# Countermeasure against black scale residue by defining conditions for detecting the groove for start of machining of roller grooves on CVT pulleys

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**Summary**

The fixed secondary pulley half of a continuously variable transmission (CVT) for vehicle use has three grooves called roller grooves for sliding the movable pulley half smoothly in the axial direction. In the initial period following production launch, a black scale residue occurred on one side of some of the roller grooves, causing a chronic problem.

This article describes a study conducted to visualize and validate the effect of the machining allowance on the positional relationship between shaft outer diameter runout and roller grooves. Detection of roller groove positions and newly measured values of shaft outer diameter runout were combined to create a countermeasure for resolving the occurrence of the black scale residue.

## 1. Introduction

A black scale residue on the roller grooves of the fixed half of the secondary pulley refers to an unmachined material that remains because grinding cannot be done owing to unbalanced or absence of machining allowance on the right and left shoulders of the roller grooves due to outer diameter runout of the workpiece shaft. A black scale residue can occur even if the split angle, curve (R), contact angle and over ball diameter (OBD) of the three grooves are machined completely within the standard.

## 2. Overview of black scale residue on roller grooves

### 2.1 Outline of pulley machining processes and roller groove machining

The black scale residue on the fixed secondary pulley half and the pulley machining processes are shown in Figs. 1-1 and 1-2, respectively.

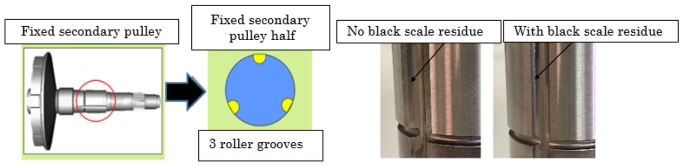


**Fig. 1-1 Diagram of fixed secondary pulley half and appearance of black scale residue**

After raw material machining, heat treatment and curve correction, center hole correction is performed as the first process of finishing machining. Roller grooves are ground in a subsequent process.

In the roller groove grinding process, the roller grooves on the shaft outer circumference are detected with a proximity indexing sensor. The center of the roller grooves is determined and the first groove is machined.

The remaining two groves to be machined are executed at 120° divisions from the position of the first groove (Fig. 2). Because the position of the grooves may be misaligned relative to the position of the grinding wheel, the machining allowance becomes unbalanced, causing unmachined scale to remain.

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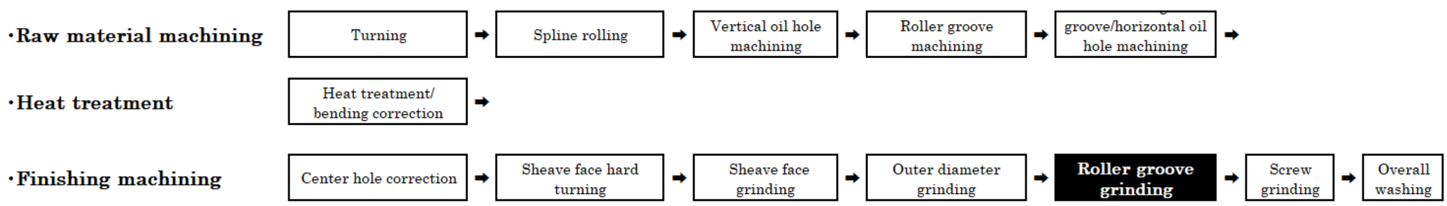



**Fig. 1-2 Diagram of machining processes**

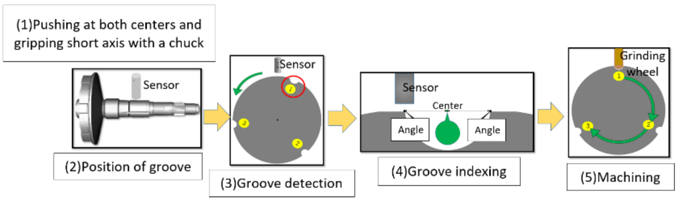



**Fig. 2 Indexing motion for machining roller grooves**

### 2.2 Relationship between workpiece outer diameter runout and black scale residue on roller grooves

Shaft outer diameter runout was investigated for workpieces that displayed the black scale residue on the roller grooves. The results revealed that the defect rate was 90% or more for workpieces with large runout.

