

SQUEAL ANALYSIS OF DISC BRAKE SYSTEM

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ABSTRACT – Squeal analysis of disc brake system continues to be a challenging issue in both industrial and academia due to its complexity and frequent occurrence. Thanks to rapid development of computational device and commercial software, finite element analysis becomes much more efficient and dominates the methods of analysis. Currently, two major FEA approaches are used in general, the transient analysis and complex modal analysis. Complex modal analysis studies the stability of the steady state system under small perturbation; if the vibration amplitude blows up, squeal may occur. Transient analysis is capable to study the vibration of the system during whole braking process. Frequencies of squeal are then calculated from Fourier transform. Particularly, nonlinearity, such as thermodynamic and wear effects could be included. In our case, a disc brake system for passenger car is modelled and analysed using both approaches. We use ANSA/META as pre/postprocessor and ABAQUS as solver. Furthermore, thermal effect is included in transient analysis. Results are compared and analysed in detail.

1. INTRODUCTION

Squeal of brake, which causes customer dissatisfaction and complaint, is reported to be one of the major contributors of automotive industry's warranty cost ^[3]. Since 1930s, research of mechanism and prevention of brake squeal has been last for decades. Much progress has been made. It is now believed that brake squeal is caused by friction-induced dynamic instability. However, methodology of research is still under development; and squeal analysis of disc brake system continues to be a challenging issue in both industrial and academia due to its complexity.

Thanks to rapid development of computational device and commercial software, finite element analysis becomes much more efficient and dominates the methods of analysis. Currently, two major FEA approaches are used in general, the transient analysis and complex modal analysis. The complex modal analysis is widely used in engineering community to predict the squeal propensity of the brake system including damping and contact for its clear physical meaning and relatively low computational cost. It studies the stability of the steady state system under small perturbation; if the vibration amplitude blows up, squeal may occur. From a complex frequency analysis, one could find all unstable modes that may develop a limit-cycle vibration ^[2]. Transient analysis is capable to study the vibration of the system during whole braking process. Frequencies of squeal are then calculated from Fourier transform. Particularly, nonlinearity, such as thermodynamic and wear effects could be included.

In our case, a disc brake system for passenger car is modelled and analyzed using both approaches. We use ANSA as pre-processor and ABAQUS as solver. Furthermore, thermal effects are included in transient analysis. Results are compared and analyzed in detail.

2. FINITE ELEMENT MODEL

To simplify the analysis, only pad and rotor are modelled. The mesh was generated by ANSA with hex elements ^[1]. We also use ANSA to assignment of the materials properties, define contacts, and set appropriate boundaries and loadings during analysis. The finite element model is shown in figure-1.

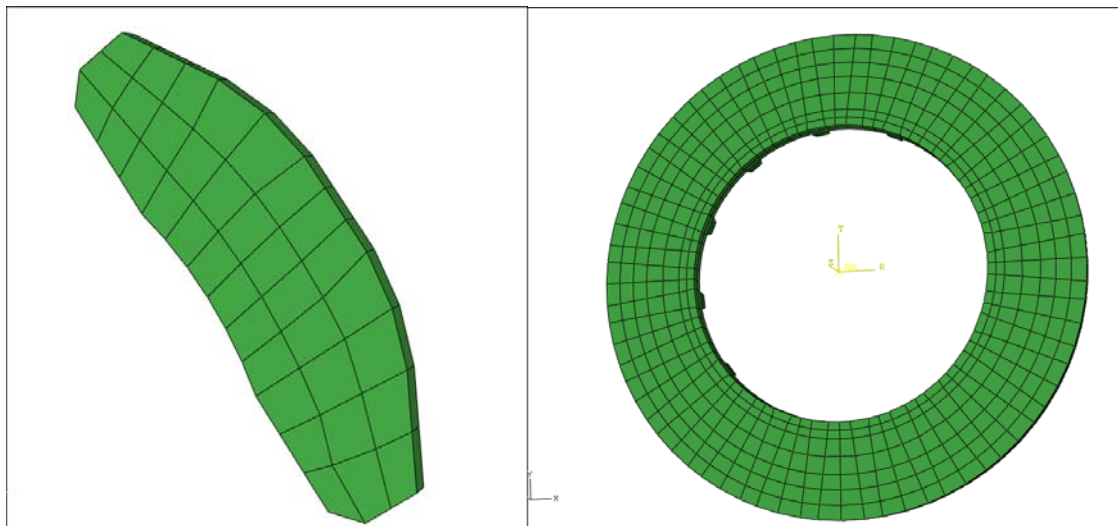


Figure 1 – FEM Mesh of pad(left) and rotor(right)

