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Simulated LACT Procedure for Predicting Lining Life for Vehicles with Regenerative Braking

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Abstract

The Simulated Los Angeles City Traffic (SLACT) test is a well-established dynamometer test procedure used to evaluate brake noise and lining wear performance under a typical US city driving conditions. This procedure is based on a vehicle test conducted on the roads of Los Angeles, California. Unlike ICE vehicles, in electric vehicles regenerative brakes do a significant amount of the work to stop the vehicle, resulting in less work required from the foundation brakes. This means that the life of a brake pad could significantly increase in electric vehicles. It is possible then to reduce the thickness of the brake pad to improve packaging and cost. However, in situations where regenerative braking is disabled due to a failure or low battery charge level, all the work must be done by the foundation brake with no support from the regenerative braking. Hence, it is crucial to select the optimal brake pad thickness for such scenarios. The SLACT test was designed primarily for ICE vehicles and may not represent the lining life of electric vehicles accurately. As more auto manufacturers have started developing electric vehicles, there is now a need to establish a test procedure that considers regenerative braking for lining life predictions. This paper discusses in detail a modified SLACT test procedure that considers regenerative braking for electric vehicle lining life prediction.

Introduction

The current SLACT procedure, designed primarily for ICE vehicles without re-gen braking, does not provide an accurate representation of the lining life for vehicles with re-gen braking. In this paper, the Authors will thoroughly examine the existing SLACT procedure's implementation on a dynamometer and propose modifications to account for a vehicle's re-gen strategy, enabling more precise prediction of lining life. Additionally, the paper will explore the potential benefits of adjusting the pad's thickness based on wear data obtained from the dynamometer test.

Simulated LACT for Non-Regenerative Vehicles

The study utilized the existing SLACT test procedure, which is based on ZF's technical specification (S-13912200). This test procedure was developed using data obtained from a 2000 LACT (Los Angeles Commute Traffic) vehicle driving cycle conducted on the roads of Los Angeles, CA. The collected data was then adapted for use in a dynamometer test. Specifically, the data included specific braking energy and adjusted initial braking speeds to align the dynamometer's energy with that of the vehicle.

For the study, the collected data was run on the dynamometer for 10 cycles, simulating a total of 2000 miles of driving (equivalent to 10 days of LACT). The dynamometer test itself required five days to complete. Throughout the test, a total of 8050 braking events (stops) were performed. It is important to note that the entire test was conducted exclusively on a LINK Performance Brake Dynamometer.

Vehicle Re-Gen Strategy and Configuration

During braking events, both the front and rear brakes collaborate to slow down and bring the vehicle to a stop. In many vehicle applications, the front brakes bear a larger portion of the braking force, while the rear brakes contribute slightly less. This distribution is influenced by the fact that most braking instances occur when the vehicle is moving forward, causing the center of gravity to shift towards the front. Consequently, the front brakes must exert greater effort to halt the vehicle's forward motion compared to the rear brakes.

TABLE 1 Regen braking power distribution between front and rear axle.

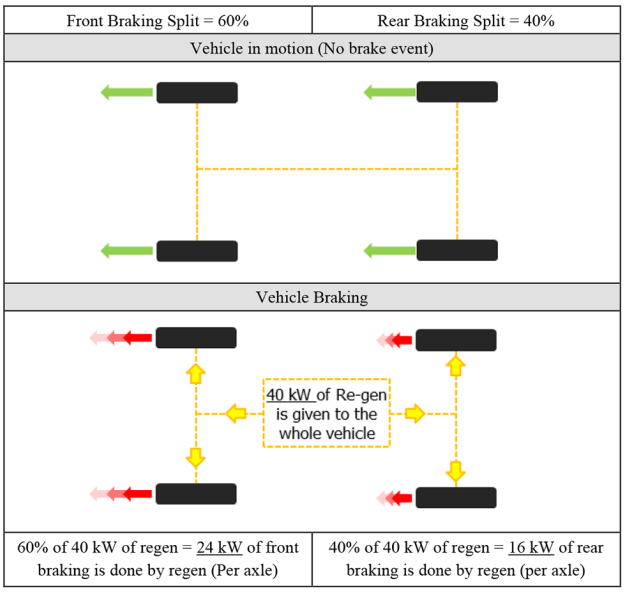


TABLE 2 Vehicle Parameters for front brake application

Front Dynamometer Inertia (single corner)	94.8 kgm^2
Rolling Radius	370.5 mm
Effective Radius	120 mm
Caliper Configuration	Single Piston, 57 mm
Pad Area	39 cm^2

This discrepancy in the distribution of braking force between the front and rear brakes is known as the "split."

