

A Study of the Relationship between Leading Offset and Squeal Noise

Joo Sang Park, Min Gyu Han, and Seon Yeol Oh
Mando Co.

ABSTRACT

This paper introduces the experimental test results of an investigation to understand the relationship between the leading offset and squeal propensity. In addition Transient Analysis (TA) and Complex Eigenvalue Analysis (CEA) are used simultaneously as a means to compare the experimental approach to two different numerical tools, so evaluating the validity of each theoretical approach. To confirm the CAE results. An ODS was recorded of the brake using a 3D laser scanning vibrometer. Even though the CEA approach is very popular in the study of brake squeal noise, there are some limitations and difficulties in replicating the real phenomenon especially containing unstable behavior. The differences are due to weak pad contact stiffness and friction characteristics which are dependent on the relative interface velocity between pad and rotor. It is necessary to consider stick-slip vibration and time domain analysis in addition. This paper introduces the differences between the transient analysis and the complex eigen-value analysis in their ability to replicate a squeal noise occurrence. There are some analogies between a floating type caliper and an opposed piston type caliper in terms of predicting squeal noise caused by a leading offset at the piston side and the finger side. In addition this study shows that a leading offset at the finger side and pad side will result in squeal noise using both the experimental approach and numerical approaches. Finally a flutter instability and a friction interface analysis is introduced to give an understanding of the relationship between noise propensity, pad length, disc wavelength and force balance of trailing and leading side.

CITATION: Park, J., Han, M., and Oh, S., "A Study of the Relationship between Leading offset and Squeal Noise," *SAE Int. J. Passeng. Cars - Mech. Syst.* 9(3):2016, doi:10.4271/2016-01-1919.

INTRODUCTION

In any brake system, it is the rotor that acts as the amplifier for any radiation of noise. For that to happen there needs to be an out-of-plane force of sufficient strength to cause the rotor to vibrate out-of-plane. That force is answered by the theory of "spragging", proposed nearly 40 years ago by Robert Spurr, a situation that may occur with a caliper pad leading offset center of pressure. Many brake systems, especially opposed piston type calipers, were designed with an asymmetric piston configuration that provides a trailing offset as a means to give an even pad wear distribution during braking. In general it counters the tendency for the pad to "dig-in" at the leading edge and helps to make pad wear and pressure distribution more uniform. There are several ways to provide a trailing offset, typically the three most common methods being to a) offset a single piston to the trailing side by about 5mm, b) with multiple piston designs to have the trailing piston larger than the leading piston and c) to employ a shim with a "D" cutout that promotes a trailing offset, the latter being more a retro-fit solution.

Some researchers [1, 2, 3] were interested in understanding the mechanism related to the pad leading offset generated by uneven dynamic pressure distribution during braking. Fieldhouse revealed the squeal mechanism caused by spragging-angle. The remedy of a squeal noise was proposed in terms of studying the friction coefficients and the distance of disc rubbing surface from carrier

mounting face on a knuckle. Some engineers [5] updated a CEA model to consider the influence by a pad dynamic pressure distribution measured.

The paper provides results from 4 different, but related, studies:

1. An investigation of a floating type caliper (sliding fist) and the pressure distribution at the piston side pad.
2. An opposed piston type caliper investigating the pressure distribution at the inboard and outboard sides.
3. A comparison of the CEA and Transient tools to the experimental investigations
4. A study of three different brake systems which have the same disc and pad interface geometry are compared to describe the mechanism in relation to the wavelength of disc out of plane mode and the pad length.

FLOATING TYPE CALIPER- FINGER LEADING OFFSET

Vehicle Test

A floating caliper system had a squeal problem only during reverse braking conditions with 5bar pressure and 2kph speed. To determine the pressure distribution of the finger pad, under a non-braking condition, static pressure film was used at the disc and pad interface.

The distribution showed the finger leading side to have partially non-contact area so inducing an uneven pressure distribution skewed to the trailing end. Under forward braking there was a trailing offset and no noise whereas in reverse there was now a leading offset and noise. It must be noted that the squeals disappeared when the finger face was re-machined to provide full contact faces, so meeting the specification of the brake design. It may be concluded that the overall centroid of finger pressure when moved towards the trailing side may be beneficial for the reduction of squeal noise.

