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An Experimental Investigation of Wear Particles Emission and Noise Level from Smart Braking System

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Abstract: Long-term or prolonged noise sensitivity as well as wear particles such as Particulate Matter 10 (PM10) and Particulate Matter 2.5 (PM2.5) emitted from conventional disc brake system has been attributed to a variety of health issues including stress, reduced concentration, decreased productivity at works, and exhaustion from a lack of sleep, among others. Automobile brakes are widely used in city traffic to control the vehicle. Since the use of automotive brake is frequent, the friction and wear exist between the contact pairs of disc brake may cause unnecessary noise level/wear particles. To tackle this, it was intended to develop the smart braking system and evaluate the significance of noise level and wear emission from the newly developed braking system. A noise measuring unit such as a sound intensity meter or decibel (dB) meter with data recording capability, as well as a wear particle measuring device for measurement of PM2.5 and PM10 particles, were used to investigate the noise and wear emission behavior of the proposed braking system. The numerous trials were conducted thoroughly on the test rig for the wear particle analysis and noise analysis. The findings show that the proposed smart brake blending system is very much efficient to reduce noise emission and wear emission during the braking of a vehicle. The outcome from the present study will help develop the noise-free eco-friendly braking system to enhance the human health aspects related to noise and air pollutions.

Keywords: Electric Vehicle, Noise Level, Wear Particle Emission, Smart Braking System

1. Introduction

India is considered as the world's second-largest population as well as the sixth-largest economy[1)]. Developing countries like Ethiopia, Yemen are struggling with certain situations such as heavy traffic, uncontrolled pollutions, and a rise in populations[2–5)]. The prominent reasons for uncontrolled pollutions and heavy traffic are not limited to urbanization but as a result of a change in lifestyle[6)]. Analysts on human health believe that 25% of the disease burden is associated with environmental threats[7)]. Various diseases like heart disease (cardiovascular disease), influenza and pneumonia, chronic lower respiratory disease, cancer, high blood pressure, sleep disturbances, and stress are ascending up, because, the well human health is associated with a good atmosphere and controlled pollution level[3,7,8)]. Among these diseases heart disease, high blood pressure, sleep disturbances, and stress are observed commonly among young adults. Air pollution, noise pollution, the environment, and many more are likely to cause these diseases[10,11)]. Air pollution exposure is considered to be linked to respiratory, cardiovascular, and cerebrovascular disorders[10)]. Since the traffic in metro cities from India is increasing every day by following the exponential trend, the rise in pollution levels is also chasing up the trend accordingly. In view of this, it becomes the foremost requirement to address pollution-related issues to adhere with good atmospheric situations, subsequently well human health[12)].

According to a recent report from World Health Organization (WHO), even as governments and social organizations are continuously recognizing and addressing the issue of air pollution, progress seems to be too gradual, particularly in the world's most badly impacted regions. In most nations, unhealthy air emissions are retained and acute peaks frequently exist[13)]. Air pollution is complicated because it comes from a

variety of places and is affected by seasonal, geological, and topographic influences[14]. There are solutions; however, they necessitate long-term preparation and interventions; there is no immediate remedy[3,13,15]. Similarly, noise pollution causes specific diseases that must be researched for a better future[16]. Street noise levels have increased, creating a serious health concern following the increasing number of automobiles in India. Noise has become one of the main factors impacting human health, according to the World Health Organization (WHO)[7]. Noise emission is mostly caused by road traffic, railways, airline noise, building noise, truck noises, noise from factory installations, sound systems, and many more. Among various types of noise sources, road traffic noise is considered a prominent factor associated with noise pollution[16]. Noise-related ambient air quality regulations suggested by the government of India are given in Table 1. The pandemic situation arises due to Covid-19 has stuck the local railways nearly for a year (March 2020 – 2021) for common people particularly in Mumbai where millions of passengers travel in a day. As a result, heavy road traffic was observed on the road which has added significant polluting factors to the atmosphere since the last few months. As the noise produced by heavy traffic cannot be regulated, all sources of noise must be considered cautiously to improve the atmosphere and human health. The scenario of noise pollution from the Mumbai region is shown in figure 1. Almost 70% of the Mumbai Metropolitan Region is affected by excessive noise, particularly in Mira-Bhyandar, Thane, Mumbai, and Vasai-Virar. In the case of the high level of noise emission in MMR, the current research suggests possible potential solutions, along with a better understanding of the noise's consequences to improve human health.