The focus of this paper is on an electric vehicle (EV) with a typical brake split of around 60/40. In other words, during braking, 60% of the braking force is applied by the front axle, while the remaining 40% is applied by the rear axle simultaneously.

The considered EV vehicle has the capability to utilize regenerative braking to stop the vehicle as long as the regen energy produced is 40 kW or less. Any braking energy exceeding 40 kW is allocated to the foundation brakes to engage. Applying the 60/40 split to the front and rear brakes results in 24 kW allocated to the front axle and 16 kW allocated to the rear axle. A detailed calculation outlining this distribution is provided in Table 1.

Additionally, there are several relevant parameters used in the energy calculations for this EV, which will be further discussed in the paper. These parameters are presented in Table 2. The primary focus of the paper will center around the application of the front brake system.

Re-Gen Application

As mentioned previously in the paper, the existing SLACT test procedure, originally designed for ICE vehicles, consists of 8050 stops. To incorporate the re-gen strategy of the EV into this procedure, the full SLACT procedure was performed as it would normally be conducted on a non-re-gen vehicle. The data obtained from the dynamometer tests was then utilized to calculate the total energy for each of the stops. Subsequently, the total available re-gen energy was subtracted from each stop, resulting in the development of a new and simplified version of the SLACT test procedure. This modified procedure was subsequently conducted on the brake dynamometer.

Power Calculation Method

The following equations show the step-by-step calculation of the power at each corner for each stop. This will be used to discuss the example calculation in the next sub-section of this paper.

$$\textit{Angular}\ \text{Velocity}, \omega\left(\frac{\text{rad}}{\text{s}}\right) = \frac{\text{Velocity}, V\left(\frac{\text{k}}{\text{hr}}\right)}{\text{Rolling Radius}, RR(\text{mm})} \times \frac{1000\,\text{mm}}{1\,\text{m}} \times \frac{1000\,\text{m}}{1\,\text{k}} \times \frac{1\,\text{hr}}{60 \times 60\,\text{s}} \quad (1)$$

$$\text{Kinetic Energy}, KE(J) = \frac{1}{2} I\left(\omega_i^2 - \omega_f^2\right); \text{Units for } I = \text{kg} \times \text{m}^2 \quad (2)$$

$$\text{Stop Power per Corner}, P(J/s)_{\text{Corner}} = \frac{KE(J)}{T(s)} \quad (3)$$

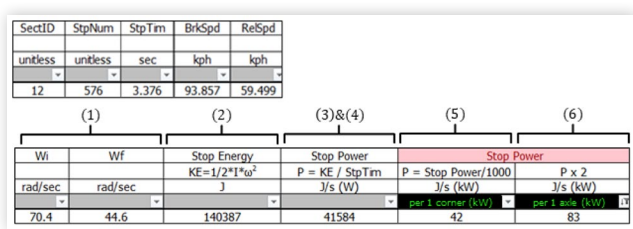
Unit Conversion

$$1\frac{J}{s} = 1\,W \Rightarrow P(J/s)_{\text{Corner}} = P(W)_{\text{Corner}} \quad (4)$$

$$W \text{ to } kW \Rightarrow \frac{P(W)}{1000} = P(kW) \quad (5)$$

$$\text{Stop Power per Axle}, P(kW)_{\text{Axle}} = P(kW)_{\text{Corner}} \times 2 \quad (6)$$

FIGURE 1 Example showing the power calculation for a single stop from SLACT dynamometer test with no re-gen applied. The numbers on top of each individual cell corresponds to the equations numbered in the previous sub-section.



