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Effect of lateral run-out on calliper drag in automotive disc brakes

S.H. Masood[1] and Lakhwinder Singh[1]

[1]Faculty of Engineering & Industrial Sciences,
Swinburne University of Technology, Hawthorn, Victoria 3122

Abstract: Efficiency of an automotive disc brake system is affected by several factors such as lateral run out (LRO), caliper housing stiffness, lining compressibility, seal/groove design, brake fluid, and pad material. A minor deviation in any of these factors may lead to problems like brake noise, vibration and off-brake caliper drag in the brake system. This paper presents an experimental study of the effect of LRO on calliper drag by measuring drag with respect to LRO for different types of callipers at varied speeds. This study is important because in automotive industry, different methods are used for testing different types of calipers with different LRO values. Results indicate that the effect of increasing LRO on off-brake caliper drag is caliper dependent.

Keywords: Disc brakes, brake callipers, calliper drag, lateral run out, design

1 Introduction

In the development of a vehicle, the task of specifying a brake system is one of the most crucial decisions. Improved vehicle aerodynamics, more horsepower, higher loads and increased road safety all create the need for more effective brake systems. Like suspension technology and fuel-system technology, brake technology has come a long way in recent years.

A typical disc brake system consists of a caliper and a rotor. During brake application, fluid pressure activates the piston towards the rotor, which forces the brake pads to rub against the rotor and generate braking torque. The caliper housing is deflected during brake application and springs back into its original position after brake release. The caliper housing may not fully retract after the brake is released. This leads to a residual contact between pad and rotor and hence generates off-brake calliper drag. This drag affects fuel efficiency and lining life and increases temperature and wear of rotor and pads. This off-brake calliper drag is greatly affected by lateral run-out (LRO), which is defined as the side-to-side motion of the rotor as it turns on the hub.

LRO is most often the result of small inconsistencies in the rotor and vehicle hub that are magnified when combined. LRO can also be induced by uneven wheel torque, improperly adjusted or worn wheel bearings, corrosion, or damage from hitting a curb or pothole. Any of these conditions can easily lead to a poor brake performance that will worsen over time.

LRO within the specified limits helps to reduce the off-brake caliper drag by pushing the piston back. Due to the side-to-side motion of rotor, it hits the pads back from contact of the disc and pushes back the unretracted piston. The general specification for lateral disc run-out should be less than 0.15 mm but should not exceed 0.20 mm even in exceptional cases.

Although many studies have been reported that deal with stability analysis of brakes and its components [1-6], meagre literature is available on relationship between various physical parameters existing in a brake system. This may be attributed to the fact that majority of these test studies are conducted in industry and are not reported in the literature as they are considered to be confidential to the industry.

Tamasho et al [7] investigated the relationship between calliper inclination and disc rotor wear for reducing brake drag torque in the non-braking mode for a floating disc brake. Calliper behaviour was then correlated with drag torque by measuring the displacement of brake components along with drag torque in the non-braking mode with the disc rotating freely.

Anwana et al. [8] identified several critical design parameters in the seal/seal groove assembly and quantified their impact on the brake performance parameters. Design of seal-groove assembly plays important role in controlling the factors which directly affect the brake performance parameters such as fluid displacement, piston retraction, piston sliding force and brake drag. Asymmetric finite element model of the seal groove assembly was developed, which can reasonably predict the seal retraction behaviour analytically for a given set or space of design parameters. This may be helpful in modifying other components of the brake calliper system at early stage of product design cycle.

MacLennan [9] has conducted an analytical and experimental study to demonstrate that the spline profile and the disc geometry have a little effect upon drag, while the position on which the calliper was mounted had a considerable influence. The experimental studies show that a high drag torque is acquired without applying force to the brake pads. This implies that a strong relationship exists between the calliper position and the drag torque.

This paper presents an experimental investigation on the behaviour of drag with respect to lateral run-out in disc brakes. A calliper drag rig has been used to conduct drag tests. It has been proposed that a dependency exists between calliper drag and LRO. Tests have been conducted to measure drag with varying lateral run-out at different speeds using different types of callipers.