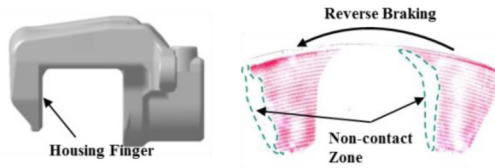


Figure 1. Housing Finger Pressure data

Comparison of CEA and Transient Tool with Vehicle Test

CEA is one of the useful CAE tools used to simulate squeal noise in terms of self-excited vibration among each of the brake components. A CEA model was created to duplicate the squeal noise generated by the real vehicle test. To replicate the noisy brake, the finger face profile within the model was modified to be the same as the real fingers - with uneven flatness. The modifications are shown in the Figure 2. There are two finger profiles, “good” and “bad”, the “bad” (or noisy) clearly showing the non-contact region on the finger faces. In case of the “good”, full contact, finger profile, the noise does not occur during test. However in the brake with the badly profiled finger, noise is readily reproduced during braking tests. Figure 3 shows there is no different degree of negative damping ratios between the “good” and “bad” profiles under the 24 combination conditions of three friction levels (0.4, 0.6, 0.8), four pressure levels (5, 10, 15, 20 bars), and forward and reverse driving.

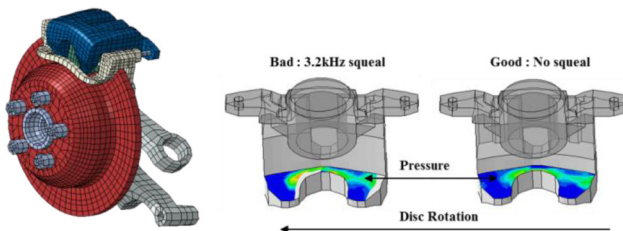


Figure 2. CEA Model with “bad” and “good” housing

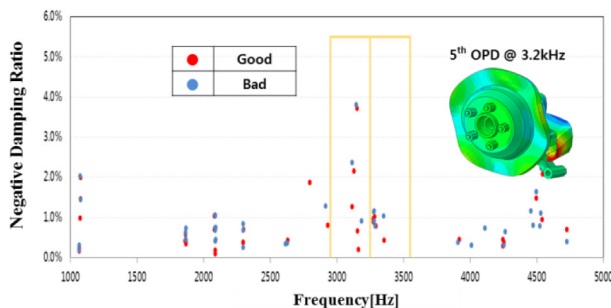


Figure 3. CEA Results showing negative damping ratios and ODS shape.

It means that the CEA has limitations to mimic the squeal noise due to two different finger configurations while the negative damping ratios are not zero. So another simulation tool is required to duplicate the 3.2 kHz squeal generation and the Transient Analysis process was selected. The results by a transient analysis are as shown in Fig. 4

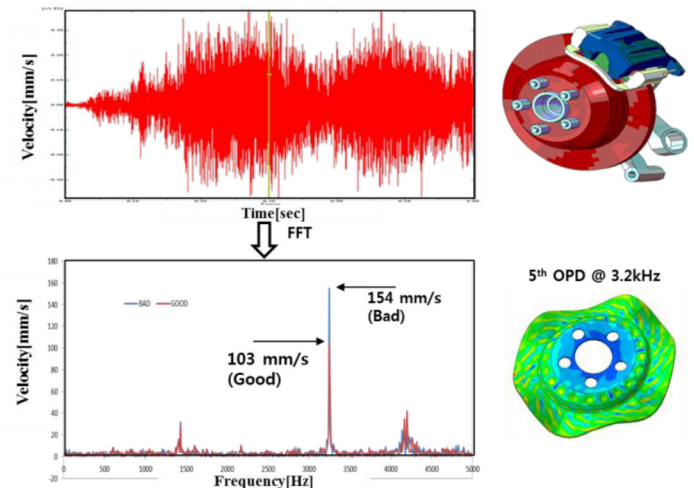


Figure 4. TA Results

The transient analysis tool has a good correlation with the real vehicle test while CEA is a popular CAE tool to in automotive brake fields. It is believed that the CEA has a limitation to simulate a squeal noise due to the unstable behavior of pad and finger uneven pressure distribution because the tool cannot be considered time dependent when pressure fluctuations exist.