SectID	StpNum	StpTim	BrkSpd	RelSpd
unitless	unitless	sec	kph	kph
12	576	3.376	93.857	59.499

(1)		(2)	(3)&(4)	(5)	(6)
Wi	Wf	Stop Energy	Stop Power	Stop Power	
		KE=1/2*I*ω^2	P = KE / StpTim	P = Stop Power/1000	P x 2
rad/sec	rad/sec	J	J/s (W)	J/s (kW)	J/s (kW)
				per 1 corner (kW)	per 1 axle (kW)
70.4	44.6	140387	41584	42	83

The calculation process begins with Equation 1, which involves calculating the angular velocity. This equation is used twice in the calculation: first to determine the initial angular velocity (ωi) using the "Brake speed" extracted from the dynamometer data, and then to find the final angular velocity (ωf) using the "Release speed" which is also obtained from the dynamometer data.

Next, Equation 2 is employed to calculate the kinetic energy. This equation determines the energy based on the values obtained from the previous step.

Moving on to Equation 3, the stop power per corner is computed by dividing the results from Equation 2 by T(s) or "Stop time," which is extracted from the dynamometer data.

In Equation 4, the units are converted from joules per second (J/s) to watts (W).

Equation 5 further converts the units from watts to kilowatts (kW).

Lastly, in Equation 6, the result is multiplied by 2 since the objective is to determine the total stop power per axle.

These calculations, outlined in equations 1 to 6, are essential in analyzing and quantifying the stop power distribution and characteristics for the front and rear axles of the EV.

Applying Power Calculation Method to Dynamometer Test Results

As mentioned earlier, a dynamometer test was conducted using the existing SLACT procedure without considering re-gen braking. During this test, data was collected, and the power for each of the 8050 stops was calculated. Figure 1 provides an example of the calculation performed for one of these stops.

To calculate the total energy for this specific stop on the front axle, the given variables from this stop (StpTim, BrkSpd, and RelSpd) are utilized, along with the front dynamometer inertia and rolling radius provided in Table 2. The application of equations 1 to 6 demonstrates how the calculation is performed to obtain a total energy of 83 kW for this particular stop on the front axle.

By following the steps outlined in equations 1 to 6, the calculation ensures an accurate determination of the total energy for each stop, enabling an in-depth analysis of the braking performance on the front axle of the EV.

(1)
$$\omega i = \frac{93.857\,\text{kph}(\text{BrkSpd})}{370.5\,\text{mm}(\text{Rolling Radius})} \times \frac{1000\,\text{mm}}{1\,\text{m}} \times \frac{1000\,\text{m}}{1\,\text{k}} \times \frac{1\,\text{hr}}{60 \times 60\,\text{s}} = 70.4\,\text{rad/sec}$$

$$\omega f = \frac{59.49\,\text{kph}(\text{RelSpd})}{370.5\,\text{mm}(\text{Rolling Radius})} \times \frac{1000\,\text{mm}}{1\,\text{m}} \times \frac{1000\,\text{m}}{1\,\text{k}} \times \frac{1\,\text{hr}}{60 \times 60\,\text{s}} = 44.6\,\text{rad/sec}$$

(2)
$$\text{Stop energy, KE} = \frac{1}{2} I\left(\omega_i^2 - \omega_f^2\right) = \frac{1}{2}(94.8\,\text{kgm2})\left(70.4^2 - 44.6^2\right) = 140387\,\text{J}$$

(3-4)
$$\text{Stop Power per Corner, } P\left(\frac{\text{J}}{\text{s}}\right)_{\text{Corner}} = \frac{\text{KE(J)}}{\text{T(s)}} = \frac{140387\,\text{J}}{3.376\,\text{s}(\text{StpTim})} = 41584\,\frac{\text{J}}{\text{s}} = 41584\,\text{W}$$

(5)
$$\text{W to kW} \Rightarrow \frac{41584(\text{W})}{1000} = 42\,\text{kW}$$

(6) Stop Power per Axle, $P(\text{kW})_{\text{Axle}} = 42 \times 2 = 83$ kW

Following the calculation of power for each of the 8050 stops, a filtering process was implemented to exclude stops with a power below 24 kW. This filtration was undertaken because it is known that there is 24 kW of power available for the front axle to decelerate the vehicle. Consequently, any stop with a power below 24 kW is assumed to be entirely accomplished through regenerative braking rather than the foundation brake. As a result, the initial 8050-stop test was reduced to approximately 925 stops.

Moreover, to expedite the test completion, the timing was condensed from the original 5-day duration to just 1 day. This adjustment allowed for a more efficient testing process while still capturing the relevant data and performance metrics.