Table 1. Noise-related Ambient Air Quality Regulations[17]

S. N.	Category of Area / Zone	Limits in dB(A)	
		Day Time	Night Time
1	Industrial area	75	70
2	Commercial area	65	55
3	Residential area	55	45
4	Silence Zone	50	40

The government of India has introduced certain policies such as the National Green Tribunal Act, 2010, The Air Act (Prevention and Control of Pollution), 1981, The Water Act, 1974, The Environment Protection Act, 1986 in regards to control of pollution for maintaining better environmental state; however, the pollution from various unknown sources like noise pollution during vehicle braking operations cannot be avoided. Thereby, it was proposed to develop a new kind of smart brake blending system. The present study aimed to evaluate the significance of noise and wear emissions from a newly developed braking system. What's more, numerous trials have been conducted on a smart braking prototype to evaluate the performance related to noise and air pollution. A smart braking system was preferred to quantify the significance of health risk from noise emissions toward measuring the intensity of noise pollution and to compare the same with the conventional braking systems. The noise measuring devices such as Sound intensity meter or decibel (dB) meter with data monitoring capability as well as wear measuring device was used to examine the behavior of the proposed smart braking system.

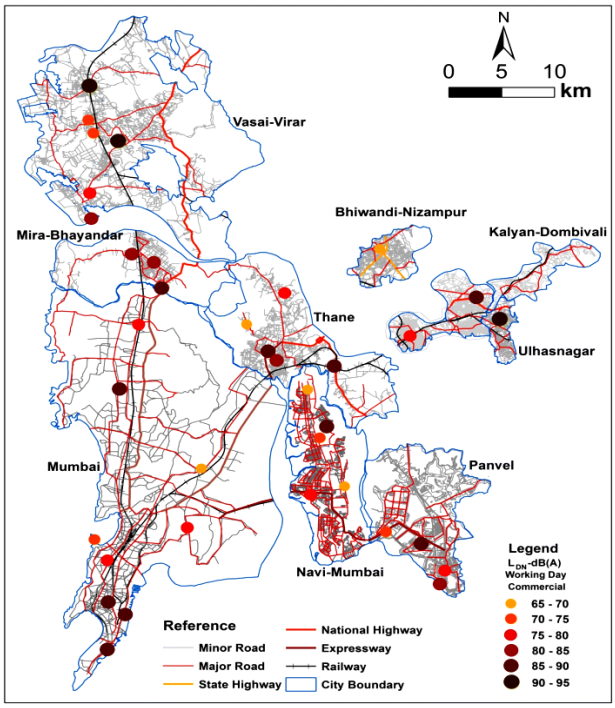

Fig.1: The scenario of noise pollution - Mumbai region[18]

The rest of the article is structured as: Section 2 focuses on the numerous brakes squeal results from previous studies. The wear particles generated during braking operations have also been presented to understand the implications. Section 3 introduces the experimental setup and systematic technical procedure adopted during trials. Section 4 describes the comprehensive results obtained from the present study. Furthermore, the impacts of noise on human wellbeing, as well as prior researcher's investigations relative to our findings have been explored in section 5. Finally, the conclusive remarks are highlighted in section 6.

2. Literature Review

In cars, brakes are among the most essential safety and performance elements. Since the invention of the car, brake production has been focused on increasing stopping distance and stopping time. In brake component design and manufacturing, noise generation and control of vibration have become significant concerns [19]. Although squeal noise has little impact on braking performance, the resulting self-exciting vibrations are

undesirable, because they can create unwanted noise to passengers and thus pose an important expense for customer health. Numerous studies have been devoted to the estimation of squeal noise in this sense across the globe. According to World Health Organization (WHO), the noise epidemic is of considerable severity. The increase in noise emissions is unsustainable seeing that it has both immediate and indirect harmful impacts on health[20]. In regards to this, several studies considering theoretical, experimental, and mathematical techniques were used to analyze brake squeeze and presented with thorough interpretations [21–23].