3. COMPLEX FREQUENCY ANALYSIS

The appearance of squeal is associated with coupled modes whose frequencies are close. When they merge at same frequency, one of the modes becomes unstable. Its amplitude grows exponentially and the squeal may occur. We use the damping ratio $-2 \times \text{Re}(\lambda) / |\text{Im}(\lambda)|$, where λ is the complex eigenvalue to identify unstable modes. Mathematically, a negative damping ratio indicates unstable mode.

To apply complex frequency analysis in ABAQUS, we first setup a static step. In this step, all of the DOF at the centre of rotor except rotation about axis are constrained. The frictional contact of pad and rotor is established, see figure-2. And the pressure between pad and rotor is applied through contact. A following static step is used to applied rotor motion. The third and final step is a linear perturbation step to extract natural frequencies.

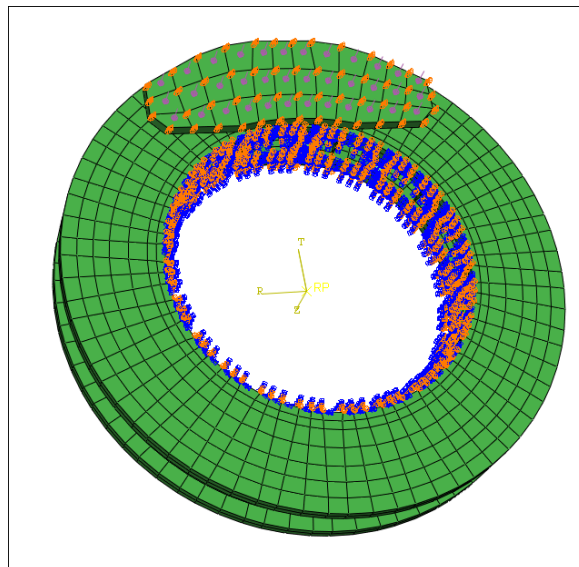


Figure 2 – Boundary conditions and contact relation

In order to investigate the dependence of friction and squeal, we solve the problem with different friction coefficients (FC). The frequency-damping ratio curves are shown in figure 3 and figure 4. A comparison of results reveals that the effect of FC on unstable modes is limited especially when FC is mild. Both curves contain a negative extreme at frequency of 7549Hz indicating that a strong coupled mode may exist. The vibration mode of the system at 7549Hz is shown in figure 5. It can be seen a significant out of plane vibration of rotor.

