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Automotive Brake Disc Design to Suppress High Frequency Brake Squeal Noise

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Abstract

Of the various countermeasures used to address disc brake squeal noise, noise shims have proven to be very effective in addressing medium to high frequency squeal related to rotor bending vibration. However, for squeal noise at low frequency and squeal related to rotor in-plane vibration, noise shims are less effective. Recently, there is more and more evidence showing that many field claims of brake squeal noises are related to the brake rotor's in-plane vibration modes.
So it becomes necessary to review brake design for suppression of high frequency brake squeal noise.

Introduction

Disc brake noise generation during braking is one of the most important issues faced by automotive manufacturers worldwide. Despite brake noise is not a safety issue and has little impact on braking performance, it gives customers the impression of underlying quality problems of the vehicle. In addition, the customers view that the noise emitted from the brake system is indicator of malfunctioning condition and consequently lose confidence on the quality of the vehicles.

Brake noise complaints forms a major warranty costs to vehicle and brake manufactures. Also it affects the brand image of the brake manufacturer. Considering all above it has become prime objective to minimize brake noise during vehicle design and development phase. To achieve this, understanding the root causes for brake noises observed during development phase is essential and countermeasure need to defined based on such deeper understanding of brake noise phenomenon.

Hypothesis

The high frequency brake squeal propensity significantly increases if there is modal coupling between brake disc in-plane and out of plane modes.

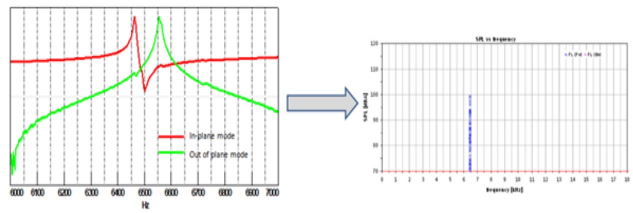


Figure 1 : High frequency brake squeal hypothesis

Experimental case studies

Above hypothesis is true for one of the development project and hence to further confirm the same three different case studies are done as below:
Case study 1 : Structural modifications like slot, hole are done on existing brake disc
Case study 2 : Structural modifications like slot, chamfer, cut-out on brake pad + changes in shim
Case study 3 : Change in vane pattern (existing disc is of 37 straight vanes whereas new disc is of 31 straight vanes)

Existing plain brake disc

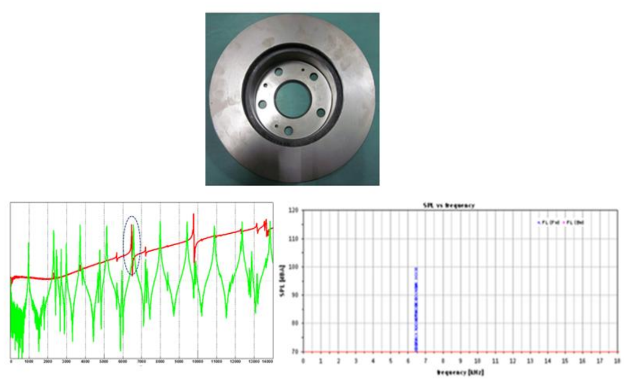


Figure 2: Brake squeal noise with existing brake disc

In existing brake disc there is modal coupling between in-plane and out of plane modes at 6.5kHz. And in squeal noise test also the major frequency observed is 6.5kHz. So the hypothesis is true for this case.

Case study 1:

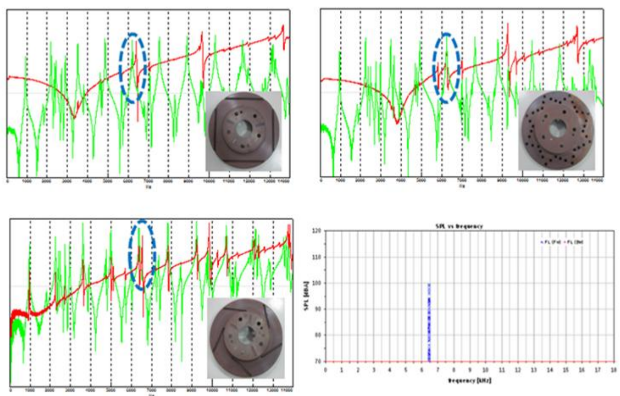


Figure 3: Brake squeal noise with structural modifications in existing brake disc

Any of structural modification (rectangular slot / holes / inclined slot) in brake disc could not decouple in-plane and out of plane modes at 6.5kHz. And during squeal noise tests with these brake discs show prominent occurrence of 6.5kHz.

Case study 2:

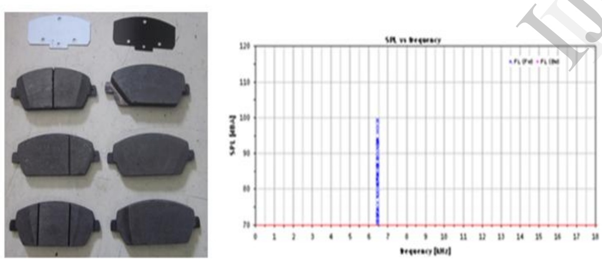


Figure 4: Brake squeal noise with structural modifications in brake pad + different shims tested with existing brake disc

With existing brake disc (37 straight vanes) different pad modifications (like slot, chamfer, cut-out as shown in figure 4) and different types of shims brake squeal noise is evaluated and in all these cases there is a common squeal frequency which is 6.5kHz.