Accelerometers are the most essential device for assessing vibration mode types including forced system reaction[24]. An experimental setup was built especially for squeal measurement and was distinguished by a straightforward architecture that encourages measurements and modelling. The various trials were intended by past researchers to define the core factors that influence the squeal phenomena so that a model of the setup can be developed [21,23,25]. In the auto sector, the Complex Eigen value Analysis (CEA) has become the most commonly used tool for predicting squeal noise[22]. The study conducted by Denimal et al. suggests the use of the Kriging approach to surrogate the CEA's measured Eigen values by taking into account some unknown parameters, including the friction coefficient and two small masses applied to the calliper, which corresponds to a typical preference of structural changes that have been used in the final stage of a brake configuration to prevent squeal noise[23]. The effect of disc geography on the occurrence of squeal in automotive disc brakes has been investigated for a better understanding of the event. It has been observed that if the coefficient of friction is less than 0.4 brake squeal does not occur,[26] however, the braking torque capacity largely depends on friction of coefficient[27]. The prominent influential factor from different components of automobile braking system related to squeal analysis was studied with findings that the internal interaction factors were seen to play a significant role[28]. Moreover, the noise-reducing characteristics of a spiral-shaped alteration of the brake disc surface topography have been explored by researchers [29].

In certain regions of the world, air pollution is becoming a serious challenge[30]. The Air Quality Standards (2005) include an evaluation of the health impacts of air pollution as well as levels of pollution that are harmful to human health. The below are the PM2.5 and PM10 thresholds:

PM2.5 size particles - 10µg/m3 annual mean
25 µg/m3 24-h mean
PM10 size particles - 20µg/m3 annual mean
50 µg/m3 24-h mean

Developing nations like Brazil, India, and China are continuously striving to meet the quality standards of human life, however, 91% of the world's population lived in places where WHO air quality requirements have not been met reported in 2016[30]. There could be some explanations for such occurrences as heavy traffic, uncontrolled pollution, urbanization, and many more. Matter of fact, as exhaust particle emissions have been reduced with using electric vehicles, non-exhaust particles, particularly brake particles, have emerged into the picture. In countries such as Germany and the United Kingdom, brake wear adds more to PM2.5 emissions than exhaust particles [31].

The recent analysis shows that the brake wear particles are having a significant effect among others as shown in figure 2. The elevated concentrations of PM10 and PM2.5 mostly in ambient air within the urban area raise questions for adverse health effects[9].

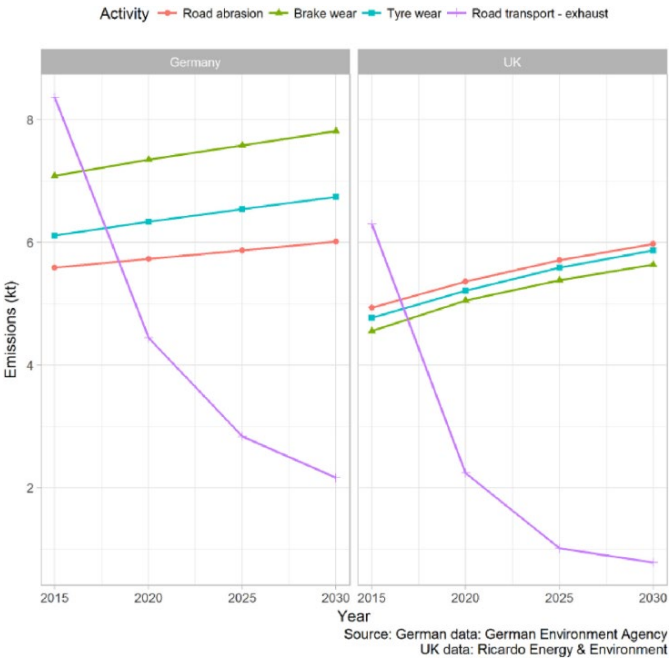

Fig.2: Analysis of PM 2.5 particles between Germany and UK [31]

The recent analysis shows that the brake wear particles are having a significant effect among others as shown in figure 2. The elevated concentrations of PM10 and PM2.5 mostly in ambient air within the urban area raise questions for adverse health effects[9].

The most widely used material for the disc in a disc brake system is the cast iron. The detailed investigations related to different types of gray cast iron such as gray iron grade 250, high-carbon grey iron, as well as titanium alloyed grey iron used in brake disc rotors were analyzed and compared to that of a compact graphite iron (CGI)[32]. A pin on disc apparatus was commonly used in a variety of brake pads, shoe, and rotor wear investigations [32–35]. Carbon ceramics discs are well substitute as they possess not only high-temperature resistance but also low wear.