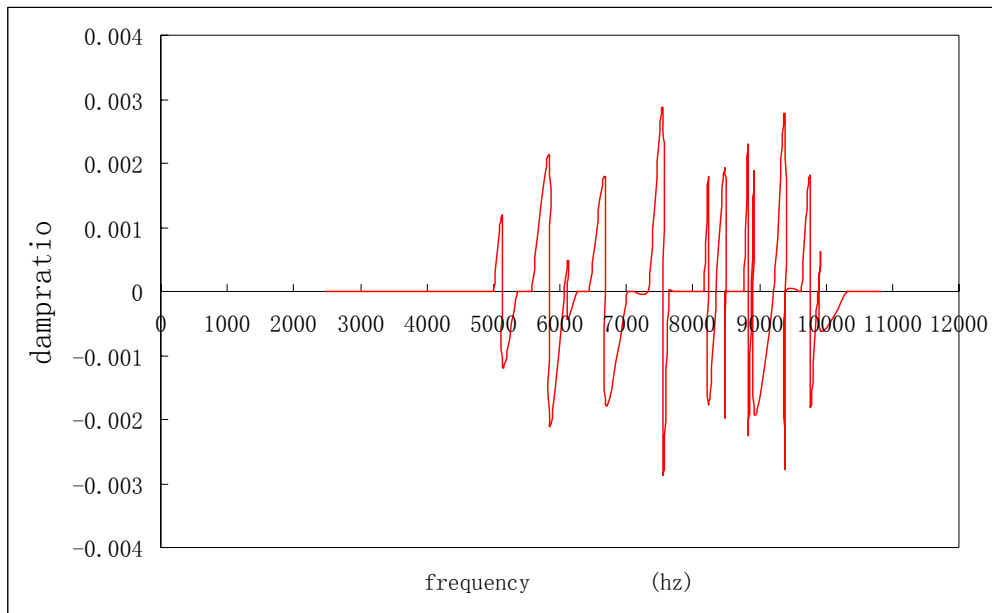


Figure 3 – Freq.-Damping ratio curve with friction coefficient 0.319

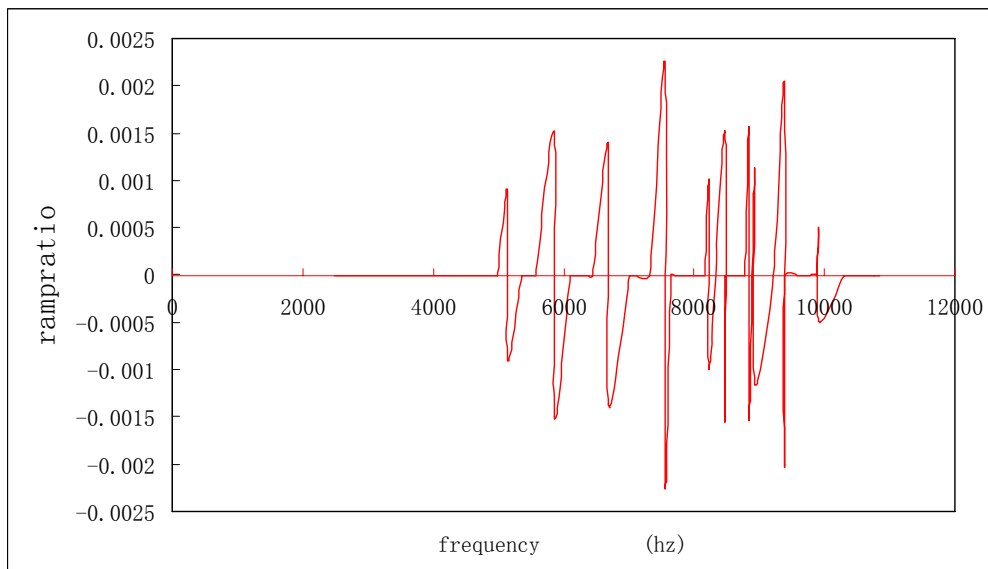


Figure 4 – Freq.-Damping ratio curve with friction coefficient 0.25

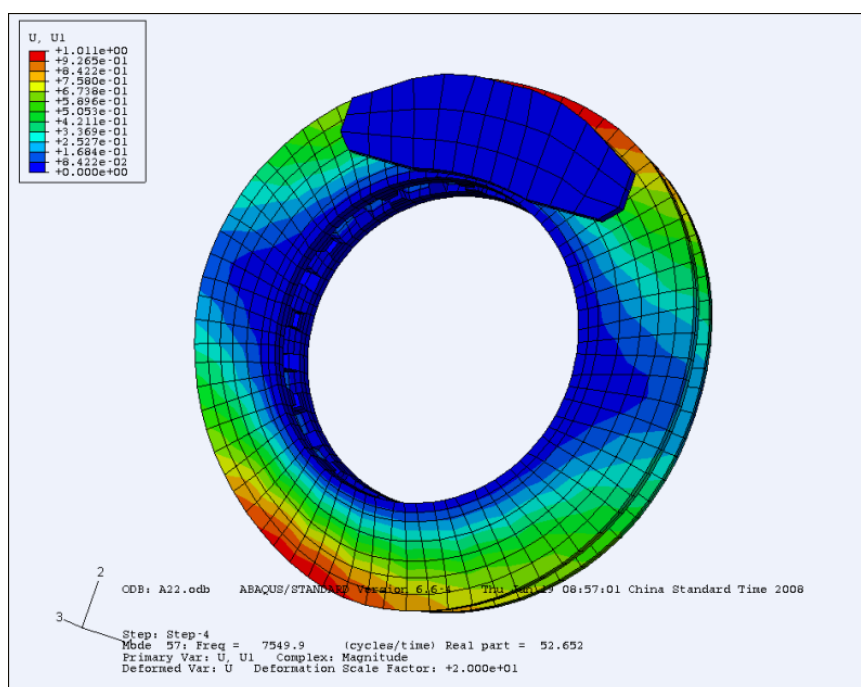


Figure 5 – Vibration mode of system at 7549Hz

4. TRANSIENT ANALYSIS WITH THERMAL EFFECT

A subsequent transient analysis with ABAQUS/Explicit is taken to study the thermal effect during deceleration of brake ^[4]. The velocity of rotor is initially 266.1 rad/s, and decrease to 0. And it is assumed that the motion of rotor is only affected by pads. Both the pressure and friction between pads and rotor are speed dependant, as shown in table 1.

Table 1 – Pressure and FC

Speed (Km/h)	Angular velocity (rad/s)	Pressure (MPa)	FC
0	0	0.758407	0.374
10	6.459948	0.758407	0.278
118	76.22739	0.556197	0.251
230	148.5788	0.414978	0.25
350	226.0982	0.263906	0.319

To implement the speed dependence of loads, we developed an ABAQUS subroutine VUAMP. The Angular velocity is stored in a state variable SVARS (1) and the subroutine interpolate pressure to be applied to pad surface linearly according to SVARS (1). In addition, when the angular velocity became zero, the subroutine terminates the analysis. In this case, we only include convectonal heat exchange between brake system and environment.

The temperature and stress distributions at different time are shown through figure 6 to figure 8. Since the speed of heat generation is much rapid than convection, thermal stress appears due to temperature gradient. After several rotations, the distribution of temperature and stress become axisymmetrically uniform.