2 Test Procedure

All the tests have been conducted on a drag test rig, which was fitted with a dial gauge to measure LRO and a G-clamp to push back the piston. The same rig is also used to measure fluid displacement in a caliper. The caliper assembly is mounted over the rotor ensuring the friction material is not damaged by the edge of the rotor. Before fixing the caliper to the fixture it is important to keep the caliper bleed screw to the top for proper orientation. Figure 1 shows the set up for later run out measuremet, in which the rotor is turned manually (about 1 revolution in 10 seconds) and the difference between the minimum and maximum reading on the dial gauge for a full rotor rotation gives the lateral run out value. For larger/smaller LRO adjustment, aluminium foil/steel shims are placed between rotor and rotor adapter to induce the correct amount of lateral run out.

Before starting the drag test on rig, necessary tasks to prepare the caliper for drag testing included: purging air from the caliper, setting the start position of the pads 0.5mm from the rotor friction surface, and venting the guide pin boot pressure to atmospheric pressure in the test start position

Tests have been conducted to measure the pre-knee point off-brake drag. As the pressure applied on calliper increases, a point comes where drag increases suddenly, that is, the slope of drag-pressure curve undergoes a sudden increase due to zero running clearance. Drag values prior to this point are called pre-knee point drag. In this study, only pre-knee point off-brake drag has been analysed.

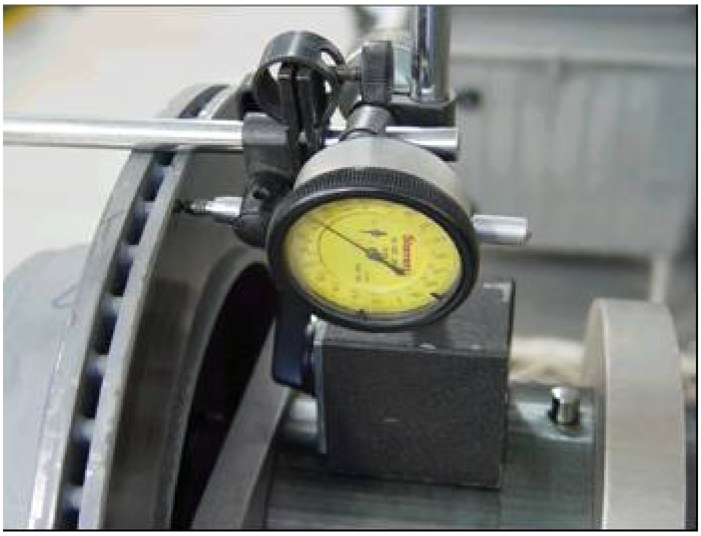

Figure 1 Measurement of lateral run-out

Furthermore, tests have been conducted in the following two modes: (a) with indexing: in which the rotor returns back to its original position prior to a new pressure pre-condition, and (b) without indexing: in which the rotor does not return to its original position with subsequent pressure pre-conditions.

Drag tests have been conducted on a range of calipers (Table 1) to quantify the effect of LRO on caliper drag at three different speeds (400 rpm, 850 rpm and 900 rpm). These calipers are of different designs used in different automobiles by different manufacturers. Three LRO settings have been used for the testing. These settings are 15 ±5 µm, 55 ±10 µm and 110 ±10 µm.

Table 1 Description of callipers used

Caliper ID	Piston Type	Caliper Type
C-1	Double piston	Pin slide
C-2	Double piston	Pin slide
C-3	Double piston	Pin slide
C-4	Six piston	Opposed piston
C-5	Double piston	Pin slide
C-6	Single piston	Pin slide

3 Results and Discussion

Results have been obtained for each caliper in terms of variation of average drag (in Nm) with variation in lateral run out with indexing mode and without indexing mode for different rotor speed in rpm. Analysis has been carried out for each of the six calipers to predict the relationship between drag and lateral run-out and effect of indexing. In order to determine the effect of indexing, paired t-test at 95% level of significance has been applied to percentage change in average drag.