Due to its high cost, such disc uses are minimal. Another way to reduce the rate of wear over cast iron disc would be to apply a wear-resistant hard coating to the surface of the friction[36]. These coatings are intended to minimize wear and increase high-temperature wear resistance, and perhaps even the brake system's thermal fatigue resistance, while retaining balanced frictional properties. What's more, Cryogenic processing now can enhance the lifespan of many automobile components wherein friction and wear play a crucial role in their performance and ultimate failure. Thereby, Physical consequences of deep cryogenic treatments on wear resistance of grey cast iron (SAE J431 G10) were examined through optical microscopy and associated with changes in its microstructure[37]. The findings show that deep cryogenic treatment improved the wear rate of grey cast iron by 9.1–81.4 percent in areas where substantial wear occurs.

In the Asia region, studies in the context of human health safety based on pollution aspects were also found with numerous results. The existing literature established two Cu-free brake components, which were used as a substitute for copper fibre by carbon fibre or carbon nanotube, and tested their tribology, particular emissions, and brake squeal noise. The varying brake squeeze spectra between the brake components are primarily leading to variations in wear processes as well as to the various numbers of friction surfaces scattered on the face of a pin[38]. The misalignment of brake pads, and or brake bending vibration could be the possible reasons for brake squeal/wear emission. It can be minimized by lowering the coefficient of friction, introducing a new shape of brake pads as well as escalating the stiffness of the disc[39]. An interpretive structural approach was developed to measure the health burden imposed by air pollution and to create an index focusing on health effects in China[10].

Such studies are found rare in India, particularly when it comes to the relation between vehicle braking on noise. Vehicle honking appears to be the most common cause of noise in towns. Despite the fact that the laws prohibit unwanted honking, it nevertheless occurs. Many technological policies and regulatory advances are required for this source of background noise[18]. Khairnar et al. studied the comparative investigation of disc and drum brake to establish coefficient of friction using simulation to improve the active safety of vehicle[27]. The braking action takes place as a result of friction between two surfaces (disc and brake pads); consequently, wear between disc and brake pad takes place which may hamper the braking torque. To analyze this, recently, Kalhapure and Khairnar studied the wear analysis of disc brake[33]. What's more, Abdo et al. successfully reduced the squeal effects from the disc brake system by using the FEM approach [40].

To the author's knowledge, the control of wear particle emission during braking of the vehicle is a typical challenge to automobile scientists. The numerous articles are intended on wear reduction methods for brake materials; however, it is not completely tackled. PM 2.5 and PM 10 particles are harmful to human health. To do so, it was planned to examine the wear particle emission analysis by conducting numerous trials on a newly designed brake blending test rig. Furthermore, available literature emphasizes on certain numerous techniques for reducing the squeal effects from the conventional braking system. A variety of instruments such as accelerometer, frequency measurement unit, noise measuring instruments have been adopted to measure the significance of noise generated in disc braking system. Previous researches based on the impact of pollution on public wellbeing have suggested that pollution be regulated first and foremost for the sake of human health. The remedial strategy/modification is the first prerequisite of conventional braking systems as the noise generated during vehicle braking is adversely affected human health. In view of this, the authors have conducted various trials on a smart braking test rig to analyze the significance of noise for better human health. The aim of this research is to introduce a smart brake blending system that will help to mitigate noise pollution by reducing the amount of noise generated while braking operation. As a result, it will contribute to the advancement of human health for better life and safety.

3. Experimental Investigation

3.1 Test Setup

The trials were performed on the newly developed smart braking prototype. It consists of a motor, contactors, sensors, flywheel, disc brake, controller, and hydraulic actuators as shown in figure 3.