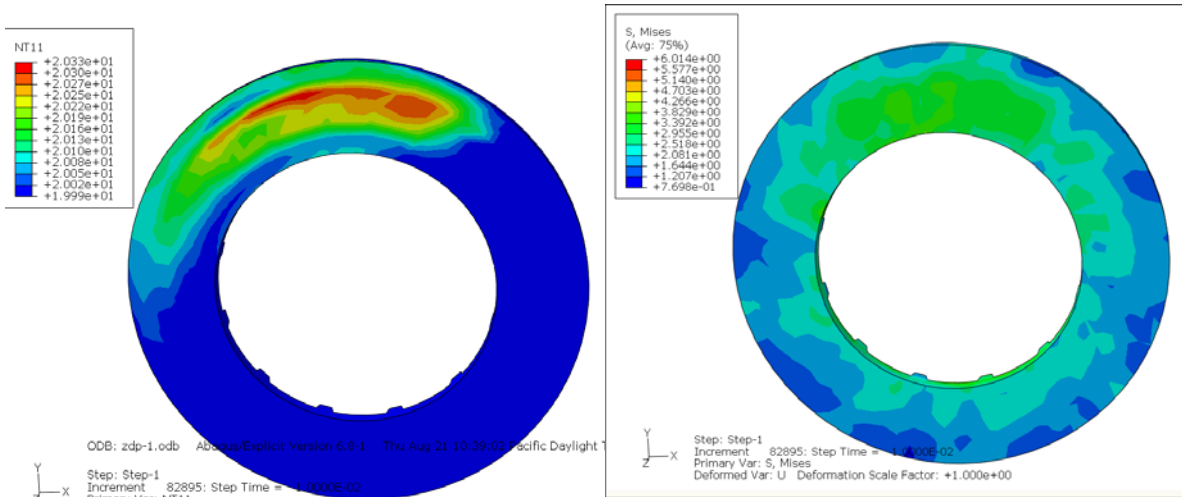


Figure 6 Temperature (left) and stress (right) distribution at the beginning

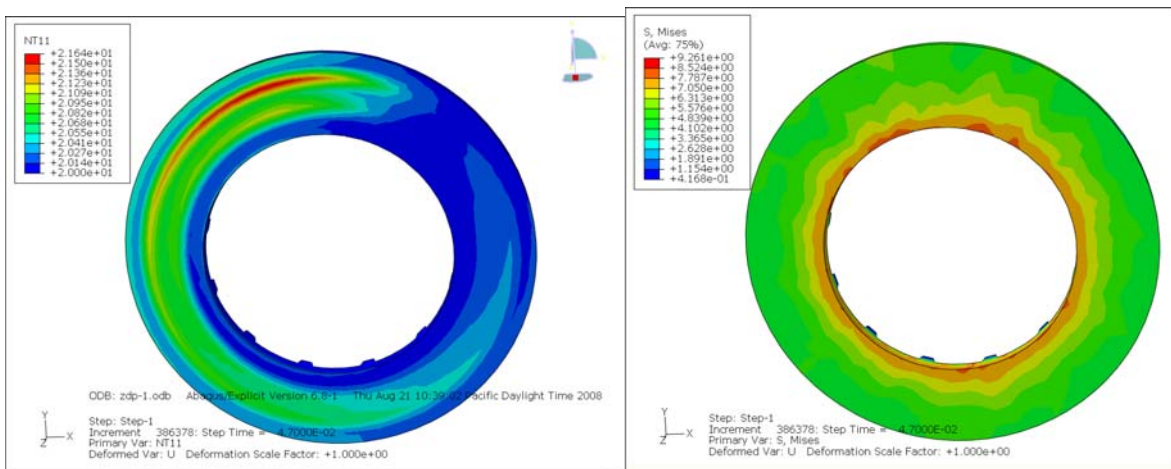


Figure 7 Temperature (left) and stress (right) distribution at 1st rotation

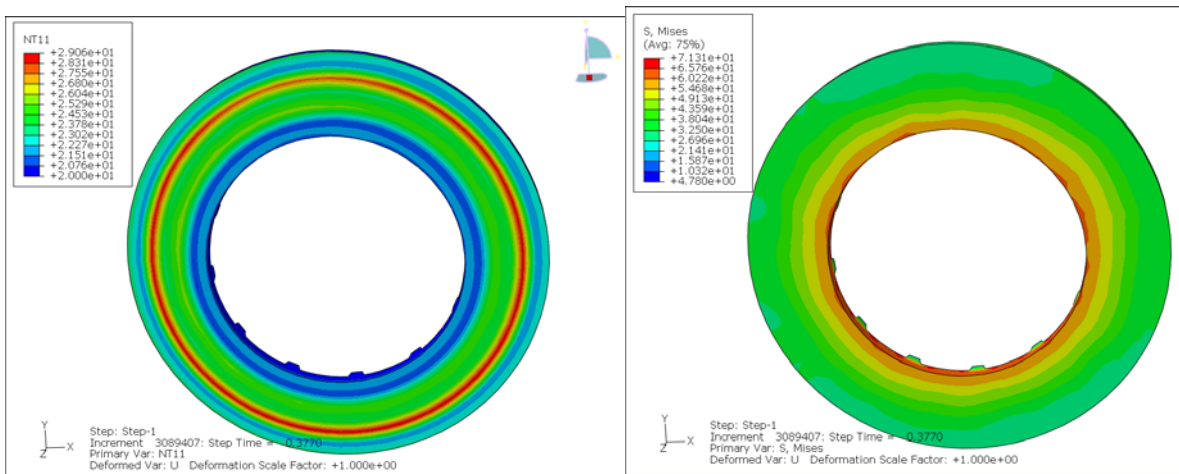


Figure 8 Temperature (left) and stress (right) distribution at 7th rotation

5. CONCLUSIONS

In this paper, we present a method of brake squeal analysis with aid of ANSA and ABAQUS. Complex modal analysis is employed to extract natural frequencies and a transient analysis is carried out to study the thermal effects during braking. The effect of friction in complex modal analysis is investigated. The coupling of thermal effect and squeal is to be studied in future.

REFERENCES

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- (4) ABAQUS Analysis User's Manual, 6.10