Effect of a Variable Radius Cam Shaft on Brake Shoe Engagement Sequence in Cable-Operated Drum Brakes: An Experimental Study Using Dial Gauge Measurements

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***Abstract*—This paper examines a simple design change to the cam shaft of a cable-operated drum brake enlarging the contact-face corner radius on the leading shoe side while retaining the standard radius on the trailing shoe side and quantifies its effect on brake shoe engagement using direct dial gauge measurements. Two cam shafts were tested on the same drum brake assembly: a Constant Radius Cam (CRC) with all four corner radii equal at 2 mm, and a Variable Radius Cam (VRC) with 4 mm corners on the leading side and 2 mm corners on the trailing side. Dial gauges mounted on both shoes recorded radial expansion at 5 mm increments of cam lever travel, from the free position (120 mm) to full application (85 mm).**

With the CRC, both shoes expanded together: the trailing-to-leading expansion difference remained within ±0.02 mm over the full stroke, indicating engagement that is simultaneous within the resolution of the measurement. With the VRC, the leading shoe lifted markedly more slowly at 5 mm of stroke it had expanded 0.073 mm against 0.190 mm for the trailing shoe, a trailing-to-leading ratio of 2.60 so the de-energized trailing shoe contacts the drum first at every stroke position. The three nominally identical 2 mm faces (CRC leading, CRC trailing, and VRC trailing) produced closely matching lift curves, agreeing within 0.005 mm at first contact, which serves as an internal consistency check on the measurement. The study measured engagement kinematics only; acoustic noise was not measured, and the implications for brake noise are inferred from the measured engagement sequence together with mechanisms established in the literature. The full data set, the mechanism, and practical design guidance are presented.

I. INTRODUCTION

Persistent brake-noise complaints are common on cable-operated drum brakes fitted to motorcycles and scooters. A lining change is the usual field response, yet the complaint often returns, because the lining is frequently not the root cause. In many cases the contributing factor lies further upstream, in the cam shaft and the way it distributes lift between the two brake shoes.

This paper reports a focused experiment. A drum brake assembly was mounted on a bench fixture, dial gauges were placed on both brake shoes, and the radial movement of each shoe was recorded at every 5 mm of cam lever travel. The procedure was carried out for two cam shafts that differ only in the corner radii of their contact faces. The measurements reveal a clear kinematic difference between the designs and point to a preferred geometry.

The cam found to behave more favourably the Variable Radius Cam (VRC) has a larger corner radius on the leading shoe side and the standard radius on the trailing shoe side. Although a 2 mm difference in a corner radius appears minor, its effect on the shoe engagement sequence is large.

Scope of the Study

Two cam designs are compared directly using shoe expansion measurements:

- Constant Radius Cam (CRC): all four-cam contact-face corner radii equal at 2 mm; a common production design.

- Variable Radius Cam (VRC): leading-side corners 4 mm, trailing-side corners 2 mm; the proposed design.

The study quantifies engagement kinematics. It does not measure acoustic noise: statements about noise are presented as expectations drawn from the measured kinematics and the published literature, not as measured results.

II. BACKGROUND

Drum brake squeal has been investigated since the 1950s. Fosberry and Holubecki at the Motor Industry Research Association showed experimentally that squeal is associated with self-excited vibration of the shoe against the drum, with the leading shoe implicated as the principal source [1]. Millner subsequently developed a theory of drum brake squeal linking instability to the coupling of system vibration modes [2], and Hultén demonstrated that such friction-induced instability can arise even with a constant coefficient of friction, with the shoe acting as the “motor” of the vibration [3]. The review by Kinkaid et al. summarises the mode-coupling framework that now underpins brake squeal analysis [4]. Experimental work on drum brake noise counter-measures, such as that of Kusano et al., has concentrated on shoe, lining, and drum modifications [5].

Limpert [6] and Day [7] describe how the cam converts cable tension into shoe force and how cam profile geometry sets the shoe expansion rate. However, a deliberate radius difference between the leading and trailing cam contact faces does not appear to have been examined in the open literature as a means of ordering shoe engagement. Providing direct, simultaneous dial gauge measurement of both shoes for two cam radius configurations is the specific contribution of the present study.

The engagement behaviour at low cam stroke is of particular interest for electric two-wheelers. With regenerative braking handling routine deceleration [8], the mechanical drum brake on an electric scooter is applied mainly in light, short applications at low cam stroke, and the near-silent powertrain leaves any brake noise fully audible. The low-stroke region is therefore the operating zone that matters most on such platforms.

