

# Strain Analysis of Belt Element-Pulley Interaction of an Automobile CVT under Actual Vehicle Speed Condition

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## ABSTRACT

In order to improve shift response, durability and transmission efficiency of the CVT system, it is essential to precisely understand the behavior of individual belt elements. Although there have been some previous works measuring the strain or load on belt elements, they have been performed for speed ranges that are far below actual vehicle operation speeds due to limits in measurement techniques. We therefore developed measurement equipment that can be fitted on a CVT belt to enable measurement during actual CVT operation, and obtained the strain on belt elements under transient conditions including acceleration and transmission ratio shifts. The results showed that the strain peaks due to normal force on V faces of elements around the entrance and/or exit of the pulleys. The bending component of the strain fluctuated on the straight section from the secondary pulley to the primary pulley. The results of a finite element method analysis indicated that the compression forces between elements acted on rocking edges unequally, which was determined by the entering the behavior of belt elements on the pulley. These results demonstrate that our unique method makes it possible to obtain an understanding of a phenomenon that was not previously verifiable under the conditions of actual CVT operation.

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## INTRODUCTION

The growing demand for fuel efficiency for automobile transmissions has increased the share of CVTs in several regions of the world [1] since the structure of CVT belt converged to metal pushing V-belt in which V-elements are strung together by 2 sets of thin metal bands from a perspective of production costs, noise reduction, and durability [2]. In order to achieve further improvement in the efficiency, durability and downsizing of CVTs, it is important to accurately obtain physical interactions between variator components and stress distribution inside them during transient conditions such as start-up, ratio change and fluctuation of load. Kanehara et al. [3] experimentally obtained six force components acting on an element using strain gauges and a telemeter system under various operating conditions. The results demonstrated the elements' behavior in detail, such as the fact that the ring adheres to the block around a large pitch pulley, whereas the saddle surface of the block in the smaller pulley always moves ahead of the ring. However, the measurements were implemented at a considerably low speed range that actual vehicle don't generally use. On pulley side, surface interaction with the belt was measured at higher speed ranges using a thin film pressure sensor coated on the pulley sheave and a stand-alone miniature data logger [4], even though the transmission ratio was limited to a constant. There are no cases that have measured physical interactions on belt elements and pulleys under the conditions of actual vehicle operation. By contrast, the FEM simulation has predicted some characteristic

behavior of variator components. Saito [5] simulated the behavior of belt elements at start-up conditions and demonstrated that a belt element displays concave bending around the exit of the driving pulley, which leads to different stress on its front and rear neck surfaces. Such results must be experimentally verified.

In this study, the authors measured strain fluctuation on a belt element under actual vehicle CVT operating conditions including acceleration and CVT ratio change. In addition, the results were subjected to FEM calculations to examine loads acting on single elements and subsequent deformations.

## EXPERIMENTAL METHODS

Forces acting on the elements of a push belt CVT can be separated, as shown in [Figure 1](#). This study focused on normal forces acting between the V-surface of the belt elements and pulleys, the compressive force between the belt elements and the frictional forces on the elements' V-surface. Two strain gauges were attached below rocking edge on the front and the rear surfaces as shown in [Figure 2](#), and these gauges were sensitive to the above force components.

In order to separate strain variations in the measurement results into different components related to each force component, strain data on normal force on V-surface and compressive force toward running

direction of the belt were individually confirmed before measurements. Figure 3 (a) shows the former and Figure 3 (b) shows the latter relation. The force corresponding to the horizontal axis in Figure 3 (b) was generated by the concentrated load on the center of the rocking edge, constraining the running movement of the V-surface without normal force. The strain on gauges No. 1 and No. 2 indicated a negatively linear relation to the normal load on the V-surface, and the ratio of these values was 1:1.3. In addition, gauges No. 1 and No. 2 showed a linear relation, with the opposite sign to the compressive force acting on the running direction. The ratio of these absolute values was 1:1.2. It is assumed that the strain measured with gauges No. 1 and No. 2 can be separated into strains due to two individual load components with these relationships.