A test was conducted to reproduce the black scale residue for workpieces displaying large shaft outer diameter runout. It was found that there were workpieces on which the black scale residue occurred and those where it did not occur.

### 2.3 Relationship of eccentricity between machine center and workpiece center

It was found that workpieces displaying the black scale residue had the following characteristics (Fig. 3).

(1) Large shaft outer diameter runout.

(2) The phase of the maximum convex portion or minimum concave portion of shaft diameter runout was close to the phase of the roller groove position.

(3) Eccentricity was caused by the effects of heat treatment distortion and the center correction performed in the first finishing process.

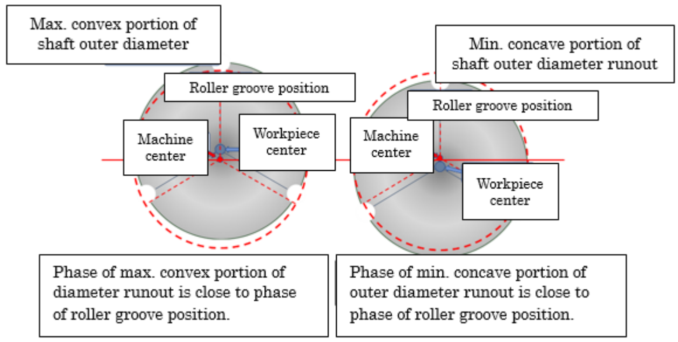



**Fig. 3 Positional relationship between shaft outer diameter runout and roller groove**

Figure 4 shows the results of the investigation of workpieces for which the phase of the maximum convex portion of shaft outer diameter runout and the phase of the roller groove position were close. Designating the groove where the phases were close as the 0-deg. groove, grooves were defined as the 120-deg. groove and the 240-deg. groove in the clockwise direction.

- The black scale residue did not occur on workpieces machined from the 0-deg. groove, as shown in the top row in the figure.
- The black scale residue occurred at the 240-deg. groove for workpieces machined from the 120-deg groove, as shown in the middle row in the figure.
- The black scale residue occurred at the 120-deg. groove for workpieces machined from the 240-deg. groove, as shown in the bottom row in the figure.

For workpieces displaying the black scale residue, eccentricity occurred between the workpiece center position and the machine center position owing to the effect of outer diameter runout of the workpiece shaft. In cases where the position of the phase of the maximum convex portion or the minimum concave portion of the

