

Virtual Tool to Predict Trunk Spring Movement Including Tolerance Variation

Jason Rogers
Honda of Canada Manufacturing

ABSTRACT

A 3D-and-Excel-based predictive tool was developed to determine trunk spring movement for preventing recurrence of a noise problem. While effective, the tool could not completely explain measured results on the completed body unit (CBU). Since design data is used as the input, it was hypothesized that the difference between predicted and actual results was related to tolerance variation on the actual vehicle.

Using Siemens® Variation Analysis software, the CBU was built and simulated virtually with tolerances using a Monte Carlo model. The study found that the hypothesis was correct; tolerance variation was fully responsible for the differences. In addition, the study also allowed accurate prediction of failure rates.

CITATION: Rogers, J., "Virtual Tool to Predict Trunk Spring Movement Including Tolerance Variation," *SAE Int. J. Mater. Manf.* 8(3):2015, doi:10.4271/2015-01-0489.

INTRODUCTION

Trunk springs are commonly used in vehicles to assist the customer in opening and closing the trunk. Typical design layout incorporates a steel rod with one end secured to the trunk hinge and the other to the body. The spring is typically bent to some pre-determined shape for this design and is then installed to the CBU pre-loaded with a certain amount of torque. Two springs normally complete the system, the total torque of which is sufficient to counteract the trunk weight and usually elevate the trunk to some pre-determined height upon opening. See [Figure 1](#) for a typical trunk spring layout.



Figure 1. Typical trunk spring layout as viewed from the rear of the vehicle with the trunk open (11M Honda Civic shown).

A design problem that arose during the development of the 12M Honda Civic was a creak noise that occurred when opening the trunk. Failed CBUs amounted to approximately 25% of four-door units and 100% of two-door units.

Root-cause investigation showed that the noise was caused by movement of the trunk spring across the trunk hinge bracket (the spring end secured to the body); due to the high torque of the spring, pressure applied by the spring on the bracket created a "stick-slip" condition that caused the spring to stick on the bracket and thereby

bend the bracket out of its original position. The creak noise was caused when the hinge bracket snapped back toward its original position. See [Figure 2](#).

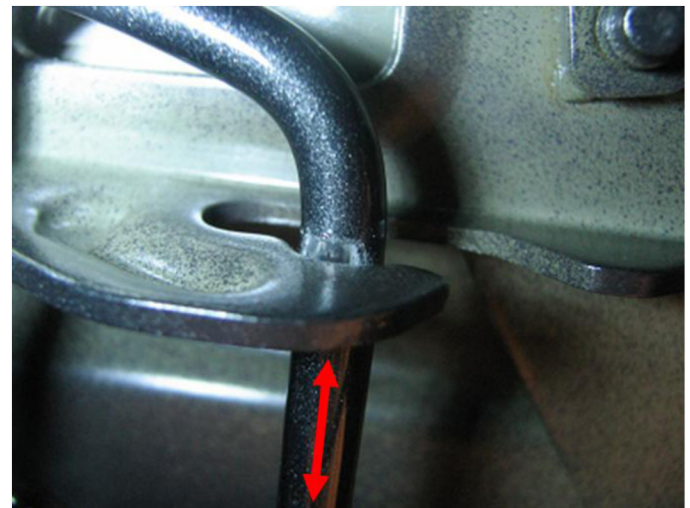


Figure 2. Trunk spring in its installed condition. Witness marks in the form of paint wear on the spring indicate the cross-car movement (the wear is incidental and does not otherwise affect function/durability).