In the scenario where a stop power exceeds 24 kW, indicating that regenerative braking alone cannot fully decelerate the vehicle, a combination of regen and foundation brakes is employed. For instance, in the case of a 25 kW stop, approximately 24 kW would be primarily handled by regenerative braking, while the remaining 1 kW would be contributed by the foundation brakes to aid in slowing down the vehicle.

As a result, for the 925 stops that were filtered from the original dataset, each stop would require an adjusted inertia that accounts for the presence of regenerative braking. This adjustment ensures that the data accurately reflects the interaction and division of braking forces between regen and foundation brakes during the stops. By considering the impact of regenerative braking on the overall braking performance, a more precise analysis can be conducted to assess the efficiency and effectiveness of the braking system.

In the scenario where regenerative braking is disabled, either due to a low battery charge level or a malfunction in the regen system, the entire braking force must be provided by the foundation brakes without any support from regen. To account for this, a subset of the 925 stops is selected.

Out of the 925 stops, 5% of the stops with the highest calculated power will be conducted without considering regenerative braking. This 5% value is chosen as a safety factor. This corresponds to 47 stops from the dataset. These 47 stops will be tested using the normal vehicle inertia without adjusting for regen effects. The specific inertia value to be used

can be found in Table 2, which in this case is 94.8 kgm2 for the front axle.

The selection of these 47 data points ensures that a representative sample is taken from the stops with the highest calculated power, allowing for a comprehensive analysis of the braking performance when regenerative braking is unavailable. By conducting these tests both with and without regenerative braking, a thorough understanding of the system's performance under different conditions can be obtained.

For the remaining 95% of the stops, which amounts to a total of 878 stops, an adjusted inertia will be utilized. The calculation to determine this adjusted inertia involves working backwards using equations 2 to 6. This process ensures that the correct values are obtained to accurately represent the braking performance considering the presence of regenerative braking.

To illustrate this calculation, let's refer to the same stop mentioned in the previous example. By applying equations 2 to 6 in reverse order, the adjusted inertia for this specific stop can be determined. Please note that the actual calculations and values would need to be provided in order to demonstrate the specific steps involved in this process.

Given that the power per axle at the specified stop is 83 kW,

$$83\,\text{kW} - 24\,\text{kW}\left(\text{Front re}-\text{gen}\right) = 59\,\text{kW of power per axle} \quad (7)$$

Working backwards from equation 6,

$$\text{Stop Power per corner}, P\left(\text{kW}\right)_{\text{Corner}} = \frac{59}{2} = 29.5\,\text{kW} \quad (8)$$

From equations 4 and 5,

$$\text{W to kW} \Rightarrow 29.5\,\text{kW} \times 1000 = 29{,}500\,\text{W} = 29{,}500\,\frac{\text{J}}{\text{s}} \quad (9)$$

From equation 3,

$$\begin{aligned}\text{Stop Energy}, KE\left(\text{J}\right) &= P\left(\frac{\text{J}}{\text{s}}\right)_{\text{Corner}} \times T\left(\text{s}\right)\\ &= 29{,}500 \times 3.376\,\text{s}\left(\text{StpTim}\right) = 99{,}592\,\text{J}\end{aligned} \quad (10)$$

From equation 2,

$$\text{Inertia}, I = \frac{2\,KE}{\left(\omega_i^2 - \omega_f^2\right)} = \frac{2\left(99{,}592\right)}{\left(70.4^2 - 44.6^2\right)} = 67.13\,\text{kgm}^2 \quad (11)$$

The calculation process described earlier has been applied to all the remaining 878 stops. The dynamometer script has been modified for each individual stop to incorporate the adjusted inertia values. Subsequently, a new dynamometer test has been conducted using the updated dynamometer script.

The results obtained from this comprehensive dynamometer test will be thoroughly examined and analyzed in the next section of the paper. By discussing these results, valuable insights will be provided regarding the impact of the adjusted inertia and regenerative braking on the overall braking performance of the EV. The analysis will contribute to a deeper understanding of the braking system's efficiency and effectiveness, leading to potential improvements and optimizations in the design and operation of the EV's braking system.