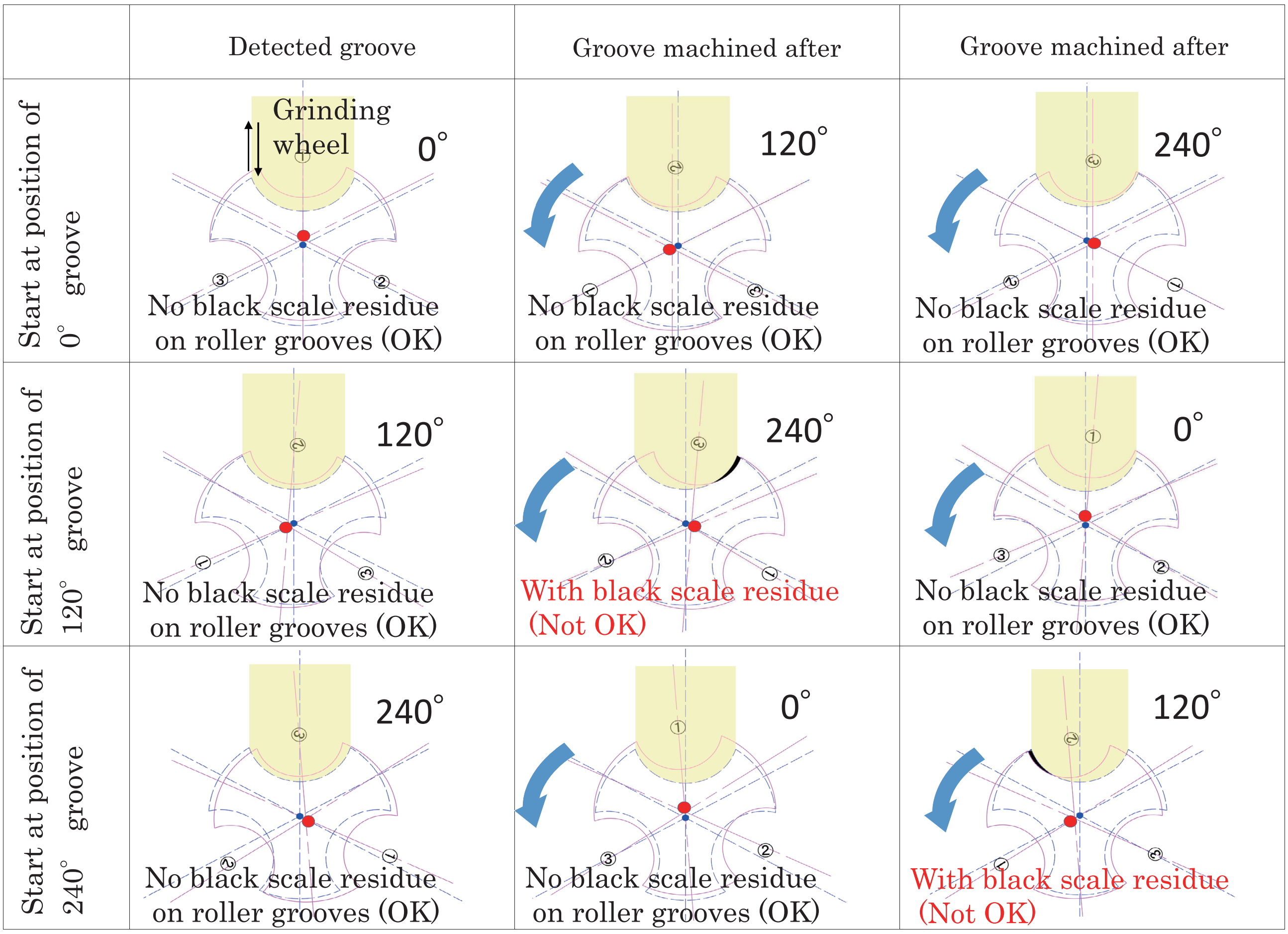



**Fig. 4 Validation diagram of misalignment when roller groove is at maximum runout point**

runout amount was close to the phase of the roller groove position, it was found that misalignment of the roller grooves increased when machining began at any groove other than the 0-deg. groove.

## 3. Analysis of mechanism causing black scale residue on roller grooves

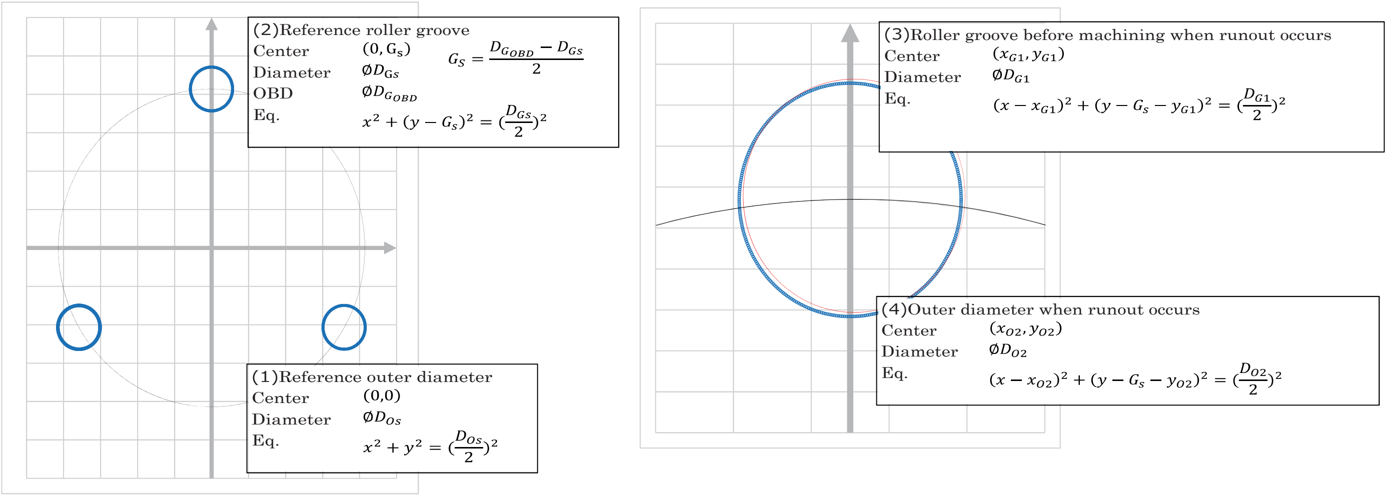
### 3.1 Analysis of roller groove misalignment and black scale residue