In-house repair was implemented to correct the problem; however, the failure mechanism for the spring movement was unknown. Root cause investigation revealed that while the spring movement caused the creak noise, the cause of the spring movement was inherent in the trunk hinge, spring and retaining clip geometry. The following factors contribute to the movement:

1. Cross-car pitch between hinge arm and clip
2. Concentricity between hinge pivot circle and clip position
3. Distance from hinge pivot to spring location on hinge arm

Once an in-depth understanding of the behavior of the trunk spring system was gained, a process was developed whereby the spring movement-and therefore the potential of a given spring system to develop a creak noise-could be predicted for any given design. By creating 3D points that represent the motion path of the hinge arm and measuring to each of these points from a single point representing the spring's static position in the spring clip, these measurements could be plotted using Microsoft® Excel to create a graph that directly correlates to the actual cross-car motion of the spring. Measurements taken from the 3D data are shown in [Figure 3](#).

Two Excel plots are shown in [Figure 4](#), representing the predicted spring movement for 12M Civic four-door and two-door. Depth and shape of the curves indicate the predicted motion of the spring and are noticeably different between four-door and two-door models based on the three geometrical factors listed above.

A value of 2mm was empirically established as a limit to spring movement beyond which a creak noise can be expected to occur and was based on extensive problem investigation. This limit was used to evaluate the spring condition on multiple models (see [Figure 5](#)).

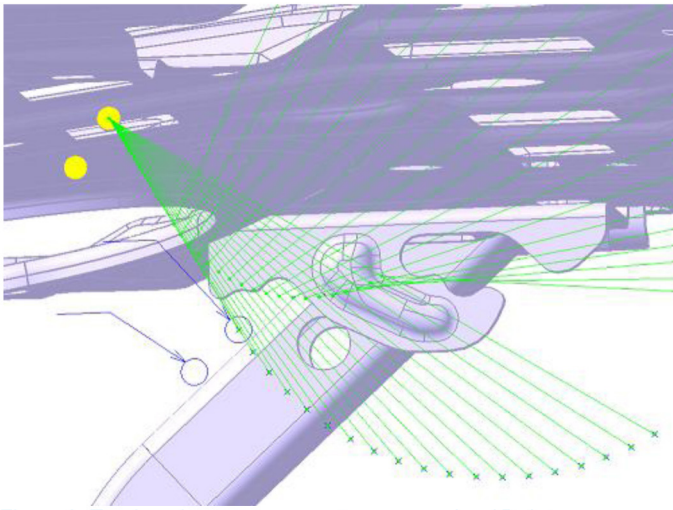


Figure 3. Trunk spring measurement process using 3D data.

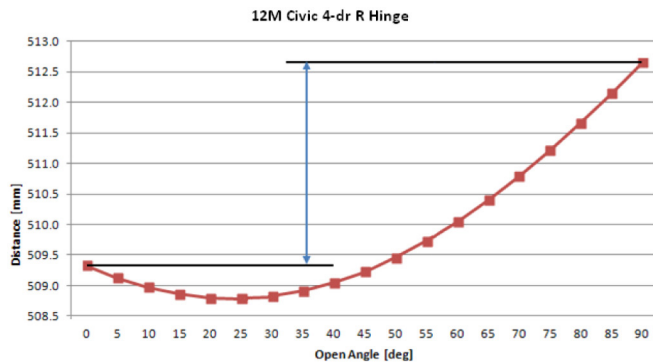


Figure 4.

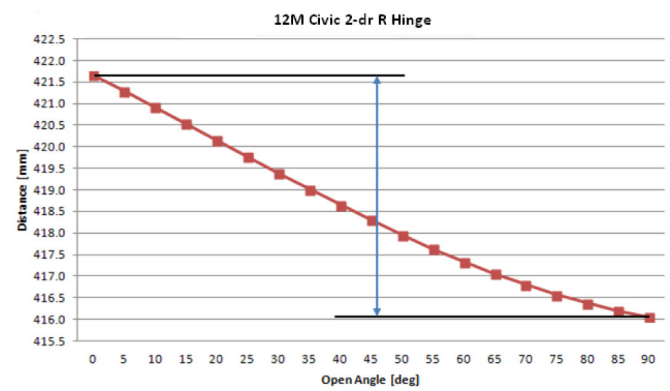


Figure 4. (cont.) Typical data plot from 3D/Excel, showing results for four-door (top) and two-door (bottom). Net distance (Y axis) and curve asymmetry serve as indicators for the potential for a creak noise to occur. Note the complete asymmetry on the two-door plot.

