stiffness that includes consideration of belt durability.

1. Introduction

The increasing demands for additional environmental compliance by automobiles have caused manufacturers to turn their attention to the continuously variable transmission (CVT) as a transmission technology that simultaneously achieves improvement in both performance and fuel economy. CVT performance is characterized by quietness and smooth acceleration without shift shocks, while it achieves fuel economy superior to that of other automatic transmissions by using integrated control with the engine to maintain a rotational speed range with high combustion efficiency. As the need to increase the transmission capacity of the CVT continues to rise, however, it has also become essential to realize the contradictory goal of reducing the weight of the CVT. As the belt and pulley assembly accounts

for a major proportion of CVT weight, the issue will be how to assure durability of this assembly while making it lighter in weight. This paper describes the modification of our previously reported technique for simulation of metal belt behavior and stress⁽¹⁾ to give it the capability to account for pulley flexional stiffness. This has made it possible for the first time to define the influence of pulley flexional stiffness on belt strength, and this result is also reported here.

2. Development Aims

Fig. 1 shows the main section of the CVT used in this project. The driving torque is shifted and transmitted from the drive pulley to the driven pulley by a metal belt.^{(2), (3)}

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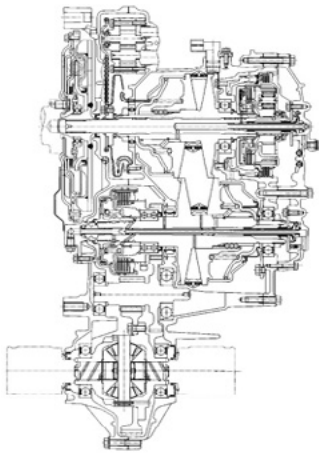


Fig. 1 CVT main section

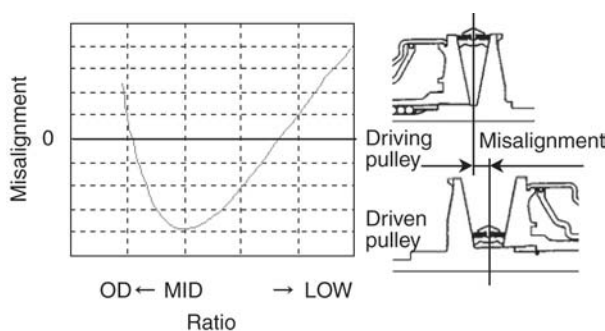


Fig. 2 Belt misalignment variation by ratio

When the metal belt wrapped around the drive pulley and driven pulley is in operation, its center does not move within a single plane, but rather displays a slight out-of-plane movement. This out-of-plane displacement of the metal belt is termed misalignment. Durability tests have shown that greater misalignment reduces the life of the metal belt. This misalignment is not reduced to zero even when the pulleys are defined as rigid bodies (Fig. 2), and the amount of misalignment is determined by the distance between the pulley axes and the transmission ratio.

Furthermore, the rigidity of the actual pulleys is limited, so it is crucial to take their deformation into account when considering misalignment.⁽⁴⁾ As things presently stand, however, the relationship between the amount of misalignment during CVT operation and the strength of the metal belt is not sufficiently established.

Given the above, the development aims were defined as follows:

- (1) To clarify misalignment during CVT operation and
- (2) To explain the influence of pulley rigidity on belt strength.

3. Misalignment

3.1. Misalignment during CVT Operation

Due to the difficulty of measuring belt alignment during operation, the first step taken was to use previously reported simulation methods to study this behavior.⁽¹⁾ Fig. 3 shows the analysis model used for the simulation. The model was simplified to use 280 elements and three rings in each layer in order to reduce the computation time, as the objective in this case was to determine the influence of pulley rigidity.

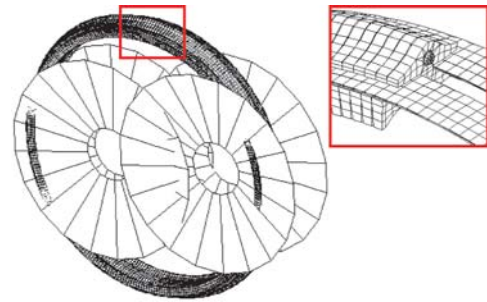


Fig. 3 Metal pushing V-belt Model

Both the drive pulley and the driven pulley were defined here as rigid bodies, and the pulley deflection was not taken into account. The initial condition was set for only a specified amount of misalignment. Points a, b, c, and d in Fig. 4 represent boundary points on the belt track, while DR is the section b-c wrapped around the drive pulley and DN is the section d-a wrapped around the driven pulley. With this arrangement, the misalignment of an element is a fixed value in the sections wrapped around the drive pulley and the driven pulley, and the element displays a sudden change in behavior immediately before the drive pulley entrance. The alignment reference value of zero designates the center of the belt around the opposing side of the pulley on the driven side.