Projected Lining Life Calculation

Before showing the test results, it is worth discussing how lining life is calculated based on the SLACT test procedure. The equation for calculating the average projected lining life is the following:

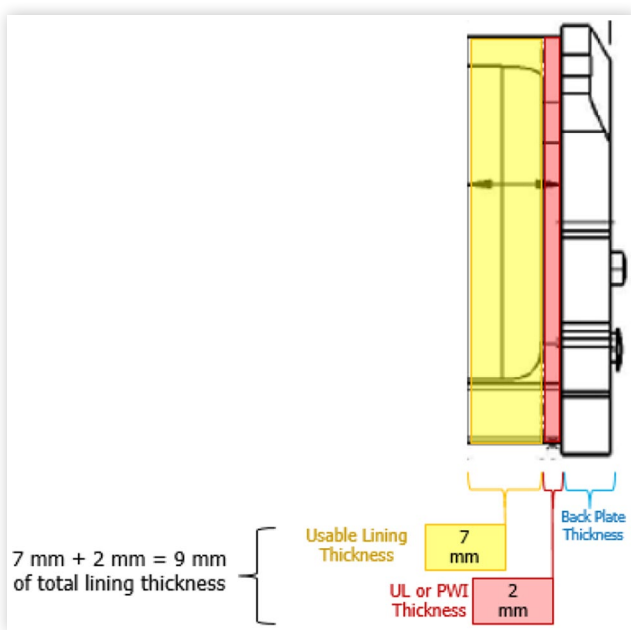
$$\begin{aligned}\text{Projected Pad life}\left(\text{Miles}\right) &= \left(\frac{\text{Test Miles}}{\text{Amount of Wear}\left(\text{mm}\right)}\right)\\ &\times \text{Usable Lining Thickness}\left(\text{mm}\right)\end{aligned} \quad (12)$$

The test miles in equation 12 is fixed value of 2000 miles for this procedure. As indicated early in this paper, these miles simulate the 10 cycle, 1 day test on dynamometer (or 10 days of LACT).

The usable lining thickness value is the thickness of the available friction on the pad assembly, past the pad wear indicator. Figure 2 best illustrates this.

Finally, the amount of wear is a calculated value that is pulled from the test. The brake pad thickness is measured at 8 points around the pads, just few millimeters away from the

FIGURE 2 Side view of a brake pad drawing. The yellow highlight indicates the usable lining thickness past the PWI. The red highlight is the underlayer (if applicable) or PWI thickness, located past the backplate on the friction end.



edges, before the dynamometer test starts and again at the end of the test. The difference between the "New pad condition" thickness and "End of test" thickness is then averaged out for all 8 points. This is done for both, inboard (IB) and outboard (OB) pads. The final value for each is averaged once again and used in equation 12.

SLACT with Re-Gen Test Results

Running all 925 stops with the modified SLACT procedure took approximately 1 day to complete. Thickness measurements were taken before and after completion of the test. The results are shown in Table 3.

It was found that the lining life is around 230k miles. A baseline SLACT test was also completed prior to modifying the test procedure and the results are shown in Table 4.

There is a significant increase in the lining life when running the test procedure with re-gen. This is due to less work needed from the foundation brakes and more reliance on re-gen braking to slow down the vehicle.

Adjusting the Pad Thickness

As mentioned previously in this paper, one potential approach to improving packaging and reducing costs is by reducing the thickness of the brake pad. In vehicles equipped with regenerative braking, the electric motors play a significant role in decelerating the vehicle. Consequently, the brake pads may experience less wear and require less frequent replacement.

TABLE 3 SLACT with re-gen applied test results. The 8-point thickness measurements are included in the Appendix, table 7 and figure 3.

Test Miles	2000
Usable lining thickness (mm)	10
IB Pad Average Wear (mm)	0.078
OB Pad Average Wear (mm)	0.099
IB Average lining life (miles)	258,065
OB Average lining life (miles)	201,258
Average Projected lining life (miles)	**229,661**

TABLE 4 SLACT without re-gen applied test results. The 8-point thickness measurements are included in the Appendix, table 8 and figure 4.

Test Miles	2000
Usable lining thickness (mm)	10
IB Pad Average Wear (mm)	0.662
OB Pad Average Wear (mm)	0.716
IB Average lining life (miles)	30,234
OB Average lining life (miles)	27,948
Average Projected lining life (miles)	**29,091**

TABLE 5 SLACT with re-gen applied test results, assuming a thinner pad with a 7 mm of usable lining thickness.