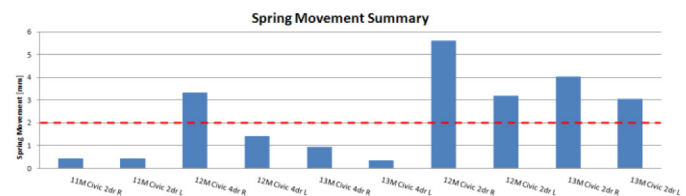


Figure 5. 11-13M Civic four-door & two-door spring movement summary. Values above the red line (2mm) required countermeasures.

PROBLEM

Experiments were carried out to obtain data regarding the actual spring movement on the CBU to verify the accuracy of the predicted results. The data revealed that although the 3D/Excel tool is generally effective in its predictive ability, the actual spring movement values were incorrect. In other words, correlation between the predicted value and actual value was not one-to-one.

The first test on a 12M Civic two-door CBU showed a cross-car spring movement magnitude of 2.8mm for the right-side spring, as shown in [Figure 6](#). A secondary test was carried out on the same CBU in which the stationary end of the spring was removed, thereby eliminating any effects of friction that would reduce the spring movement. As expected, the measured magnitude was larger, at 4.3mm (also shown in [Figure 6](#)), indicating that spring movement was reduced by 1.5mm due to friction. From this information, two facts became clear:

1. The 3D/Excel tool does not account for the shift in curve shape due to the effects of friction.
2. Since the 3D/Excel tool predicted a value of 5.6mm (as shown in [Figure 4](#) and [Figure 5](#)), this indicates that there is 1.3mm less movement on the measured CBU than what was predicted by the 3D/Excel tool despite correcting for friction, per the calculation below.

$$\text{Difference} = \text{predicted} - \text{friction} - \text{actual}$$

(1)

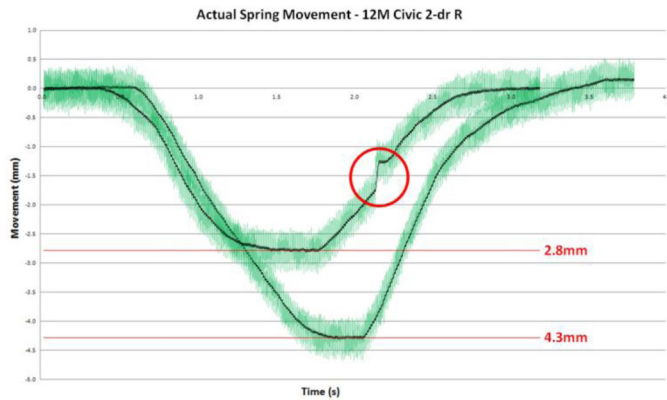


Figure 6. Plot of spring movement vs. time with raw data (green) and noise-filtered data (black). Note the sharp deviation (indicated by the red circle), which shows the creak noise captured in real-time.