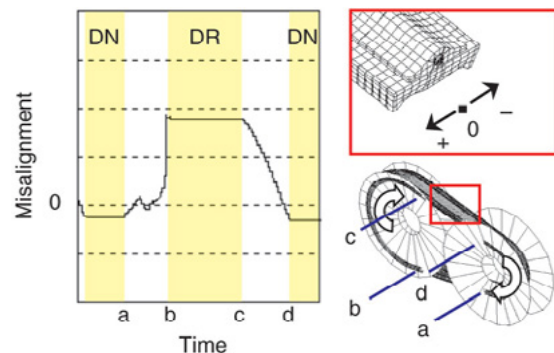


Fig. 4 Misalignment of element

Meanwhile, as shown in Fig. 5, misalignment of the left and right rings differs from misalignment of the elements. The ring moves smoothly over the saddle surface while maintaining a constant relative speed differential.

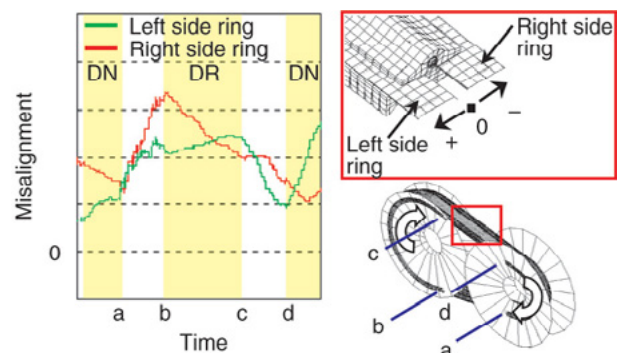


Fig. 5 Misalignment of rings

3.2. The Influence of Ring Stress

Fig. 6 shows the stress waveform for the left and right side ring edges at this time. It is apparent that the rings are influenced by the misalignment of the elements, so that the left and right side rings display different stress conditions. The ring edges show even greater stress.

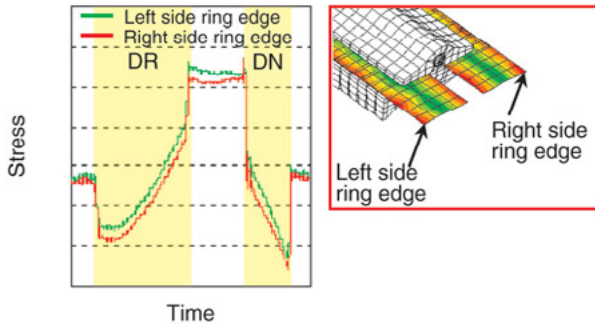


Fig. 6 Ring stress distribution

4. Pulley Flexional Stiffness

4.1. Pulley Rigidity and Misalignment

In order to investigate the influence of pulley rigidity, the next step was to insert rotational springs (Fig. 7) representing pulley flexional stiffness as an addition to the previously-reported simulation model.⁽¹⁾ The flexional stiffness was calculated by creating a three-dimensional finite element (FEM) model of the pulley and applying a belt load statically. The pulley displayed deformation in both radial and circumferential directions according to its rigidity. The greatest flexional deformation, however, was in the radial direction. Consequently, attention was focused solely on pulley deflection.

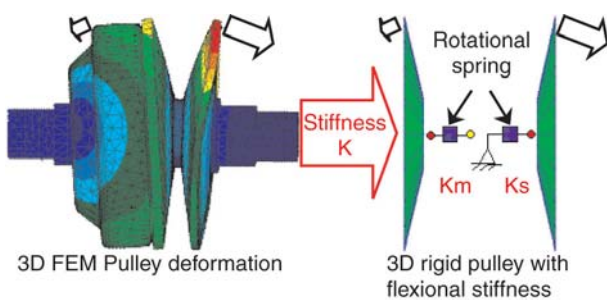


Fig. 7 Analysis model

Fig. 8 shows element misalignment with reference to flexional stiffness. The pulley rigidity here only takes into account the drive side, where deflection is greatest. Different values are set for the left and right sides of the pulley, since the left and right of the pulley section ordinarily differ in shape. It is apparent that, as a result, the amount of misalignment when the belt is wrapped around the drive pulley is greater than it was with the rigid pulley above.