Test Miles	2000
Usable lining thickness (mm)	7
IB Pad Average Wear (mm)	0.078
OB Pad Average Wear (mm)	0.099
IB Average lining life (miles)	180,645
OB Average lining life (miles)	140,881
Average Projected lining life (miles)	**160,763**

By sacrificing some of the extra pad life, it becomes possible to achieve cost savings or create additional space within the braking system for other enhancements. This can be accomplished by reducing the thickness of the pad lining. Such a modification allows for improved packaging efficiency and potentially opens up opportunities for implementing other improvements in the vehicle's braking system.

From Table 3, it was found that the pad life is around 230k with a 10 mm of usable lining thickness. What if we reduced the thickness down to 7 mm? Table 5 shows the results of the same test results, assuming a thinner pad is used. The only difference here is the lining life would change based on changes to the usable lining thickness as per equation 12. It is assumed that the average wear is the same if the thickness of the pad is changed.

Table 3 provides the information that the current pad life is approximately 230,000 units, with a usable lining thickness of 10 mm. However, if we were to reduce the thickness of the pad to 7 mm, the expected lining life would be affected. Equation 12 is utilized to estimate the changes in lining life based on the alterations to the usable lining thickness. It is assumed that the average wear remains consistent even with the adjustment in pad thickness.

Table 5 presents the results of the test conducted with the thinner pad assumption. The key distinction in this table is the variation in lining life due to the modified usable lining thickness. The exact values and comparisons can be found in the table, allowing for an evaluation of the potential impact of reducing the pad thickness on the overall longevity of the brake pad.

Upon reviewing Table 5 and comparing the results with Table 4, it is evident that even with the thinner pad option, the lining life remains favorable. Despite reducing the pad thickness from 10 mm to 7 mm, the estimated lining life is still improved compared to the initial configuration.

This finding suggests that opting for a thinner pad can still provide satisfactory performance and durability while offering potential benefits such as cost savings or enhanced packaging. It highlights the viability of reducing pad thickness as a viable option without significantly compromising the overall lifespan of the brake pads.

Varying Pad Thickness of Different Test Samples

In the study, a series of tests were conducted using six different lining materials. All of the test samples shared the same pad

TABLE 6 SLACT with re-gen applied test results for different samples at various thicknesses.

	Average lining life at various usable lining thicknesses							
Material	8 mm	7 mm	6.5 mm	6 mm	5.5 mm	5 mm	4.5 mm	4 mm
A	103,548	90,604	84,133	77,661	71,189	64,717	58,246	51,774
B	132,889	116,278	107,972	99,667	91,361	83,056	74,750	66,445
C	107,241	94,260	87,393	80,525	73,658	66,790	59,923	53,056
D	136,376	119,761	111,070	102,378	93,686	84,994	76,302	55,552
E	102,044	89,289	82,911	76,533	70,156	63,778	57,400	51,022
F	108,604	95,028	88,241	81,453	74,665	67,877	61,090	54,302

shape, surface area at the rotor, as well as the caliper and rotor design. The objective was to compare the performance of these different lining materials and assess the impact of pad thickness on the pad lining life.

Table 6 presents the findings from these tests, showcasing the pad life for each sample at various usable lining thicknesses. The thicknesses range from 8 mm down to 4 mm. By examining the table, one can observe the variations in pad life for each lining material as the thickness is reduced.

This comparison allows for an evaluation of the performance characteristics and durability of the different lining materials under varying pad thickness conditions. It provides valuable insights into the relationship between pad thickness and lining life for each specific material, aiding in the selection of the most suitable lining material for different operational requirements and preferences.

Examining Table 5, it is evident that the lining life decreases as the pad thickness is reduced, irrespective of the friction material used. It is important to note that samples A to D represent the average results of two samples, while samples E and F are based on a single sample run.

It is common for the SLACT test to exhibit some variations, particularly at higher lining life numbers. Therefore, individual results may vary, with some samples showing better or worse performance. However, the overall average results should provide a more representative indication of the actual LACT vehicle test.