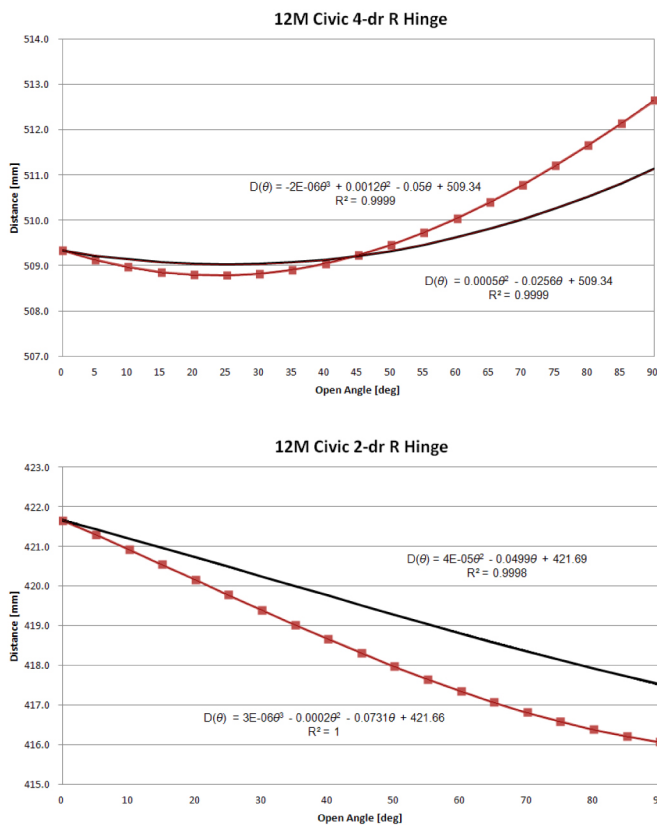


Figure 7. Original four-door (top) and two-door (bottom) spring movement curves (dark red, with data points) with curves corrected for friction (solid black).

To correct Fact #1, frictional effects were incorporated into the 3D/Excel tool. The shift in the movement curve was modeled mathematically by knowing the “end state” reduction in movement (1.5mm) and accounting for system effects with a negative multiplication factor based on the rate of change of spring movement (the slope of the curve; negative as friction always opposes motion) and an addition factor due to the known reduction in spring torque with increased trunk angle (additive as the reduction in torque decreases normal forces and therefore

opposes the negative frictional factor). The unknown multiplication and addition factors were solved by applying identical formulae for four-door and two-door curves and varying the factors until both curves were reduced by the required 1.5mm overall. The same curves from Figure 4 are shown again in Figure 7 with the original curves in dark red and the friction-corrected curves in black.

Despite the correction for the effects of friction, the key assumption in the 3D/Excel tool remained; the assumption is implied by using the part data in 3D, which is to assume that all parts are in their nominal position, which is unrealistic. Therefore, it was understood that based on the ability of the parts to vary within a given tolerance range, the 3D/Excel-generated, friction-corrected curve can be considered as the “nominal” curve and would also be expected to have a tolerance range, which could be interpreted as an “envelope” around the nominal curve. However, given only the 3D data, the tolerance range could only be measured after CBUs are built, counteracting the effectiveness of the 3D/Excel tool’s predictive ability.

Realizing the inherent weakness in the original 3D/Excel tool and given Fact #2 above, it was hypothesized that the 1.3mm gap between the prediction and actual was at least partially related to tolerance variation on the actual CBU.

OBJECTIVE

The objective of this analysis was to establish the tolerance envelope around the nominal friction-corrected 3D/Excel spring movement curve and to determine what portion of the 1.3mm gap between the predicted value and measured value is attributable to part variation.

METHOD

Many methods exist for studying the cumulative effects of dimensional tolerance variation. The root-sum-squared (RSS) method is commonly used and is effective in a one-degree-of-freedom (1DOF) case. However, the trunk system incorporates many assembled parts and experiences multi-axis variation that cannot be adequately described given the mathematical limitations of the RSS method.

Siemens® Variation Analysis software (VSA) provides 6DOF simulation of dimensional tolerance variation based on the Monte Carlo method. Given model features, known variation for each feature and an assembly hierarchy, the Monte Carlo method runs iterative simulations, applying a statistically random value to each model feature, assembling the features virtually and accumulating the results to obtain overall variation for any designated measurement. It was determined that a VSA tolerance study was required to capture the complex variation within the trunk system. Figure 8 shows a typical VSA interface (not the trunk spring model from this study).

To understand what portion of the 1.3mm gap between the predicted and actual cases could be attributed to part variation, as much of the VSA study as possible used actual white body production data. This