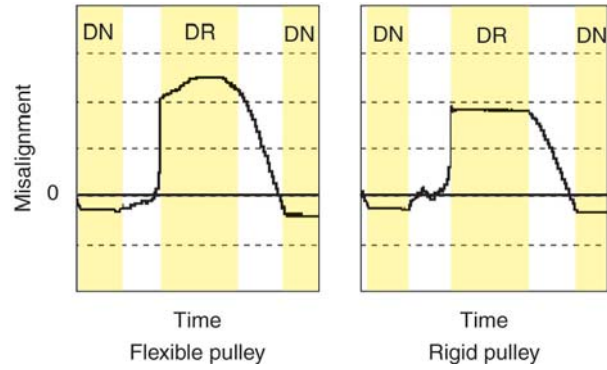


Fig. 8 Influence of flexibility on misalignment

4.2. Parameter Study of Pulley Rigidity

The next step was to examine how ring stress changes under the effect of pulley rigidity. Fig. 9 shows the combinations of left and right pulley rigidity values in p through u as used in the parameter study.

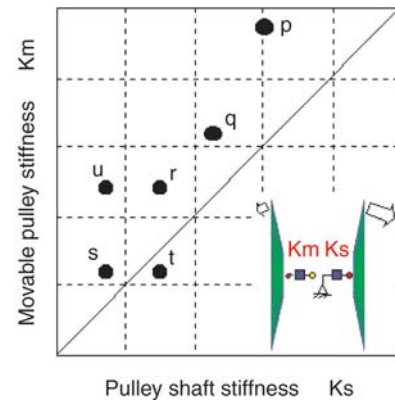


Fig. 9 Pulley stiffness used in parameter study

4.2.1. Absolute value of pulley rigidity

When only the absolute value is changed and the ratio of left and right pulley rigidity is kept the same, then the stress amplitude in the ring increases as the rigidity is raised. Points A, B, C, and D in Fig. 10 represent locations in the lateral direction on the ring. The maximum values for stress in the circumferential direction are plotted.

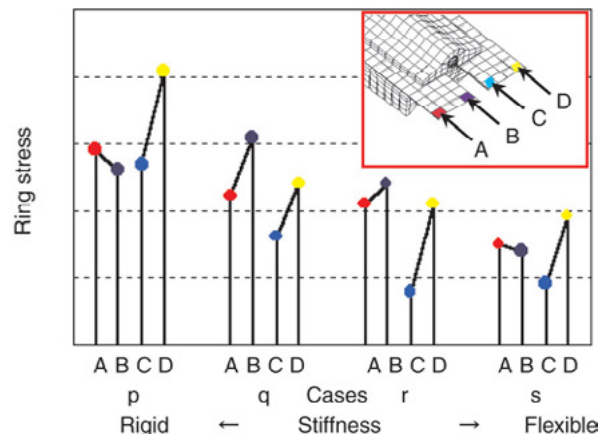


Fig. 10 Ring stress distribution by absolute values for stiffness

Fig. 11 shows the ring stress waveform for the rigidity combinations p and s. The rigidity value is higher in p than in s, and it is apparent the stress amplitude increases at the pulley entrance and exit.

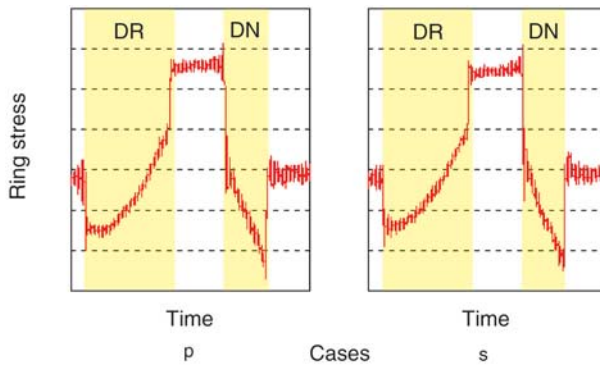


Fig. 11 Ring stresses difference

It is conceivable that this is the result of ring stress caused by the increased impact load on the V-surface of the element at the pulley entrance when the flexional stiffness is high (Fig. 12).

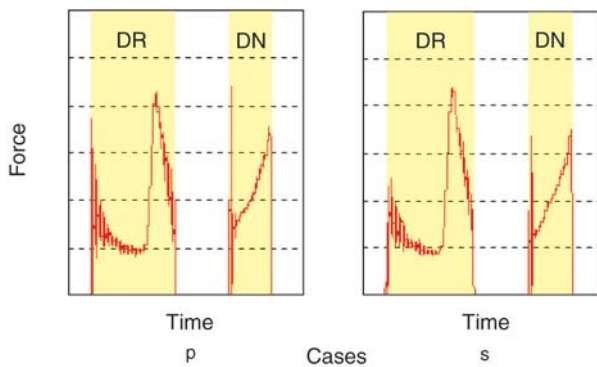


Fig. 12 Element normal force on V-surface

4.2.2. Pulley rigidity ratio

For the next step, Fig. 13 shows the stress amplitude in the rings when the ratio of rigidity on the left and right sides of the pulley is changed.