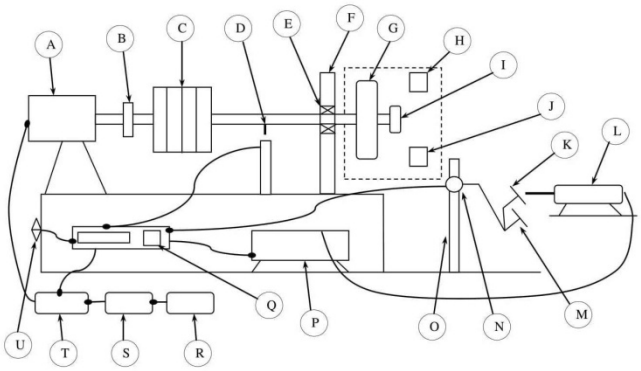

Fig.3: Layout of the smart braking system

(A-3 Phase Ac Induction Motor, B-Coupling, C-Flywheels, D-Bolt to detect motion for proximity senor, E-Bearing, F-Support plate, G-Disc Brake, H- Noise measuring device, I-Provision for attachment of wheel, J-Wear particle measuring device, K-pedal extension for automatic braking application, L-Hydraulic plunger, M-Manual brake pedal, N-pressure sensor, O-stand for support to brake pedal assembly, P-Hydraulic actuator, Q-Relays, R-Starter, and Miniature Circuit Breaker, S-Variable Frequency Drive, T-Contactors, U-Ultrasonic Sensor)

The 3phase - 5HP electric motor has been used in an advanced brakes model to obtain the vehicle's eventual driving condition. The variable-frequency drive controls the speed of the vehicle depending on a value set either by the operator or driver. Flywheels were used to introduce the necessary load of the vehicle to achieve momentum for the vehicle. Moreover, the speed of the vehicle was controlled by using the brake pedal mounted together with a pressure sensor. Although disc brakes have been used in the intelligent braking framework, they are only used in limited circumstances.

3.2 Working of Smart Braking System

Automobile brakes have a major effect on road safety and human health. The continuous noises generated during braking actions have an adverse effect on human health. The prominent reason for the noise is reported as a result of wear and friction between the disc pad and the disc. Whilst still various coating techniques extend the life of disc brakes, the risk of wear cannot be ignored after a certain period of time, especially in traffic environments where the use of brake is frequent. To tackle this, contactless brakes would be the possible alternate solution. Thereby, keeping this in mind, it was proposed to develop a smart braking system that can address the same issues. Although multiple simulation studies for the smart braking system have demonstrated that the concept is valid, real-time results must be tested with real-time outcomes. As a result, a prototype was designed and developed to assess the reliability of the smart braking system in terms of noise. The brake blend has been accomplished by the right torque control as seen in Figure 4.

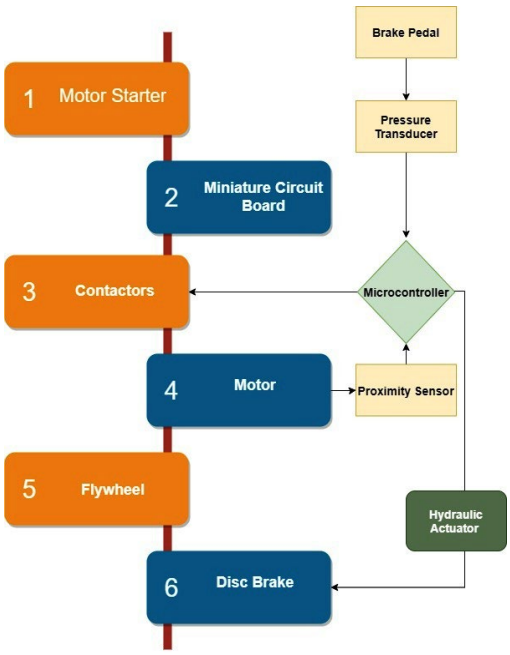

Fig.4: Flow diagram of the smart brake blending system

Despite a large number of trials conducted in our previous research on the proposed smart braking system using Simulink[41], measuring real-time noise was found difficult in a simulation environment, especially with real-time situations. Thereby, we extend our study by fabricating a prototype of a smart braking system. The goal of our current work is to evaluate the impact of noise generated during different braking situations; hence, we adopted the noise measuring device (Sound intensity meter) to examine the continuous nature of frequency compared with the traditional braking systems.

3.3 Test Conditions

Brakes in automobiles have a major impact on road safety and stability. Brakes need to be applied regularly to control the speed of vehicles, particularly in urban areas. There may be a variety of causes, including a high number of speed breakers in metropolitan areas, heavy traffic, traffic signals, and so on. Thereby, the addition of noise takes place in surrounding noise with disc brake noise A continuous noise due to braking frequent braking operation may increase the stress level as well as it irritates to the surrounding people also. Therefore, the authors conducted various trials on the proposed smart braking system in order to address this type of problem, which is especially relevant to vehicles in urban environments.

