Complex eigenvalues method and its usage as analysing tool for squeal reduction in brake system

I.A. Magomedov, U.R. Tahaev

Chechen State University, Grozny

Annotation: This work investigates squeal propensity problem arising during normal braking. Narrative of this work is suggesting complex eigenvalues method to found out tendency of squeal propensity. The work also provides a brief introduction of complex eigenvalues method and literature review of the problem, which shows study done in this field by other investigators. Frequencies and instability measurements were calculated. Afterward standard deviations were plot to found out whether squeal will be reduced or amplified, within chosen parameters. The results illustrated that by increasing the coefficient of friction the instability measurement will increase and reduce when hydraulic pressure increased.

Keywords: complex eigenvalues, squeal propensity, standard deviation, brake system, squeal reduction, instability measurements

Self-excited vibrations seem to appear in numerous mechanical systems with sliding contacts and brake system is not an exception. The followings are major reasons for excitation of mechanisms, in this case excitation of brake system: sliding velocity, applied normal load, coefficient of friction and sliding components'stiffness.Therefore, it is important to identify whether a system is stable or not by utilizing the complex eigenvalue analysis/method [1, 2].To recognize arising problem of squeal in the brake system FE (Finite Element) method was used numerous time and in the future to use it as predicting tool. The most frequentlyutilized method is the (CEA) complex eigenvalue analysis [3]. Complex eigenvalues (CE) generally result from the frictional coupling of brake components due to the off-diagonal terms that arise in the stiffness matrix of the system causing it to be unsymmetrical [4]. CE with positive real parts to be considered as unbalanced modes, which always appear in complex conjugate pairs. Therefore, these unbalanced (unstable) modes are likely tolead to squeal noise occurrence. The mainminus of carrying out a complex eigenvalue analysis usingFE analysis is time required for an analysis and consequently needslargecalculating power [5].

Lee et al [6] performed a non-linear contact analysis to investigate the interfacial interaction behavior of a disc brake system. Additionally, the modal study was performed, using CEA, to compute the natural frequencies and the mode shapes of a disc brake system. The results illustrated that the major reason to the linearization process lies in changing only the non-linear elements, which are closed (in-contact) as a result of the applied force with equivalent linear interface elements. The propensity of the system to squeal was represented by a single number as against a set of eigenvalues. The number was derived from the standard deviation of all positive instability measures of those eigenvalues within a pre-determined frequency range from the mean value of zero. It was established that the instability standard deviation was directly related to the magnitude of rubbing interface friction coefficient but independent of the brake hydraulic pressure [7].

The standard deviation of normal contact pressure can also be employed to represent the non-uniformity of contact pressure distribution. The standard deviations of friction forces and normal contact forces are proportional to the coefficient of friction. It was also found that the smaller the standard deviation of the normal contact forces, the more uniform was the interfacial pressure distribution.

M. Nouby [8] did an investigation of brake disc squeal by utilising complex eigenvalues. He used ABAQUS program in his work to look into the problem. At the beginning he conducted a hammer test to work out mode shapes and compared them with the FE results. The correlations illustrated that the percentage of difference is low. He conducted work with a different approach to find the best results by changing Young's modules, chamfer and backplates etc., but this works not taking into consideration these factors. However, he mentioned that an increase in friction coefficient leads to increase of instability in the brake system. This is due to the higher friction coefficient, which leads to an increase of friction forces, which tends to excite a greater number of unstable modes [9]. Therefore, it will lead to greater standard deviation that will subsequently increase propensity of squeal.

Results

Complex eigenvalue method was used to calculate the frequencies and instability measurements by utilizing ANSYS. Firstly, with variation of coefficient of friction in dynamic analysis the frequencies and instability measurements were computed. Similarly with variation of pressure which has been used in dynamic analysis frequencies and instability measurements were computed. Figure 1 and 2 represents frequency against instability measurement. After that the standard deviations were found for each case and then figure 3 was plotted.