III. TEST CONFIGURATIONS

How the Cam Shaft Works

The cam shaft sits between the two brake shoes at the end opposite the pivot pin. When the cable pulls the cam lever, the cam rotates and its profile pushes the shoes outward against the drum. The profile has four contact corners two on the leading side and two on the trailing side. A smaller corner radius makes the shoe follower climb the cam more steeply (more shoe movement per millimetre of lever travel); a larger radius makes it climb more gently. Figure 1 shows the CAD model of the variable radius cam; Figure 2 compares the two cross-sections, and Table 1 states the corner radius specification.

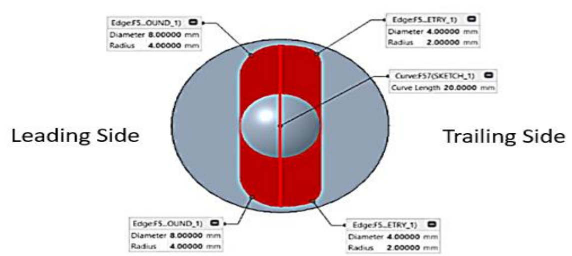

Figure 1. Variable radius cam shaft 3D CAD model showing the two corner radii and the 20 mm reference height.

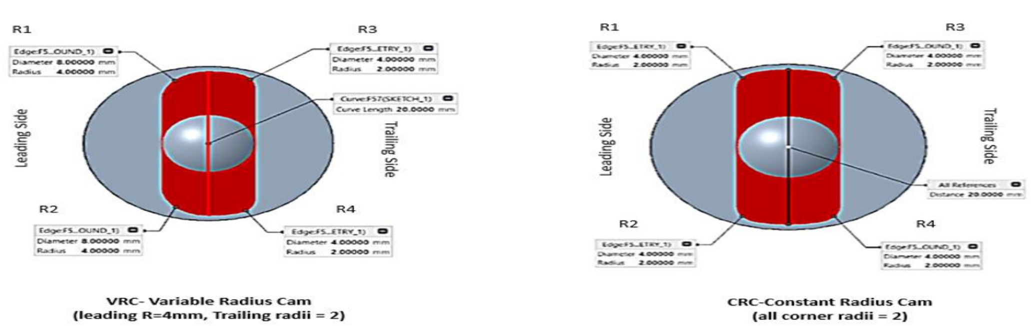

Figure 2. Cam shaft cross-sections drawn to the same scale from the geometry specification, with the four contact-face corner radii labelled R1 and R2 on the leading side and R3 and R4 on the trailing side (cf. Table 1). Left: CRC,

all radii 2 mm. Right: VRC, R1 = R2 = 4 mm on the leading side (more gradual lift) and R3 = R4 = 2 mm on the trailing side. The cam body height is 20 mm in both cases.

Table 1. Cam contact-face corner radius specification.

Configuration	R1 (lead flank)	R2 (lead nose)	R3 (trail flank)	R4 (trail nose)
Constant Radius Cam (CRC), baseline	2.0 mm	2.0 mm	2.0 mm	2.0 mm
Variable Radius Cam (VRC), proposed	4.0 mm	4.0 mm	2.0 mm	2.0 mm

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IV. TEST SETUP

Brake Assembly

The test used a complete drum brake assembly with an inner drum diameter of 130 mm. The assembly was kept intact same shoes, drum, springs, and cable for both tests; only the cam shaft was exchanged. The two cam shafts were manufactured to the same overall dimensions, lever arm length (120 mm at the free position), and shaft diameter, differing only in the contact-face corner radii listed in Table 1.

Dial Gauge Setup

A dial gauge (least count 0.001 mm) was placed at the tip of the leading shoe and a second at the tip of the trailing shoe. Both gauges measured radial outward movement the direction in which the shoe expands toward the drum and were zeroed at the free position (cam arm pull distance of 120 mm from the pivot, cable slack). Both gauges were read simultaneously at each cam position, so the two channels are directly comparable. The instrumented assembly on the bench fixture is shown in Figure 3.

Measurement Points

The cam lever was pulled in the direction indicated in Figure 4, from the free position (120 mm pull distance, corresponding to the cam arm pull curve length of 120.702 mm in the CAD model) to full application (85 mm), stopping at each 5 mm increment to record both gauges, giving seven positions per cam. One step, from 110 mm to 100 mm, spans 10 mm rather than 5 mm, reflecting the recording interval at that position; all other steps are at 5 mm resolution. The complete data set is given in Tables 2 and 3 and plotted in Figure 5.