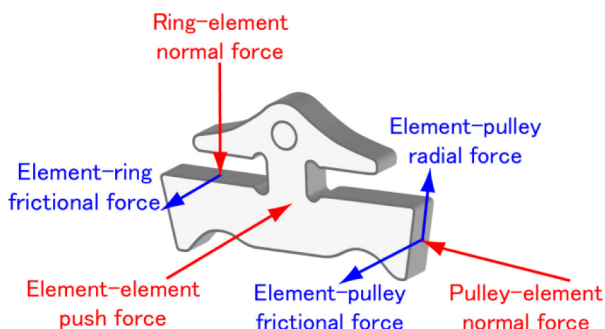


Figure 1. Forces acting on the elements of a push belt

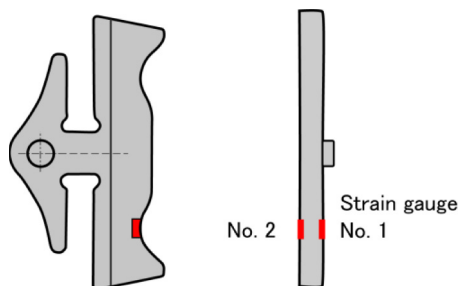
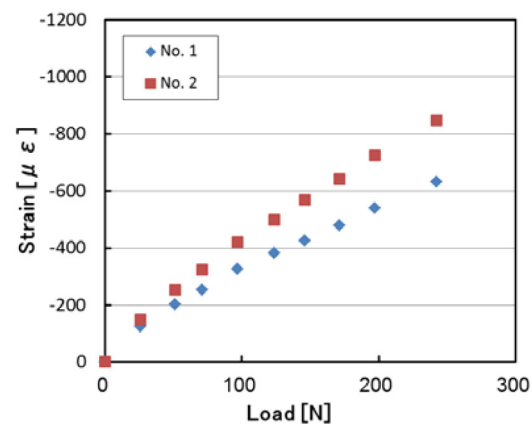
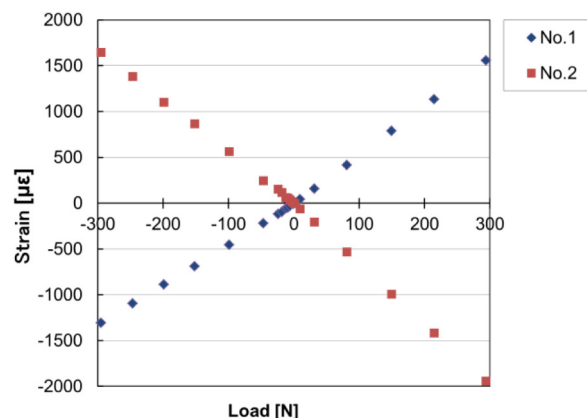


Figure 2. Positions of the strain gauges on an element



a. Strain variations in V-surface normal load



b. Strain variations in the load onto running direction

Figure 3. Sensitivity to the strain gauges for individual load components

In order to measure the strain of the element while the belt rotates quickly, changing its trajectory continuously, a miniature data logger that had been developed uniquely [4] was used. Figures 4 and 5 show the diagram and the appearance of the measurement method, respectively. The logger was installed on a belt element apart from the one with the strain gauges. The fixation structure of the logger was optimized using FEM analysis to register as fewer disturbances in the behavior of the belt as possible.

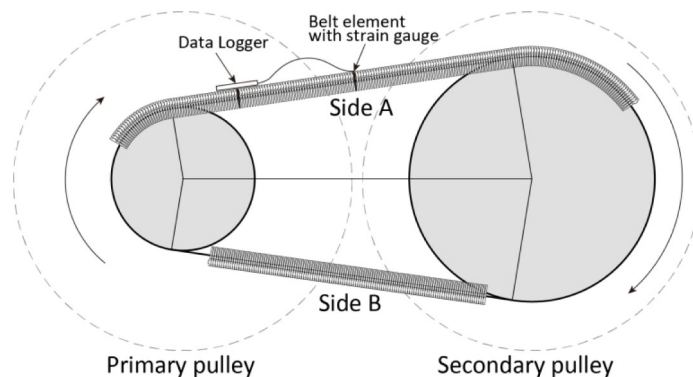


Figure 4. Diagram of the miniature data logger and the element with strain gauges installed on a CVT belt

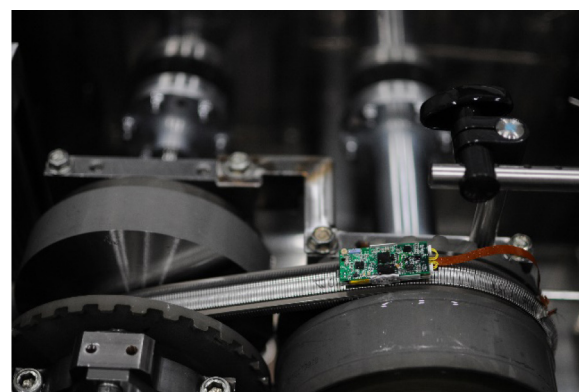


Figure 5. Appearance of the logger and wiring