Considering the average results helps to mitigate potential outliers and provides a more reliable assessment of the impact of pad thickness on lining life for different friction materials. This information is valuable for making informed decisions and selecting the appropriate lining material based on the desired balance between performance, longevity, and operational requirements.

Conclusions

The paper provides valuable insights into the implementation of regenerative braking strategies for electric vehicles (EVs) within the existing SLACT procedure. By incorporating re-gen considerations, the authors address the need for updated testing methods that align with the evolving technologies and requirements of newer vehicle applications.

The paper highlights key aspects such as understanding the integration of re-gen braking in the SLACT procedure, calculating lining life, and adjusting brake pad thickness to account for the impact on lining life. By capturing these factors, the updated procedure enables vehicle manufacturers and suppliers to predict more accurately lining life, leading to cost savings and improved braking system packaging for future vehicles.

As the automotive industry continues to shift towards electric vehicles, the implementation of regenerative braking becomes increasingly important. By following this updated procedure, manufacturers and suppliers can ensure that braking systems are effectively designed and optimized for the specific requirements of EVs, resulting in improved performance, efficiency, and overall customer satisfaction.

The paper provides a comprehensive framework for incorporating re-gen braking into existing testing procedures, paving the way for advancements in brake system technologies and enhancing the overall development and performance of electric vehicles.

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Definitions/Abbreviations

SLACT - Simulated Los Angeles City Traffic
re-gen - Regenerative
ICE - Internal Combustion Engine
EV - Electric Vehicle
PWI - Pad Wear Indicator
IB - Inboard
OB - Outboard
UL - Under Layer
KE - Kinetic Energy

Appendix

TABLE 7 SLACT with re-gen applied lining life calculation details.

Measured without shim / No Burnish	Test Miles	2000
	Usable Lining Thickness (mm)	10
	IB Pad Avg Wear (mm)	OB Pad Avg Wear (mm)
	0.078	0.099
Avg Lining life (Projection; IB | OB)	258,065	201,258
Avg Lining life (Projection)	229,661	

$$Projected\ Pad\ Life\ (Miles) = \left(\frac{Test\ Miles}{Amount\ of\ Wear\ (mm)}\right) \times Usable\ Lining\ Thickness\ (mm)$$

FIGURE 3 8-point thickness measurements for SLACT with re-gen.

		1	2	3	4	5	6	7	8	Avg wear	
OB	New	18.086	18.062	18.047	18.066	18.027	18.024	18.034	18.026	OB	
	EOT	17.953	17.98	17.959	17.902	17.927	17.956	17.964	17.936		0.099
	Δ	0.133	0.082	0.088	0.164	0.1	0.068	0.07	0.09		
IB	New	18.035	18.032	18.034	18.05	18.011	17.995	17.979	18.006	IB	
	EOT	17.931	17.947	17.959	18.005	17.926	17.92	17.905	17.929		0.078
	Δ	0.104	0.085	0.075	0.045	0.085	0.075	0.074	0.077		

TABLE 8 SLACT without re-gen applied lining life calculation details.

Re-Measured without shim / No Burnish	Test Miles	2000
	Usable Lining Thickness (mm)	10
	IB Pad Avg Wear (mm)	OB Pad Avg Wear (mm)
	0.662	0.716
Avg Lining life (Projection; IB | OB)	30,234	27,948
Avg Lining life (Projection)	29,091	

$$Projected\ Pad\ Life\ (Miles) = \left(\frac{Test\ Miles}{Amount\ of\ Wear\ (mm)}\right) \times Usable\ Lining\ Thickness\ (mm)$$

FIGURE 4 8-point thickness measurements for SLACT without re-gen.

		1	2	3	4	5	6	7	8	Avg wear	
OB	New	18.134	18.183	18.121	18.055	18.103	18.072	18.088	18.089	OB	
	EOT	17.324	17.358	17.33	17.251	17.457	17.475	17.479	17.446		0.716
	Delta	0.81	0.825	0.791	0.804	0.646	0.597	0.609	0.643		
IB	New	18.116	18.139	18.16	18.173	18.134	18.105	18.079	18.132	IB	
	EOT	17.385	17.446	17.508	17.666	17.584	17.422	17.38	17.355		0.662
	Delta	0.731	0.693	0.652	0.507	0.55	0.683	0.699	0.777		

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