Figure 3. Test setup: the drum brake assembly mounted in the bench fixture, with two dial gauges (least count 0.001 mm) positioned against the leading and trailing brake shoes to record radial shoe expansion during cam actuation.

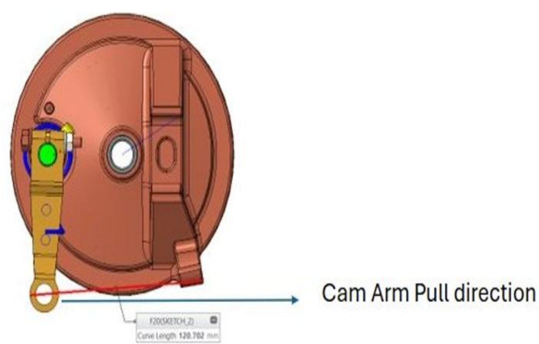

Figure 4. Cam arm pull direction. CAD view of the drum brake assembly showing the cam, the cam lever, and the direction of cam arm pull used to actuate the shoes; the free-position cam arm pull curve length is 120.702 mm.

Table 2. Variable Radius Cam (VRC): measured shoe expansion.

Cam arm pull [mm]	Stroke [mm]	Leading shoe [mm] (R = 4 mm)	Trailing shoe [mm] (R = 2 mm)	Trail − lead [mm]	Trail / lead [–]
120 (free)	0				
115	5	0.073	0.190	+0.117	2.60
110	10	0.247	0.350	+0.103	1.42
100	20	0.608	0.690	+0.082	1.13
95	25	0.772	0.889	+0.117	1.15
90	30	0.953	1.060	+0.107	1.11
85 (full)	35	1.087	1.410	+0.323	1.30

Table 3. Constant Radius Cam (CRC): measured shoe expansion.

Cam arm pulls [mm]	Stroke [mm]	Leading shoe [mm] (R = 2 mm)	Trailing shoe [mm] (R = 2 mm)	Lead − trail [mm]	Lead / trail [–]
120 (free)	0				
115	5	0.185	0.187	−0.002	0.99
110	10	0.378	0.384	−0.006	0.98
100	20	0.712	0.701	+0.011	1.02
95	25	0.920	0.900	+0.020	1.02
90	30	1.100	1.092	+0.008	1.01
85 (full)	35	1.397	1.380	+0.017	1.01

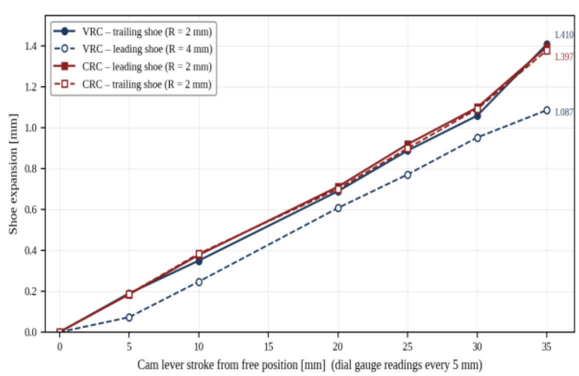

Figure 5. Measured shoe expansion versus cam lever stroke for both cam designs (dial gauge, readings every 5 mm of lever travel). The VRC trailing shoe leads the VRC leading shoe throughout the stroke, whereas the two CRC curves track together. The three nominally identical R = 2 mm faces (CRC leading, CRC trailing, VRC trailing) produce closely matching curves.

V. RESULTS

Internal Consistency of the Measurement

Three of the four measured contact faces CRC leading, CRC trailing, and VRC trailing have the same nominal 2 mm corner radius, so their lift curves should coincide if the measurement is sound. They do: at 5 mm of stroke the three faces read 0.185, 0.187, and 0.190 mm (a spread of 0.005 mm), and the agreement holds within about 0.02–0.04 mm through mid-stroke. At full application the three reach 1.397, 1.380, and 1.410 mm, a spread of 0.030 mm. This agreement across two different cam shafts and two test builds serves as an internal consistency check on the fixture, the gauge zeroing, and the repeatability of the method.

The Leading Shoe Is Retarded, Not the Trailing Shoe Accelerated

The comparison also isolates the effect of the 4 mm radius cleanly. The VRC leading shoe (R = 4 mm) expanded 0.073 mm at 5 mm of stroke about 60% less than the 0.185–0.190 mm of the three 2 mm faces at the same position. In other words, the VRC does not push the trailing shoe out faster; it slows the leading shoe down. The engagement sequence is created by retarding the self-energizing shoe.