It is apparent that, although some change occurs in the stress amplitude, the extent of its influence is slight.

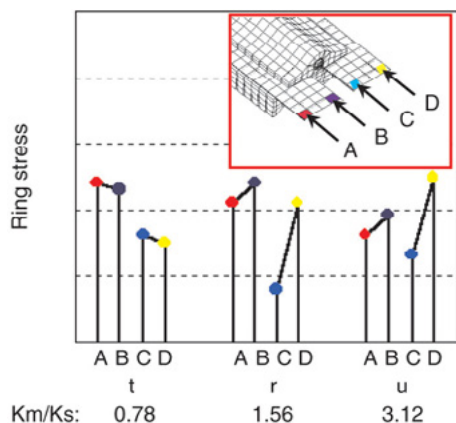


Fig. 13 Ring stress distribution by stiffness

However, the pulley rigidity ratio does have a direct effect on the relative alignment location of elements and rings. In the case of pulley rigidity t, for example, the difference in clearance between the element and ring edge during a single belt cycle is shown in Fig. 14.

The relative clearance between the element and ring inside the drive pulley has decreased, and there is reason for concern about edge contact.

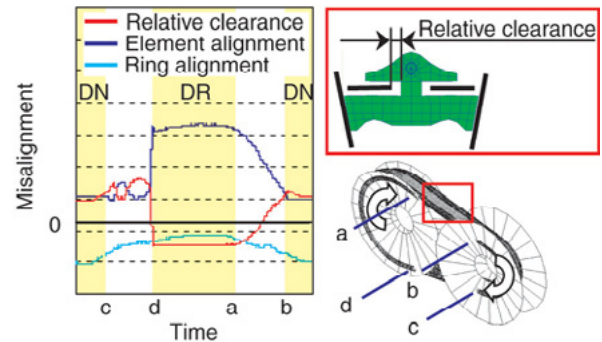


Fig. 14 Relative clearance between element and ring

Similarly, Fig. 15 shows the ring edge clearance with a different left-right pulley rigidity ratio. E and H are the clearances between the left and right ring edges and the pulley, while F and G are the clearances between the left and right ring edges and the element neck.

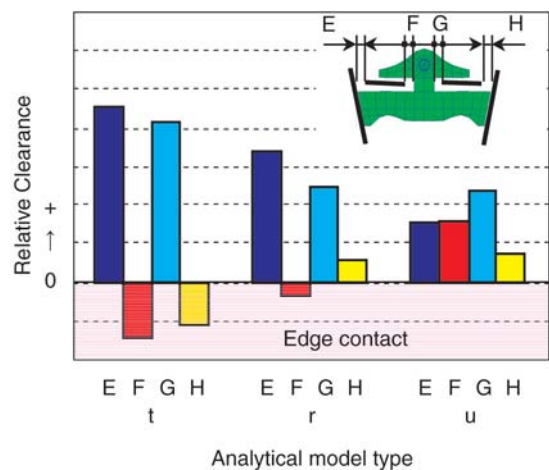


Fig. 15 Ring edge contact by stiffness

This means, in other words, that the clearance between the ring edge and the pulley or the element neck is decreased by the rigidity ratio, and as a result, ring edge contact occurs more frequently during CVT operation. When such contact occurs, there is reason for concern about damage from ring edge wear and other such factors due to the relative speed differential between the ring and the pulley, or the ring and the element. Consequently, it is important to pay careful attention to the amount of misalignment when deciding the pulley rigidity ratio.

5. Conclusion

Analysis of the influence of pulley rigidity on belt misalignment and on the ring stress that occurs with misalignment yielded the following information.

- (1) Raising the pulley flexional stiffness contributes to ring impact stress at the pulley entrance and exit, which increases the stress amplitude.
- (2) The ratio of left and right pulley rigidity has little influence on ring stress amplitude. There are cases, however, when changes in misalignment due to the rigidity ratio cause ring edge contact to occur.
- (3) Given the above, it is necessary to pay careful attention to ring impact stress and edge contact when determining pulley specifications that allow for belt durability.

6. Acknowledgements

As the belt and pulley assembly accounts for a major proportion of CVT weight, the demand for weight reduction will be never-ending. When determining the basic CVT framework, therefore, it is a matter of great significance if pulley rigidity, which is needed for drive power transmission, can be clarified in terms of belt durability.

In conclusion, the authors would like to express their deepest appreciation to the parties concerned at Hibbitt, Karlsson & Sorensen, Inc. for their great cooperation in improving solvers during the course of development of this simulation.

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