Case study 3:

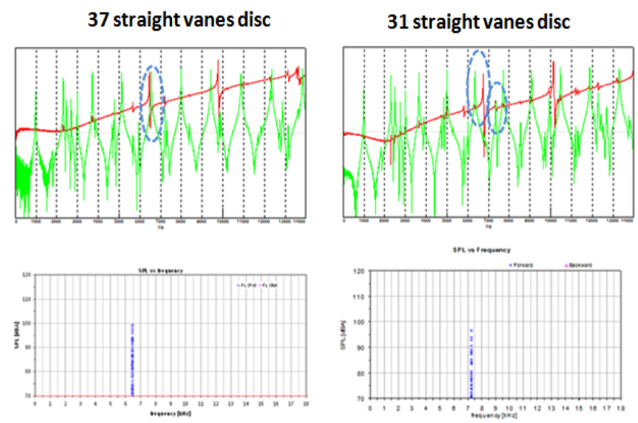


Figure 5: Brake squeal noise with 37 and 31 straight vane discs

With 31 straight vane disc there is decoupling of in-plane and out of plane modes of brake disc. However there is modal coupling at 7.35kHz but the amplitudes are comparatively lower . Squeal noise test results also shown that 6.5kHz frequency is eliminated which was present in all earlier modifications but there is occurrence of new high frequency i.e. 7.35kHz.

Based on case studies brake disc modal coupling hypothesis is confirmed. And to reduce such high frequency brake squeal noise modifications in brake disc could be an effective as well as stable solution.

Brake disc modifications:

If there is a modal coupling between in-plane and out-of plane bending modes for an existing brake disc, in order to shift modes following are two options:

1. Change stiffness by doing structural modifications in brake geometry
2. Change material properties

To do such modifications we need to understand the brake geometry, materials used for brake disc and other functional requirements of brake disc.

Brake geometry :

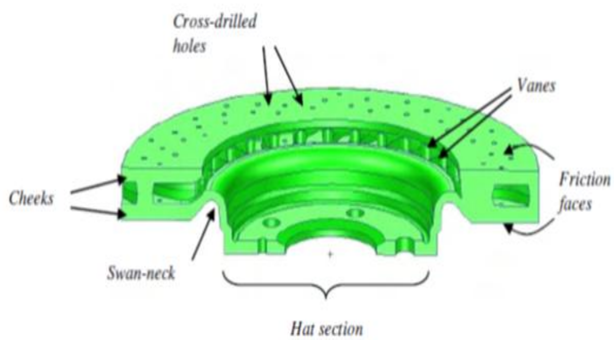


Figure 6 : Brake disc geometry

a) The rubbing surface section is a one-piece casting with cooling fins(vanes) between the braking surfaces (cheeks) to enable air to circulate between the braking surfaces and make the rubbing surfaces less sensitive to heat build-up and more resistant to fade.

b) The top hat section is mounted to the vehicle wheel hub and is shaped like a hat in order to protect the wheel bearings from the high temperatures induced during braking action at the rotor-pad interface.

c) The section that connects cheeks and top hat section is known as the neck.

Brake disc material:

Following are materials used for automotive brake disc:

a) Gray Cast Iron
b) Aluminium metal matrix composites (Al-MMCs)
c) Carbon reinforced ceramic matrix composites (CMCs)

Brake disc functional requirements:

If we are able to decouple in-plane and out of plane modes of brake disc by doing a modification, then it is equally important to verify that this change is meeting rest all functional requirements of brake disc.

Following are the functional requirements of brake disc:

1. Good cooling or heat dissipation performance

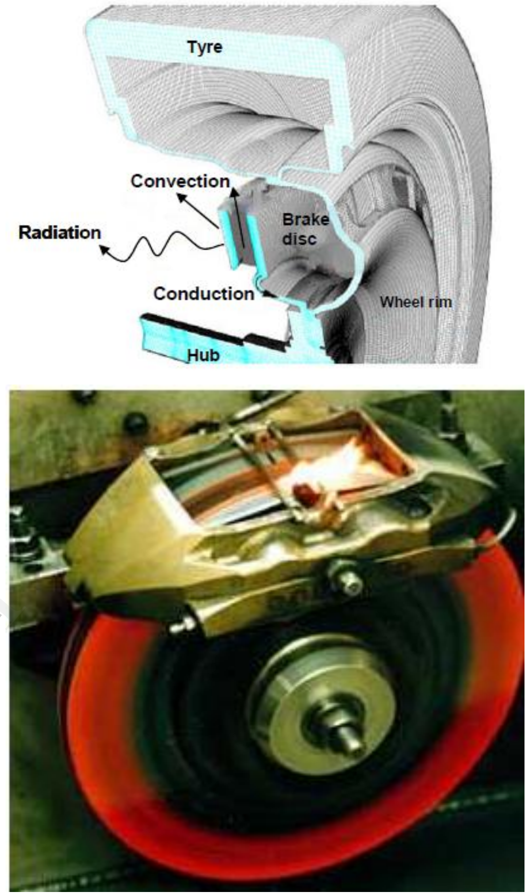


Figure 7 : Brake disc cooling

2. Thermo-mechanical distortion resistance (conning resistance)

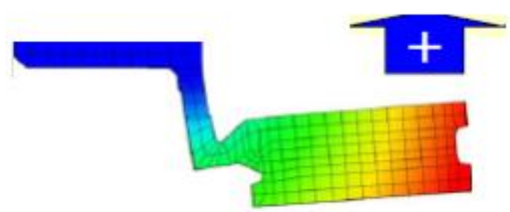


Figure 8 : Brake disc conning

3. Optimum strength to weight ratio and cost (material selection)
4. Cracking resistance

Figure 9 : Brake disc cracking

5. Degassing, glazing and debris control

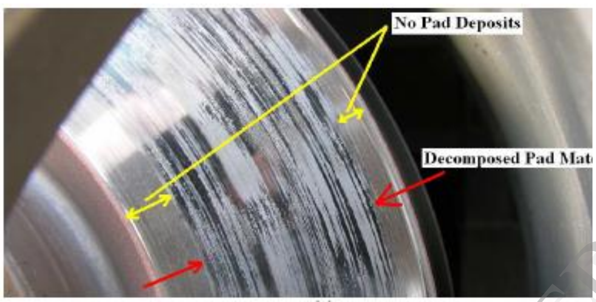


Figure 10: Brake disc glazing

6. Lower brake pad wear
7. Protect wheel bearings from heat generated during braking action

Use of FEA modal analysis for modifying brake disc design:

With the help of FEA modal analysis it is possible to modify brake disc design in order to shift modes.

In the following example with the help of Abacus software modal analysis is done for 37 straight vane disc and comparison is made between experimental modal test data and FEA modal data. Also mode shapes are evaluated as below:

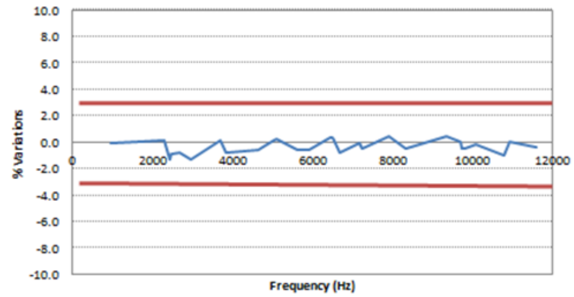
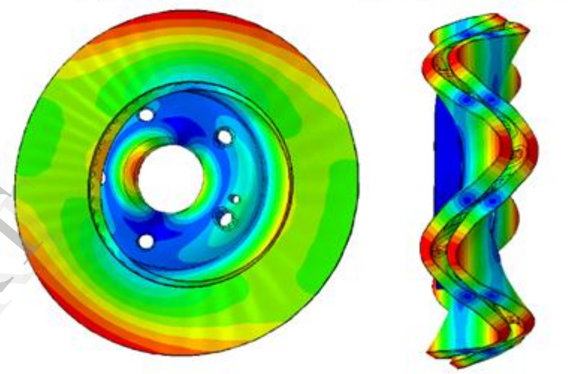


Figure 11: Co-relation between FEA and experimental test results

Mode shape :

In-plane at 6.455 kHz **Out of plane at 6.526 kHz**



Conclusion :

1.Brake squeal propensity is higher at the frequency where there is modal coupling between in-plane and out of plane modes of brake disc.

2.Influence of in-plane mode is higher than out of plane mode and hence it is very difficult to completely eliminate this high frequency squeal noise by modifications in brake pad and shim.

3.With changes in brake disc structure especially the vane pattern it is possible to split the modal coupling at a particular frequency. But there is a possibility that modal coupling at one frequency is eliminated but it appears at other frequency.

4.Considering the complexity of problem, it is advisable to have at least two different disc designs (for example, disc1 with 37 vanes and disc2 with 31 vanes) at the start of project so that if with disc1, it is not possible to suppress high frequency, then there is scope to go for disc2.

Future work

The way forward would be to completely ELIMINATE high frequency brake squeal with modifications in brake disc using FEA modal analysis.

Also considering complexity of brake squeal phenomenon we need to validate this hypothesis on more number of brakes and arrive at guideline for brake disc design to counter high frequency brake squeal noise.

References

[1] SAE Paper 2002-01-0922 "Modal Coupling and Its Effect on Brake Squeal" Research and Vehicle Technology, Ford Motor Co.

[2] "Investigation of the Effects on Braking Performance of Different Brake Rotor Designs" - Paper by Mirza Grebovic