Table 2 Average drag (Nm) of Calliper C-1 at different speeds and LROs (µm)

Speed (rpm)	Lateral run-out (µm)			Difference in average drag (Nm) by changing LRO	Percentage Change in average drag	Effect of increasing the LRO on drag (increases/decreases)
	20	52	105			
With indexing						
400	0.54	0.19	0.13	0.41	76	Decreases
800	0.55	0.16	0.09	0.46	84	Decreases
950	0.50	0.08	0.06	0.44	88	Decreases
Without indexing						
400	0.59	0.12	0.11	0.48	81	Decreases
800	0.35	0.16	0.03	0.32	91	Decreases
950	0.40	0.09	0.05	0.35	88	Decreases

Table 2 shows the results for caliper C-1, where tests were conducted at LRO values of 20, 52 and 105 micron. The table also shows the difference between the minimum and maximum drag values and the percentage change in average drag. Figure 2 shows the variation of avarage drag with LRO when tests were performed with rotor indexing, and Figure 3 shows the variation when performed without rotor indexing. It is evident from the figures that an increase in lateral run-out leads to a decrease in drag for all cases tested for C-1. Average drag decreases in the range of 0.41 Nm - 0.46 Nm and 0.32 Nm - 0.48 Nm for test with indexing and without indexing, respectively.

Figure 4 and Figure 5 show the results for calliper C-4 when tests were performed at LRO values of 19, 51 and 108 micron with and without rotor indexing respectively. The effect of increasing lateral run-out in C-4 is found to be opposite to that shown by calliper C-1. For C-4, increase in LRO causes increase in off-brake drag as shown in the two figures. Thus tests conducted both with and without indexing result in increasing drag with LRO (between 0.59 Nm and 0.77 Nm for with indexing, between 0.17 Nm and 0.48 Nm).

Results were obtained for other four callipers but are not shown here due to space limitation. Table 3 shows the summary of observations obtained from each of the six callipers tested. A comparison of the results provides some interesting observations and inferences:

- For callipers C-1, C-2 and C-3 type, the drag decreases with increase in lateral run-out for testing irrespective of the fact whether indexing has been performed or not.
- For calliper C-4, the drag increases with increase in the lateral run-out for all tests.
- Drag first decreases and then increases for C-5 when test is performed with indexing. It may be said that such behaviour does not follow any trend in particular. When tested without indexing the drag follows an increasing trend with LRO.
- For calliper C-6, the drag does not show any particular trend with LRO in all test situations.