Engagement Sequence

For the VRC, the trailing-minus-leading expansion difference is positive at every measured position: +0.117 mm at 5 mm of stroke, between +0.08 and +0.12 mm through mid-stroke, and +0.323 mm at full application. The trailing-to-leading ratio at first contact is 2.60. The trailing shoe therefore reaches the drum first at every stroke position. The widening of the gap at full application (35 mm) was observed consistently and may reflect compliance effects once firm drum contact is established; it is noted for further investigation.

For the CRC, the difference between the shoes stays within ±0.02 mm over the entire stroke, with the ratio between 0.98 and 1.02. Within the resolution of the method, CRC engagement is simultaneous: both shoes arrive at the drum together. Figure 6 summarises the gap and ratio at each position.

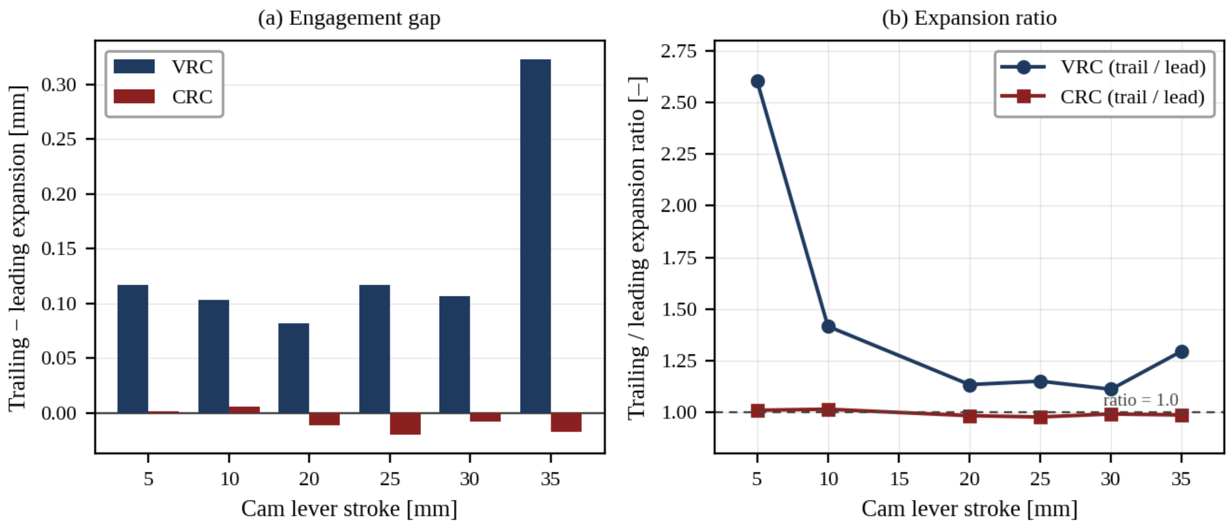

Figure 6. (a) Trailing-minus-leading expansion gap at each stroke position: positive throughout for the VRC, within ±0.02 mm of zero for the CRC. (b) Trailing-to-leading expansion ratio: the VRC starts at 2.60 and remains above 1.0; the CRC remains near 1.0 throughout.

VI. DISCUSSION

Acoustic noise was not measured in this study; the results quantify engagement kinematics. The following interpretation links that kinematics to noise expectations through the mechanisms established in the literature [1–4].

Why the Engagement Sequence Matters

The trailing shoe is de-energized: drum friction pushes it away rather than pulling it in, so its first contact involves no positive feedback and the contact pressure settles at the level the cam applies. The leading shoe self-energizes: on contact, friction pulls it tighter, raising contact force and friction again. This feedback generates braking torque efficiently, but it can also make the leading shoe's first contact a fast-rising force event, and fast-rising excitation of the shoe–drum system is the recognised trigger for mode-coupling instability and squeal [3, 4].

The measured data show that the VRC places the stable, de-energized trailing shoe on the drum first at every stroke position, with the leading shoe following through a more gradual lift. On this basis the leading shoe engages a system that is already partially braked, and its self-energization is expected to build more gradually than in the CRC's simultaneous bilateral engagement. Whether this translates into a measurable noise benefit must be confirmed by dynamometer NVH testing, for example to SAE J2521 [9], which is planned as the next stage of this work.