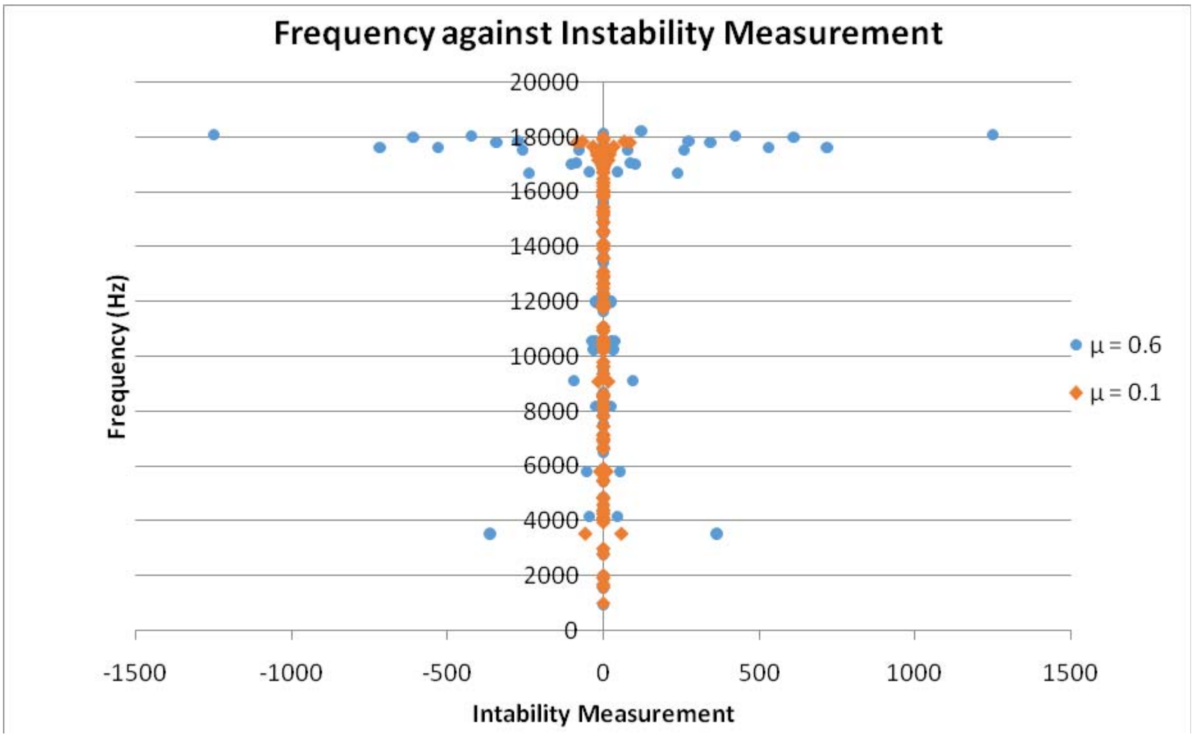

Fig.1.Frequency against instability measurement with varying friction coefficient

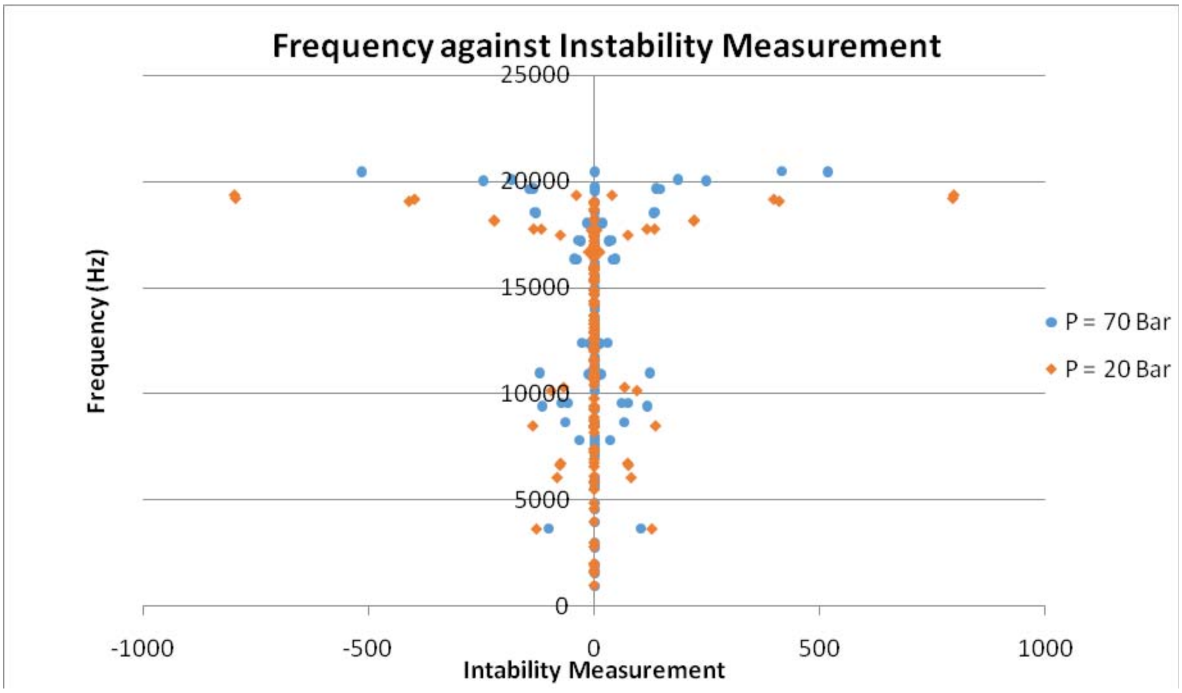

Fig. 2 Frequency against instability measurement with varying friction coefficient