Dyno Test

A dynamometer as shown in Figure 5 is used to simulate the squeal noise as observed during real vehicle testing. The dynamometer is driven by motor through a reduction gear box. As the squeal conditions are under low speed and low pressure, the dynamometer is sufficient to reproduce the noise. It was successful in generating the same 3.2 kHz squeal under vehicle squeal braking conditions.

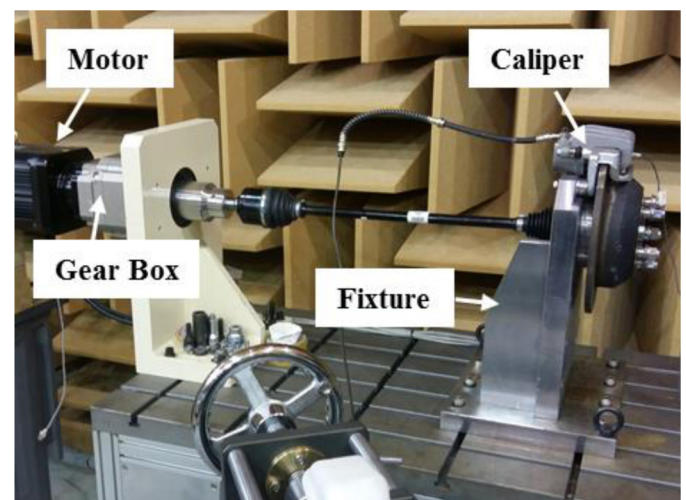


Figure 5. Dynamometer with a floating type caliper

In Figure 6, the 3.2 kHz occurred only under the reverse driving condition, with “bad” finger profiles, and corresponding to vehicle squeal conditions.

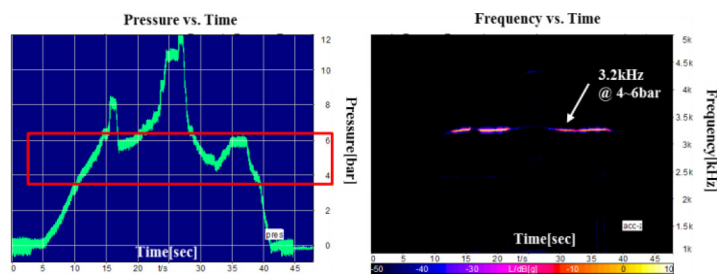


Figure 6. 3.2 kHz squeal with “bad” finger profile under 4~6bar 5kph reverse condition.

Two finger profiles were machined to evaluate the squeal sensitivity to such changes using the test dynamometer.

Comparison of CEA and Transient Tool with Dynamometer Test - Floating Caliper

Firstly, CEA is used to duplicate the 3.2 kHz noise as found during dynamometer testing. The analysis conditions are the 24 combination of three friction levels (0.4, 0.6, 0.8), four pressure levels (5, 10, 15, 20 bars), and forward and reverse driving. The CEA model was built with correlation based on component-level frequencies. The maximum negative damping ratio is around 3.0% as shown in Figure 7. However the difference between “good” and “bad” finger profile is little. These results do not coincide with those of the scale dynamometer when the “good” pad does not generate noise.