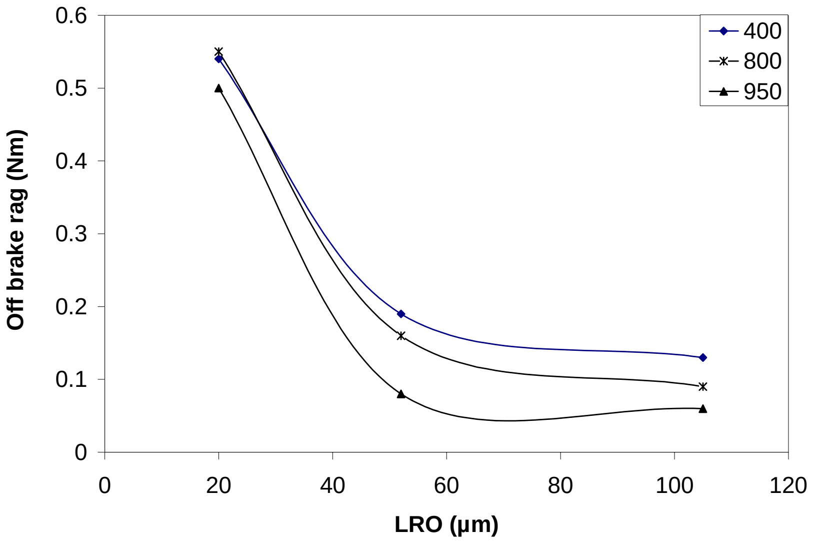

Figure 2 Average drag (Nm) of C-1 with rotor indexing

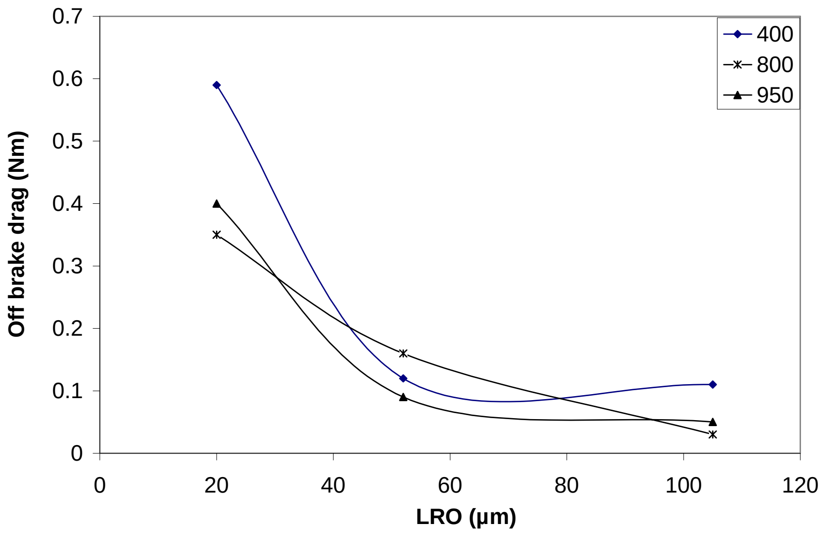

Figure 3 Average drag (Nm) of C-1 without rotor indexing

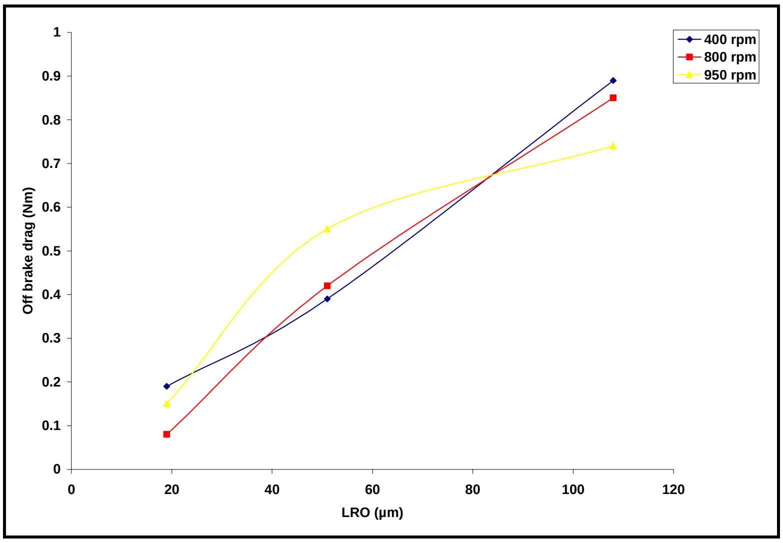

Figure 4 Average drag (Nm) of C-4 with rotor indexing

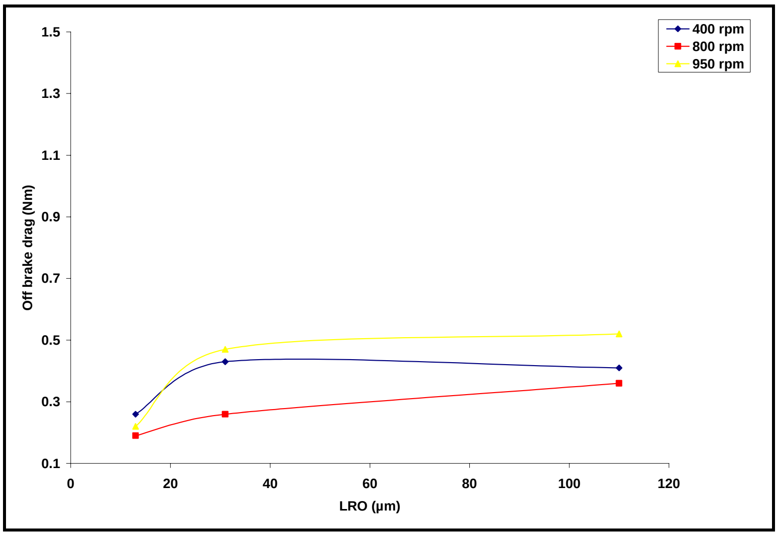

Figure 5 Average drag (Nm) of C-4 without rotor indexing

Results show that there is no conclusive evidence to suggest that indexing the rotor will produce significant changes in the drag-LRO relationship. The effect is dependent on the type of calliper. Calliper C-5 demonstrates that increasing the LRO causes increase in drag without indexing the rotor. When the rotor is indexed to the maximum inboard LRO for pressure pre- conditioning, the LRO-drag relationship shows no trend. Results indicate that only in specific cases, an increase in LRO will cause an increase in drag. It can be concluded that the effect of increasing LRO on off-brake calliper drag is calliper dependent.

Table 3 Summary of drag behaviour with respect to LRO for the six callipers

Caliper ID	Increases/Decreases (Drag from Min LRO to Max LRO)			Minimum Drag occurs at LRO(μm)	
	With Indexing	**Without Indexing**	**Statistically siginificant**	**With Indexing**	**Without Indexing**
C-1	Decreases	Decreases	No	105	105
C-2	Decreases	Decreases	Yes	116	100
C-3	Decreases	Decreases	No	105	110
C-4	Increases	Increases	Yes	19	13
C-5	No trend	Increases	No	54	18
C-6	No trend	No trend	No	61	50

4 Conclusions

Experiments were performed for studying the off-brake drag characteristics of an automotive brake calliper. The study was conducted on disc brake callipers to predict the relationship which in turn would be helpful in improving the calliper design. Behaviour of the drag with variation in lateral run-out shall be helpful in determining the optimum value