Roller groove misalignment was compared for cases where the phases of the roller grooves and the maximum convex portion or minimum concave portion of the runout amount were close and cases where they were distant. In order to investigate if the amount of misalignment became minimum when the phases were close, an equation was formulated based on the related elements for calculating the machining allowance on the right and left roller groove shoulders (Fig. 5).

The related elements refer to the reference shaft diameter, shaft outer diameter and runout amount (concave and convex), roller groove OBD, roller groove position and split angle.

The method of calculating the machining allowance is to find the difference between the intersection of the reference roller groove circle (2) and the reference outer diameter circle (1) and the intersection of the pre-machined roller groove circle (3) and the outer diameter circle (4) at the time runout occurs. Positive coordinates are for the right shoulder machining allowance and negative coordinates are for the left shoulder machining allowance.

The amount of roller groove misalignment was calculated from these machining allowances.




Calculation equation on right shoulder (mm)

$$= x_{S1} - x_{G1} - D_{G1}\cos\left\{\tan^{-1}\left(\frac{y_{O2} - y_{G1}}{x_{O2} - x_{G1}}\right) + \cos^{-1}\left(\frac{(x_{O2} - x_{G1})^2 + (y_{O2} - y_{G1})^2 + {D_{G1}}^2 - {D_{O2}}^2}{D_{G1}\sqrt{(x_{O2} - x_{G1})^2 + (y_{O2} - y_{G1})^2}}\right)\right\}$$

Calculation equation on left shoulder (mm)

$$= -x_{S2} + x_{G2} + D_{G1}\cos\left\{\tan^{-1}\left(\frac{y_{O2} - y_{G1}}{x_{O2} - x_{G1}}\right) - \cos^{-1}\left(\frac{(x_{O2} - x_{G1})^2 + (y_{O2} - y_{G1})^2 + {D_{G1}}^2 - {D_{O2}}^2}{D_{G1}\sqrt{(x_{O2} - x_{G1})^2 + (y_{O2} - y_{G1})^2}}\right)\right\}$$

**Fig. 5 Calculation equation for machining allowance on right/left shoulders and relate elements**

### 3.2 Validation of machining allowance calculation equation and black scale residue

The calculation equation was used to determine if roller groove misalignment became minimum in cases where the phase of the maximum convex portion or minimum concave portion of the runout amount was close to the phase of the roller groove position. That was done as shown in the phase diagram of the roller grooves and outer diameter runout in Fig. 6 by defining the maximum convex portion and minimum concave portion of the outer diameter runout amount at every 30° from 0°.

- The validation results were identical for 0° and 60° because these positions are on the axis of the roller grooves.
- The validation results were the same for 30° and 90° because these positions are 30° from the roller groove position.

Based on the foregoing results, validation was performed at the positions of 0° and 30°.