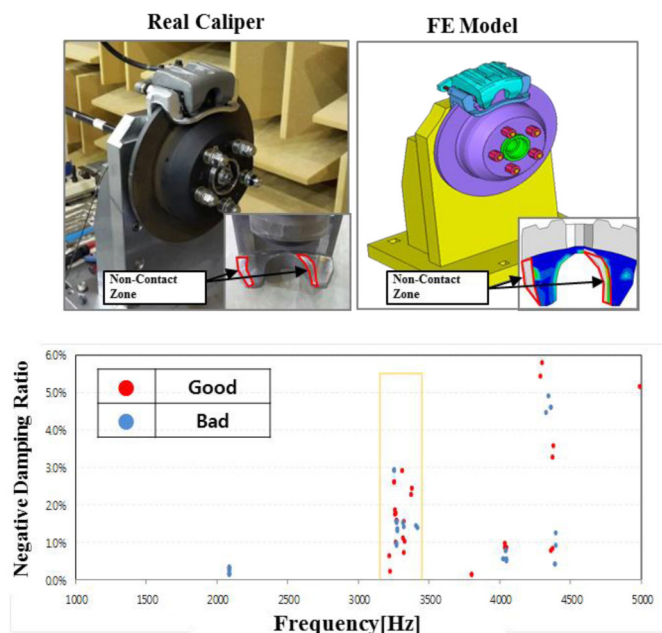


Figure 7. Comparison CEA results between “good” and “bad” finger profiles

Similar to brakes with vehicle type knuckle, the Transient Analysis was conducted to generate the squeal noise. The transient analysis model is the same as CEA.

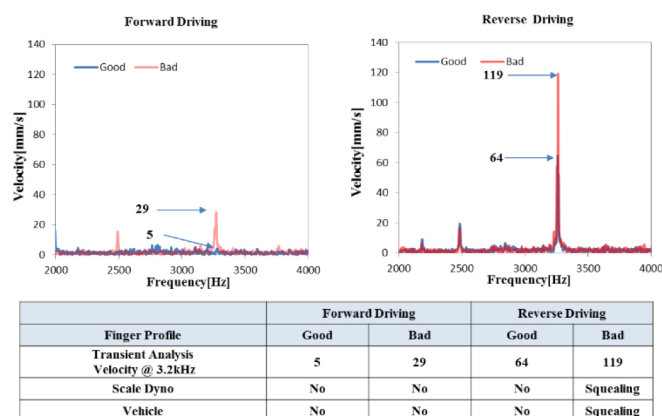


Figure 8. Comparison Transient Analysis results between “good” and “bad” finger profiles and test

The calculated results have a good correlation with dyno and vehicle test. Also the 3.2 kHz is 5th OPD (Out-of Plane Diametric) mode, same as the dynamometer testing.

OPPOSED PISTON TYPE CALIPER - PAD LEADING OFFSET

Dynamometer Test with an Equivalent Opposed Piston Type Caliper

Generally the leading offset of a pad has a critical zone for squealing. The critical zone is dependent on pad thickness, friction coefficients of pad and pad rigidity/stiffness. The relationship between pad pressure distribution and noise should be studied to understand the squeal mechanism. In figure 9, an equivalent caliper has 4 separated pistons which can be provided with different brake fluid pressures respectively to control the degree of pad leading/trailing offset. If the pressure level of trailing side pistons is higher than that of leading side pistons, the degree of pad leading offset will decrease.

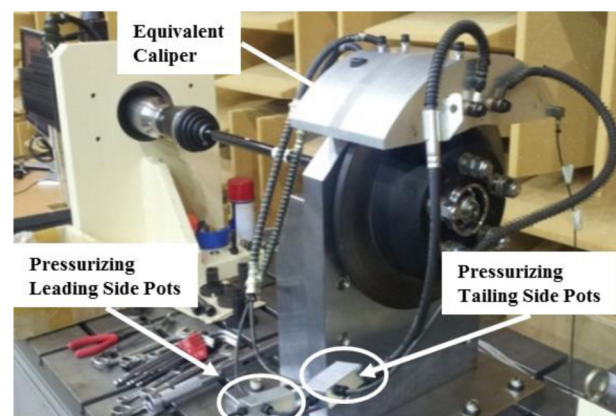


Figure 9. An equivalent caliper brake to simulate the squeal noise

The matrix tests were performed to find the conditions that readily generated the squeal noise. Most of squeal conditions were when the centroid was located on the leading side of the pad. The test results show that the higher pressure level on leading side easily produce the 3.3 kHz noise. The results are similar to the previous research by Fieldhouse [4].