Relevance to Electric Two-Wheelers

On an electric scooter, regenerative braking handles routine deceleration and the drum brake is applied mainly in light, short applications at low cam stroke [8]; the near-silent powertrain leaves any brake noise fully audible. The measured data show that the low-stroke region is precisely where the two designs differ most: at 5–10 mm of stroke the CRC ratio is 0.98–0.99 (simultaneous) while the VRC ratio is 2.60–1.42 (clearly sequential). A further consideration is the regenerative-to-friction handover, in which cable tension rises quickly through the initial engagement zone; a cam that orders the engagement even under fast application is preferable in that transition.

VII. DESIGN GUIDANCE

- Adopt the VRC geometry. Leading-side corner radius 4 mm, trailing-side 2 mm; all other cam dimensions unchanged. The change is a CNC profile program update with negligible material cost.
- Keep the radius asymmetry in range. A 1.5–2.5 mm difference suits typical 100–150 cc motorcycle and scooter drum brakes; below about 1 mm the sequencing effect is weak, and above about 3 mm

the leading shoe may engage too softly, affecting torque build-up. For the tested platform (130 mm drum, 120 mm lever arm), 2 mm asymmetry was used; scale with drum radius for other sizes.
- Foolproof the assembly. Reversed installation gives the leading shoe the sharp profile the opposite of the intent. Mark the cam (paint dot, offset keyway, or asymmetric feature) and add an orientation check to the assembly process.
- Control the supporting system. Drum surface finish Ra 1.6 µm or better; drum out-of-roundness within 0.05 mm TIR; cam bearing diametral clearance within 0.03 mm; confirm full leading-shoe retraction at zero cable tension; replace stiff or kinked cables.

VIII. LIMITATIONS AND FUTURE WORK

The present study measures cam-driven shoe kinematics in isolation. The test was conducted without drum rotation, brake torque, or thermal loading, so the roles of self-energization on the leading shoe and de-energization on the trailing shoe are reasoned from established theory rather than measured directly; a dynamometer run with instrumented shoe-force measurement would close this gap. The widening of the trailing-minus-leading expansion gap observed at full application (35 mm of stroke) remains unexplained and may arise from structural compliance or from migration of the shoe–cam contact point once firm drum contact is established; strain-gauged shoes or a shoe-stiffness model would resolve its origin. Finally, acoustic noise was not measured in this work, and the expectation of reduced noise rests on the mechanisms reported in the literature; dynamometer NVH testing of both cams to SAE J2521 [9] would provide direct confirmation and is planned as the next stage of this work.

IX. CONCLUSIONS

- With all four contact-face corner radii equal (CRC), the two shoes engage the drum simultaneously within measurement resolution: the expansion difference stays within ±0.02 mm over the full stroke.
- Enlarging the leading-side corner radius to 4 mm (VRC) retards the leading shoe 0.073 mm at 5 mm of stroke against 0.185–0.190 mm for the nominally identical 2 mm faces so the de-energized trailing shoe contacts the drum first at every position, with a trailing-to-leading ratio of 2.60 at first contact.
- The three nominally identical 2 mm faces produced closely matching lift curves (within 0.005 mm at first contact), providing an internal consistency check on the measurement.
- Sequential trailing-first engagement is expected, on established mechanisms, to soften the leading shoe's first contact; confirming an acoustic benefit requires dynamometer NVH testing, which is planned.
- The change is a minor machining specification update: only the four contact-face corner radii differ between the two cams.

ACKNOWLEDGMENTS

The authors thank the laboratory and workshop staff at Advik Hi-Tech Pvt. Ltd. for their support in setting up the dial gauge fixtures and conducting the cam shaft tests.

DEFINITIONS/ABBREVIATIONS

CRC – Constant Radius Cam; all four contact-face corner radii 2.0 mm (baseline)
VRC – Variable Radius Cam; leading side R = 4.0 mm, trailing side R = 2.0 mm (proposed)
R1, R2 – corner radii on the leading shoe side of the cam [mm]
R3, R4 – corner radii on the trailing shoe side of the cam [mm]
Stroke – cam lever travel from the free position [mm]
Trail/lead ratio – trailing shoe expansion divided by leading shoe expansion at a given stroke
Self-energization – drum friction pulls the leading shoe tighter into the drum, amplifying contact force
De-energization – drum friction pushes the trailing shoe away, reducing effective contact force
NVH – noise, vibration, and harshness
TIR – total indicator reading

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