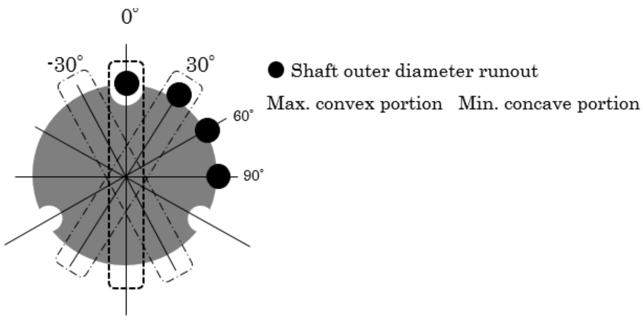



**Fig. 6 Phase diagram of roller grooves and shaft outer diameter runout**

The vertical axis of the graph in Fig. 7-1 is the amount of misalignment of the roller groove position found by CAD software and the horizontal axis shows the amount of roller groove misalignment calculated with the calculation equation. Good agreement is seen between the two sets of results.

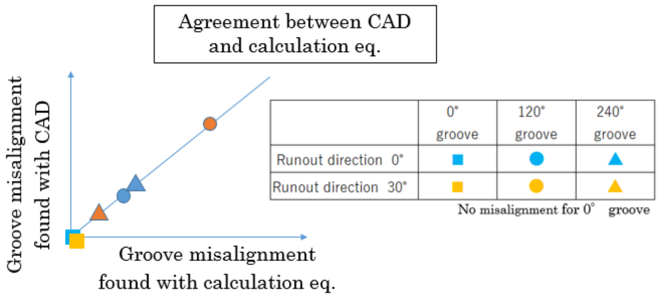



**Fig. 7-1 Validation of misalignment found with CAD and with calculation equation**

The vertical axis of the graph in Fig. 7-2 is the amount of roller groove misalignment found with the calculation equation. The upper level of the horizontal axis shows the angles of the maximum convex portion and minimum concave portion of the outer diameter runout amount, and the lower level indicates the groove for the start of machining.

The results reveal that misalignment becomes the smallest if machining starts from the 0-deg. groove when the phase is 0°. Misalignment also decreases if machining starts from the 0-deg. groove when the phase is 30°.

Accordingly, if machining starts from the 0-deg groove, misalignment becomes minimum for both the 0° and 30° phases, making it possible to suppress the occurrence of the black scale residue.

## 4. Countermeasure and effect

### 4.1 Machining start groove and construction of a detection method

A program was constructed for using the first detected groove as a reference for measuring shaft outer diameter runout. The roller groove in the region of the maximum convex portion or the minimum concave portion of shaft outer diameter runout is automatically detected and machining starts from that groove.

The groove for the start of machining is specified, and machining begins from the groove where the phases of the roller groove and the maximum convex portion or minimum concave portion of the diameter runout amount are the closest. This method suppresses misalignment, making it possible to suppress the occurrence of the black scale residue (Fig. 8).