For the urban road areas, the vehicles running at higher speed around 60km/hr to 80km/hr requires to control a vehicle if a speed breaker appears in the driving path, and in such conditions, the speed may reduce to 10km/hr-20km/hr, therefore, to examine this, it was projected to conduct trials at different vehicle speed (60km/hr, 65km/hr, 70km/hr, 75km/hr, 80km/hr).

The most common use of braking is in traffic signals. The traffic light zone is always subjected to heavy pollution either it could be air pollution or noise pollution. When fast-moving cars come to a stop at this location, the disc brake noise can be present in certain situations. Hence, to examine this, we conducted the trials with higher speed of vehicles such as 90km/hr, 100km/hr, and 120km/hr. Furthermore, brakes are commonly used in traffic conditions, and we found these scenarios as well, with speeds varying from 20km/hr to 50km/hr.

3.4 Procedure of Noise Level and Wear Particles Measurement

To evaluate the significance of noise at different circumstances, the authors have used the well-proven noise measurement technique and compared results obtained through the proposed braking system with the traditional braking system. Environmental quality is seriously threatened by noise pollution. By definition, noise is a loud or upsetting sound. Decibels are used to measure noise levels (dB). The decibel level rises with increasing volume. Human hearing may be adapted to

decibel levels. Decibels A are used to describe noise level (dBA). Noise pollution is defined by the World Health Organization (WHO) as noise that is louder than 65 decibels (dB). More specifically, noise becomes unpleasant over 120 decibels (dB) and hazardous above 75 dB. A motorbike engine operating is roughly 95 dB louder than regular conversation, which is around 60 dB louder than a whisper. The normal person hearing may begin to be harmed if exposed to noise exceeding 70 dB for an extended length of time. The ears might suffer instant damage from loud noise exceeding 120 dB. The technical findings are presented in section 4. A real-time data were captured continuously by using a sound-level data recorder. The detailed specifications of instruments are shown in table 2 and the instrument used is shown in figure 5.

Table 2. Specifications of Noise Level Monitoring System

Aspects	Specification
Model	SL-4023SD
Auto range	30 to 130 dB
microphone head	0.5" standard
sampling time	1 second - 3600 seconds
SD card capacity	1 GB to 16 GB
Resolution	0.1 dB
Accuracy	31.5Hz ± 3.5 dB 63 Hz ± 2.5 dB 125 Hz ± 2.0 dB 250 Hz ± 1.9 dB 500 Hz ± 1.9 dB 1 K Hz ± 1.4 dB 2 K Hz ± 2.6 dB

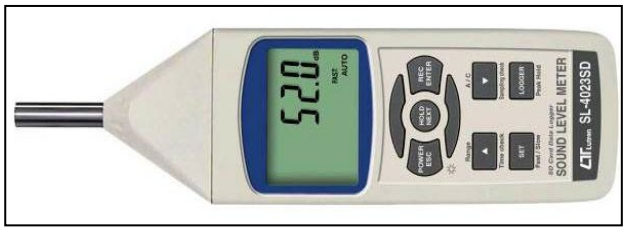

Fig.5: Noise measuring device – Sound meter

The wear particle measuring instrument was used to measure the PM2.5 and PM10 particles. The acrylic sheet box has been prepared and employed to gain only the wear particles generated during braking actions. The primary purpose of such an isolation box is to restrict the outer wear particles and to get accurate results from numerous trials. The wear particle measuring instrument is shown in figure 6.

Fig.6: Wear particle measuring device – Sound meter

4. Results

The purpose of a braking system is to slow down and stop a moving object. To achieve this, several brake system components must transform the kinetic energy of the vehicle into heat by means of friction. A simple hydraulic system in conventional brakes transfers fluid for every wheel when the brake pedal is pressed. Once drivers press the brake pedal to engage the brakes and bring the car to a halt, braking system makes use of a number of mechanical parts to increase the force on the drums or rotors. It creates the unnecessary noise. To tackle this, Authors have designed the novel contactless hybrid smart braking system. In the smart braking system, the reverse flow of current is used to control the torque of driven motor in case of electric vehicles. Therefore, no noise is produced at higher speed, particularly if want to stop the vehicle at shorter distance.