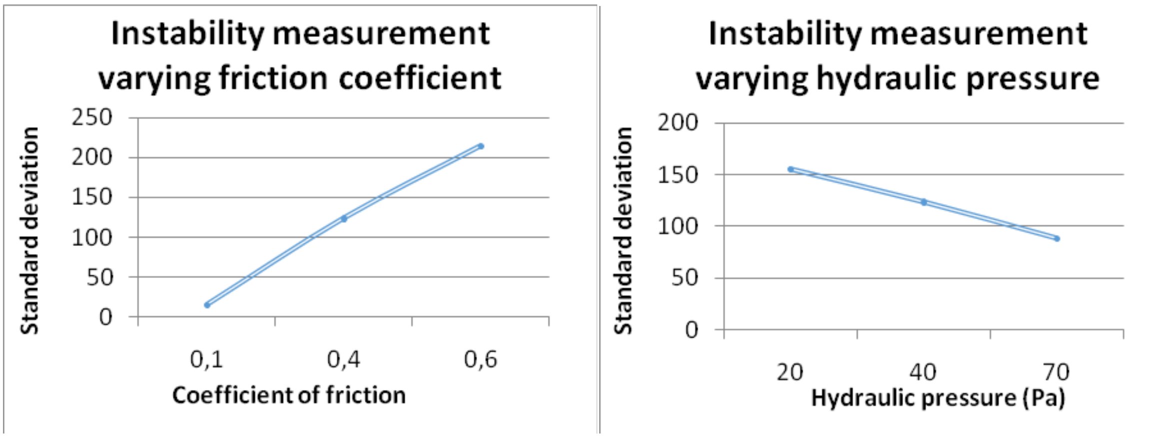

Fig. 3. Instability measurement of varying friction coefficient and hydraulic pressure

Two graphs from complex eigenvalues showed good representation of squeal propensity. It was mentioned by Nouby that greater standard deviation of instability measurement would lead to greater propensity of squeal. By observing the graphs, it can be said that by increasing the coefficient of friction the instability measurement will increase and reduction when hydraulic pressure increased.

Therefore, squeal reduction will appear when hydraulic pressure increased and pressure distribution will be more uniform as well.

Conclusion

To conclude, following work was done to investigate brake system using complex eigenvalues method. The main focus was to look into squeal propensity in the brake system and to understand which parameters can influence in terms of reducing or increasing squeal propensity. The results illustrated good correlations with previous work done by researchers in this field. It can be also said that the method complex eigenvalues method or approach needs some improvement, but in general it is able to compute the tendency of the brake system to squeal.

References

1. A. Nobari, Statistics of complex eigenvalues in friction-induced vibration, School of Engineering, University of Liverpool, United Kingdom, 1972. pp. 1-2

2. Lee, Y.S., Brooks, P.C., Barton, D.C., Crolla, D.A., “A predictive tool to evaluate disc brake squeal propensity. Part 2: System linearisation and modal analysis”, International Journal of Vehicle Design, vol. 31, pp.309-329. 20

3. J. Roberto, Analysis of brake squeal noise using the finite element method: A parametric study, Federal University of Santa Catarina, 2007. p. 3

4. A. Belhocine, Effects of material properties on generation of brake squeal noise using finite element method, Department of Mechanical Engineering, USTO Oran University, Latin American Journal of Solids and Structures,2015. pp. 1438

5. P.C. Brooks and D.C. Barton, “Brake system noise and vibration- a review”, Braking 2002: From the Driver to the Road, 2002, pp. 53-73

6. Lee, Y.S., Brooks, P.C., Barton, D.C., Crolla, D.A., “A predictive tool to evaluate disc brake squeal propensity. Part 2: System linearisation and modal analysis, International Journal of Vehicle Design, vol. 31, 2003, pp.309-329

7. Tirovic, M. and Day, A. (1991). Disc brake interface pressure distributions.

ARCHIVE: Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 1989-1996 (vols 203-210), 205(24), pp.137-146.

8. Nouby, M. and Mathivanan, D. (2009). A combined approach of complex eigenvalue analysis and design of experiments (DOE) to study disc brake squeal. International Journal of Engineering, Science and Technology, 2009. p. 2.

9. Magomedov I. A., Mezhieva A.I., Suleymanova M.A. Inženernyj vestnik Dona (Rus). 2018. №4. URL:ivdon.ru/ru/magazine/archive/n4y2018/5334.

10. Magomadov V.S. Quantum computing, quantum theory and artificial intelligence. Inženernyj vestnik Dona (Rus). 2018. №4. URL: ivdon.ru/ru/magazine/archive/n4y2018/5424.