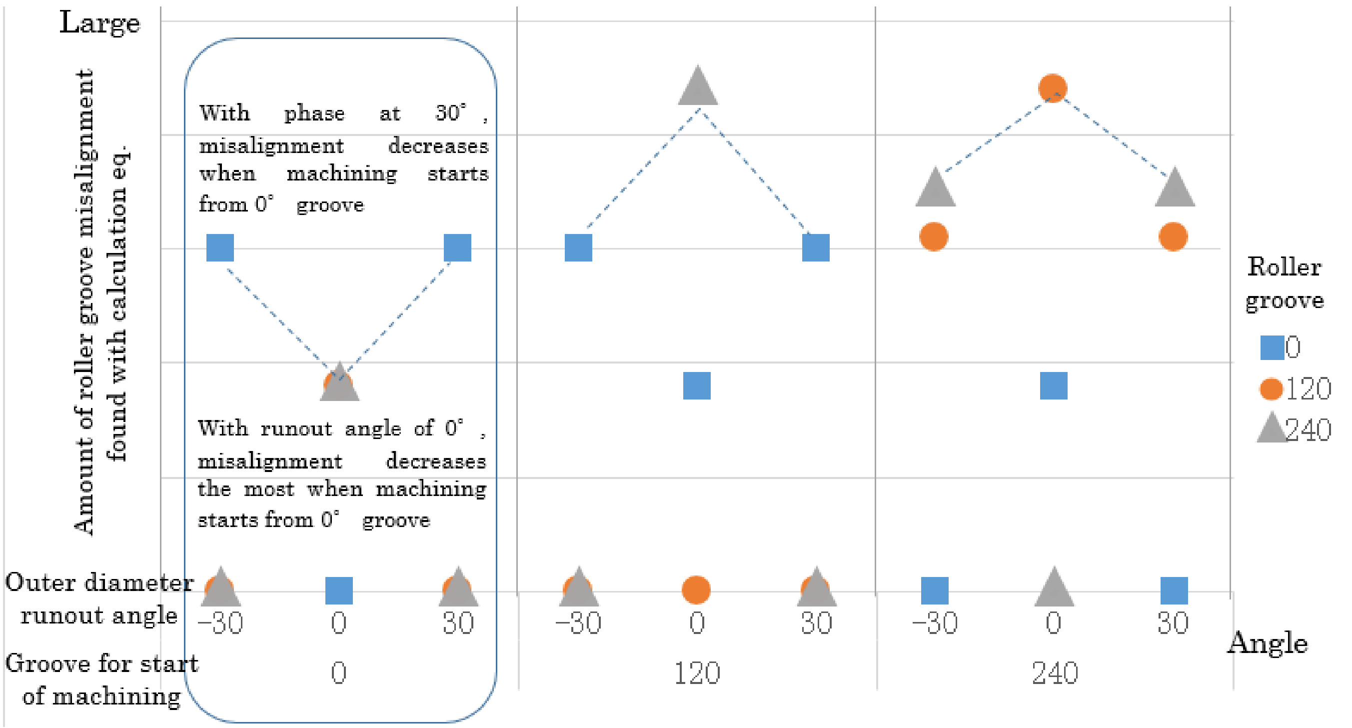



**Fig. 7-2 Validation of risk for occurrence of black scale residue**

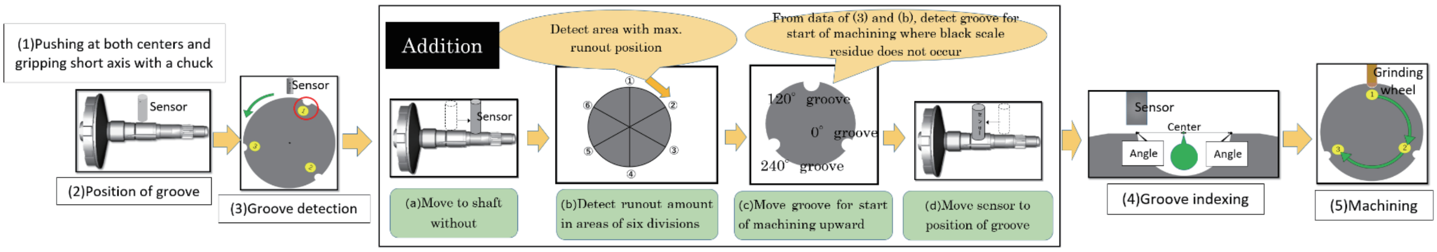



**Fig. 8 Indexing motion after addition of actions for specifying groove for start of machining**

### 4.2 Improvement effect

Since the implementation of the program for automatically detecting the groove for the start of machining prior to roller groove grinding, the previous occurrence of chronic black scale residue defects has been reduced to zero.

The operation delay due to the addition of the automatic detection program has been compensated for by shortening the cycle time.

## 5. Conclusion

Misalignment of each roller groove in relation to the start of machining at different grooves was calculated with an equation and compiled into a chart. This resulted in clarification of the mechanism causing the black scale residue on the roller grooves.

The adoption of the program for specifying the groove for the start of machining resulted in an effective measure for preventing the occurrence of the black scale residue.

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