4.1 Noise Analysis

Many times, since the continuous noise may be generated during the braking operations, it increases the stress level of drivers as well as passengers[3,7,8]. Multiple trials were conducted with various test environments, as shown in table 3 and table 4 to determine the noise effect from the novel smart braking prototype. Sound measuring data was captured during squeal incidents that occurred at various trials through a sound level meter. The results obtained from the comprehensive study exhibits that the noise generated in the case of a smart braking system is comparatively very less than that of a conventional braking system. Table 3 indicates the results of the noise study from a smart braking device, with a focus on speed breaker conditions, emergency braking situations as well as traffic scenarios. Whereas, it was projected to analyze the noise impact in various situations without smart braking arrangement as presented in table 4. It was noted that when there is no braking operation, the amount of background noise created by peripheral equipment was: Lnavg=62.7 dB, Lnmax=67.3 dB, and Lnmin=60.4 dB.

Table 3. Noise level with smart braking system

No. of Measurements	L_{max} (dB)	L_{min}(dB)	$L_{avg.}$(dB)
1	70.3	64.2	66.6
2	71.4	63.5	68.8
3	70.6	62.1	67.4
4	72.8	63.3	68.2
5	71.7	61.5	66.4

Table 4. Noise level without smart braking system

No. of Measurements	L_{max} (dB)	L_{min}(dB)	$L_{avg.}$(dB)
1	94.0	87.4	91.2
2	100.3	89.8	93.5
3	98.2	88.5	94.1
4	101.2	90.6	96.3
5	95.8	87.5	91.4

As the sound level variation range is observed during the measurement of noise at various stages, the average noise level value is considered for further calculations. It was observed that noise generated without use of smart braking system is considerably more than a smart braking system.

4.2 Wear Particle Analysis

Wear particles coming out from disc brakes are having adverse effects on human health, therefore it was intended to conduct numerous trials with contactless smart brake blending systems and without blending (pure disc brake) to examine the quantity of PM10 and PM 2.5 particles. The measured PM particles such as PM 10, PM2.5 are measured by using a wear particle measuring device. The results show that a significant reduction in wear particle emission was noticed considering the smart brake blending system.

5. Discussion

To better understand the consequences of noise generated at various stages, real-time measurement plays a significant role in investigating the probable possible occurrence of the brake noise level. Numerous trials were conducted to evaluate the performance of brakes in the context of noise and wear particles. In current research work, without altering the automobile braking performance, it was thoroughly investigated.

While disc-brake systems have developed for a century, brake squeal remains a largely unsolved issue. However, it does not mean that there has been no improvement[19]. There is a variety of knowledge gathered from laboratory experiments on the essence of squeal, not limited to vibration modes, the wear of brake parts[33], but brake friction interactions as well. What's more, Analytical research has provided valuable insights into how friction design, structure, and brake part dynamics in basic disc brake frameworks contribute to squeal or instability. To attempt to apply these observations to more precise brake models, finite elements were used. However, as previously mentioned, multiple studies have linked this instability to the frequency of squeal. The remedial action from previous research includes the introduction of a constrained barrier layer to both the brake pads which are also used for adding more damping to the braking system. Further, damping is one means of reducing resonance frequency vibrations and thereby squealing noise[42]. However, the current development work is incredibly novel in which a contactless brake was added, which increases the smooth and noiseless operation of brakes.

The main problem, though, is what persists after the instability has happened. It is well understood that a novel design and development is needed in the existing braking system to solve this problem[19]. In quest of this, our proposed model elaborates the prerequisites of the braking system by reducing the noise at a substantial level. The smart braking system exhibits the requirement of braking as prescribed by Indian Standard (IS Standard) with safe control. Even though the authors have performed various experiments on a smart braking prototype, the control technique used with the aid of an embedded framework allows for the convergence of real-time applications.