of lateral run-out so as to minimize drag. Drag tests were performed on six different types of callipers at three speeds both with rotor indexing and without indexing. It was observed that for three samples of callipers, the drag decreased with increasing lateral run-out. Drag increased with LRO on a fourth sample. A fifth sample demonstrated no trend with indexing but an increasing trend without indexing. The last calliper showed no trend in both cases of with and without rotor indexing. The results indicate that the effect of LRO on off-brake calliper drag is calliper dependant.

References

[1] Chamaillard, Y et al, ‘An original braking torque with torque sensor’, *IEEE*, No. WE-4-2, 1994, pp. 619-625.

[2] Peronne, JM et al, ‘Dynamic aspects of a caliper brake system’, *JSAE Review*, vol. 16, 1995, pp 491-496.

[3] Hohmann, C et al, ‘Contact analysis for drum brakes and disk brakes using ADINA’, *Computers and Structures*, vol. 72, 1999, pp. 185-198.

[4] Kuang, ML et al, ‘Hydraulic brake system modeling and control for active control of vehicle dynamics’, *Proceedings of the American Contro Conference*, San Diego, 1999, pp. 4538-4542.

[5] Luquan, R et al, ‘Dynamic system identification of AUDI disc brake under anti-lock condition’ *IEEE*, 1999, pp. 78-81.

[6] Jearsiripongkul, T et al, ‘Stability analysis of a new model for floating caliper disk brake’, *IEEE ICIT’02*, Bangkok, Thailand, 2002, pp. 535-539.

[7] Tamasho, T et al, ‘Technique for reducing brake drag torque in the non-braking mode’, *JSAE review*, vol. 21, 2000, pp. 67-72.

[8] Maclennan, LD, ‘Analysis of brake assembly with floting disc’, *Proceedings of Institution of Mechanical Engineers*, vol. 218, 2004, pp. 1021-1032.

[9] Anwana, OD, Cai, H and Chang HT, ‘Analysis of brake caliper seal-groove design’, *SAE 2002 World Congress* Detriot, Michigan, 2002, no. 2002-01-0927.