

Effects of Chemical Components and Manufacturing Process of Cast Iron Brake Disc on its Resonant Frequency Variation

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ABSTRACT

Many engineers have been working to reduce brake noise in many ways for a long time. So far, a progress has been made in preventing and predicting brake noise. Nevertheless, there are some discrepancies of brake noise generation propensity between testing for the prototype and the production. As known in general, the reason for this unpredicted brake noise occurrence in production is partly due to the variation of the resonant frequency, material and the other unpredictable or unmanageable variations of the components in a brake system. In this paper, effects of chemical components and casting process of gray iron brake disc on its resonant frequency variation have been studied. Especially this paper is focused on the variation in material aspects and manufacturing parameters during disc casting in usual production condition. And their effects are investigated by the variation of out-of-plane modal resonant frequency.

INTRODUCTION

Brake squeal is still annoying engineers of many other companies as its prediction and prevention are challenging. Disc modal coupling and mode lock-in are known to be effective ways of transferring and accumulating vibration energy of an unstable brake system when it squeals on braking. Also this squeal mechanism is believed to be categorized as inherent characteristic of a brake system [1]. When designing a brake system, it is known to be helpful to decouple modes of discs from the other parts such as calipers and

pads to prevent in a certain frequency range of brake squeal. It means that brake disc should maintain its modal characteristics irrespective of the materials to make a brake system be noise insensitive. Here, the inherent modal characteristic is defined as a function of modal damping, mode shape and resonant frequency. These parameters are again the function of mass, stiffness and dimension. The stiffness is closely related to the material of disc because the material resolves the modulus. The material variation may be able to make the modal decoupling action for a brake system useless if its modulus changes much from what it is supposed to be. However, this material variation is somehow inevitable to certain extent as the brake disc is manufactured by casting process. As is known this casting process is not a delicate process like semiconductor manufacturing process. J.B. Malosh mentioned in his paper that CE (carbon equivalent) plays a significant role in the modulus and so does the resonant frequency variation. The main focus of this paper is to study effects of manufacturing parameters and the chemistry within the general control range on the variation of modal natural frequency of a brake disc including the effect of CE.

THEORETICAL BACKGROUND

A brake system which is robust to squeal is described by F. Chen et al. [1]. In the view of brake disc modal decoupling, disc should maintain $\pm 1.5\%$ of resonant frequency variation for robustness, assuming that all the other brake components are decoupled sufficiently. This means that if the resonant frequency of a brake disc varies much more than $\pm 1.5\%$, it is more vulnerable to

squeal. J.B. Malosh derived some equations that predict the resonant frequency variation of discs according to the CE (carbon equivalent). The equation (1) is one of those equations applicable to disc which is manufactured within the range of $3.3 \leq CE \leq 4.8$.

$$\Delta f = \frac{\Delta CE}{2 \times \left(\frac{5.74}{CE} - 1 \right)} \quad (\text{Eq.1})$$

$$\text{where, } \Delta CE(\%) = \frac{\partial CE}{CE(\text{NOMINAL})} \times 100$$

$$\Delta f(\%) = \frac{\partial f}{\text{frequency}(\text{NOMINAL})} \times 100$$

∂CE : the variation of CE
 ∂f : the variation of frequency

One of the other equations is $E \text{ (GPa)} = 310.3 - 54.1CE$, where E is modulus of elasticity. He mentioned that CE of the iron resolves the amount and the morphology of graphite. The modulus of elasticity and the damping capacity of the iron are directly influenced by them. He finished his paper concluding that the resonant frequencies can be significantly shifted by varying carbon equivalent of the iron [2]. As gray iron consists of pearlite matrix and graphite flakes, it seems like that both the pearlite matrix and the graphite resolve elastic modulus. But, the effect of pearlite matrix of cast iron is not considered in his paper. Generally, the bulk tensile strength and the bulk hardness are sensitive to graphite and the matrix. They change along the tensile to hardness ratio as CE changes [3]. That is why the elastic modulus and the damping capacity change mainly with the graphite. These properties are believed to be highly constant along the constant tensile strength to hardness ratio as CE changes. The dislocation damping mechanism in graphite crystal irrespective of the matrix dominantly determines the damping coefficient may explain the relationship between the graphite and the damping capacity [4]. In these respects, any parameter that has an effect on the length and the morphology of graphite flake seem like to have effects on the resonant frequency as well as damping. Among the chemistry and the casting parameters, shake out time and the pouring temperature would be the major concerns for study in this paper. Other manufacturing factors such as charge material (cast iron, steel scrap, pig iron), the type of melting device, etc. which are supposed to have great effects on graphite [5] are assumed to be set for each test. They are not considered in this paper.

EXPERIMENTAL PROCEDURE

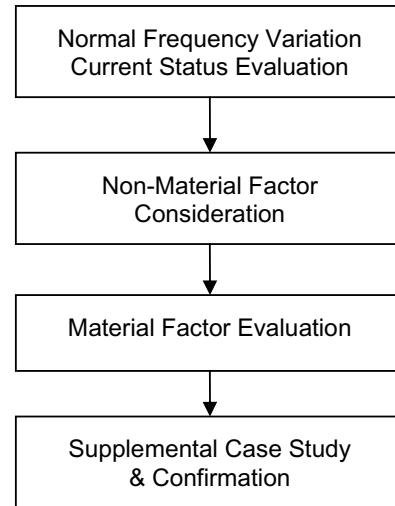


Figure 1. Evaluation Procedure

NORMAL FREQUENCY VARIATION

Two different types of commercial brake discs (disc A & B) were chosen to evaluate the correlation between the resonant frequency and the material properties (chemical composition and microstructure). These two types have different shapes and are made of different grade of gray iron. 30 pieces from each type were taken at random for several months. The resonant frequencies of those discs were measured. Especially the out-of-plane mode of the resonant frequency is displayed to represent the modal frequency of the discs as in Table 1.

Table 1. General Resonant Frequency Variation of Brake Disc A and B

Mode	Disc A		Disc B	
	Average Frequency: μ (Hz)	$\Delta f / \mu$ (%)	Average Frequency: μ (Hz)	$\Delta f / \mu$ (%)
1st	905	4.0	1068	3.4
2nd	1909	3.6	2114	4.2
3rd	2192	4.0	2384	3.5
4th	3635	4.1	3828	3.4
5th	5132	4.2	5326	3.4
6th	6660	4.2	6854	4.0
7th	8213	4.2	8413	3.1
8th	9793	4.3	9995	3.2
9th	11400	4.4	11611	3.1
10th	13022	4.3	13264	3.1