The brake noise was categorized as high-frequency squeal (above 5 kHz), low-frequency squeal (1-5 kHz frequency range), and low-frequency noise (100-1000Hz)[43]. In this analysis, it was projected to assess the noise caused by the proposed braking system under different conditions. The findings show that the level of noise generated in the smart braking system is very less, in fact, negligible compared to the conventional disc braking system. There are numerous parameters that may affect the brake performance and causes unwanted noise or even excessive wear particles[44]. Figure 7 highlights these parameters such as humidity (H), ambient temperature (T_{amb}), brake fluid temperature (T_{fluid}), the temperature of disc surface (T_{rot}), coefficient of friction (μ). These parameter changes could make the device unstable and cause friction-induced vibrations to develop either audible noise or notably squeal.

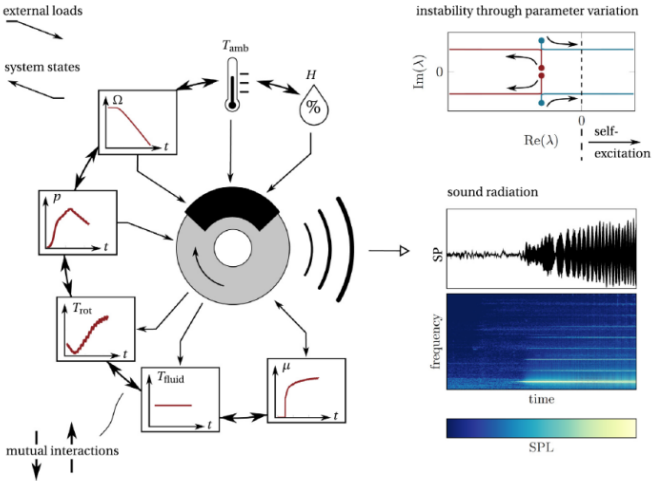

Fig.7: Various parameters associated with brake performance[44)]

In most cities, the key issue facing air quality control agencies is meeting air quality standards and requirements in high-traffic areas. Traffic emissions contribute significantly to total air pollutants in urban environments[31)]. The contribution of PM10 and PM2.5 particles to the atmosphere as a result of disc bake wear has been found in various studies; thus, authors attempted successfully and with substantial new findings to solve certain issues related to wear particle emission by developing a new smart contactless brake blending method for electric vehicles[45–47)]. The current study discovered about an 80% decrease in PM10 particles as compared to a single disc brake device. Furthermore, approximately 70% fewer PM2.5 particles were detected. The recent remedial method suggested by some researchers assured that after conducting the trials on the bench and in the car, a mass efficiency of more than 80% has been obtained[48)]. Results from present investigations are nearly in line with the same as almost 80% of reduction in PM 10 particles were noted. Although it was suggested the smart braking model reduces wear particles, some small amounts of emission of PM10 and PM2.5 particles are still observed. The repeated use of disc brakes at low speeds of vehicles could be the source of these released wear particles.

The suggestions from previous researchers include the necessity of smart braking system for electric vehicles, to control the atmospheric pollution coming out from brakes, noiseless brakes[49,50)]. In line with this, our novel smart braking system will be useful to tackle discussed issues.

The findings from the previous study primarily reflect the growing trends in modernization, urbanization, and change in lifestyle, increased traffic flows, facility transport, and industrialization which contribute the noise pollution as well as air pollution to the Mumbai Metropolitan Region. Furthermore, some researchers indicated that a prominent framework is needed to improve human health, especially in urban areas. In regards to this, it was planned to follow the suggested path to achieve the desired goal. In today's rapid world, human safety and human health need to be studied for better enhancement. Thus, we may speculate that this new approach may be one of the possible solutions to pollution-related problems.

6. Conclusions

In this study, the significance of noise level and wear emission from the newly developed braking system was successfully evaluated. The proposed smart braking system would help reduce wear particles and noise levels. The results obtained from comprehensive experimental studies have been appended as follows:

- The noise level generated during braking operations from a smart braking system is significantly less as compared to a conventional braking system.
- By using a smart brake blending system, the airborne emission in terms of number has been observed about 60% lower than the conventional brake contact pair under a similar braking condition.
- The noise pollution, as well as air pollution created due to unknown regular sources such as braking operations in vehicles, will be tackled by employing a new kind of smart braking system.
- This study will serve as a regulation tool for noise and related concerns, especially when it comes to the monitoring of high-speed vehicles on the road for well human health.

The outcome from the present study will help to develop a noise-free braking system to enhance the human health aspects related to noise pollutions.

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