

ELECTROMAGNETIC BRAKE-BY-WIRE SYSTEM (EBS) IN AUTOMOBILES

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ABSTRACT

Over the years, several technologies have been developed to maintain stability and balance of automobiles such as Anti-lock Braking System (ABS) and Sensotronic Brake Control (SBC) which have remained unsafe and inefficient because of heat dissipation [1], limited brake force [2], slower response time [7], development of bubbles in the hydraulics and reservoir of pressure [11], and prolong stopping distance. This paper focuses on Electromagnetic Brake-by-wire System (EBS) which maintains perfect stability and balance of automobiles under extreme driving conditions such as snowy or wet road, gravel, sharp bend, tire burst, corner, flood, very high speed and emergency braking with the use of Mechatronic Stability Program (MSP) and Electromagnetic brakes. In this paper, the experimental and simulation results show that heat dissipation associated with brake fail and tire burst in conventional ABS and SBC is eliminated and stopping distance is greatly reduced.

1. INTRODUCTION

Electromagnetic Brake-by-wire System (EBS) is an innovative Artificial Intelligent System [3] that interacts with its environment, determines its environmental status through its sophisticated sensors, processes such raw useful data and responds to its environment by providing most available stability through its high performance

actuators. EBS is a sensor selective, microcomputer controlled and electronic braking system that provides perfect stability, control, balance, adequate safety measures and traction control of automobiles under extreme driving conditions so as to avoid loss of control, sudden swerve, instability and skidding off the road when brakes are applied [7][8]. EBS is an alien in the

automobile industry and first of its kind in the world of brake-by-wire. The industry yearns earnestly for its discovery, the future is here. EBS is the name given to an innovative sensoelectromechanically controlled braking system by providing legendary braking comfort in a jiffy which does not apply friction to stop car wheels (Frictionless Braking System) because of the incorporation of Electromagnetic Anti-lock Braking System (EABS). EBS oriented automobiles speed heavily like a silver ghost yet brake and reduce stopping distance far more gracefully than any braking system ever in existence. Thanks to the novelty of Electromagnetic Anti-lock Braking System (EABS) in EBS which works in a relatively cool condition and satisfy all the energy requirements of braking at high speeds completely without the use of friction. Unlike friction brakes under prolong braking which dissipate heat and burst the tyres causing the usual fatal accidents [1]. However, previous work on stability of automobiles include Anti-lock Braking System (ABS) [1] and Sensotronic Brake Control (SBC) [11] developed by Mercedes Benz. ABS and SBC involve the use of friction brakes, hydraulics, reservoir of pressure, master cylinder, slave cylinder and fluid

distribution for brake force regulation. Some limitations and problems associated with ABS and SBC are as follows:

Annoyingly, ABS and SBC are limited by heat dissipation which reduces coefficient of friction leading to loss of grip and brake failure [1]. Furthermore, the fluid present in the reservoir of pressure of SBC and the hydraulics of ABS develop bubbles which results in brake failure [13]. The braking response is very slow because the transmission involves fluid distribution through mechanical systems and hydraulics. Also, ABS and SBC fail frequently because of the wear and tear the brake pads experience from friction daily - Most users are not always aware of this wear and tear until accidents occur. Furthermore, ABS and SBC are limited and inefficient where large brake force is needed because friction brakes cannot generate more than 25Bhp without self-destruction [2] which makes them inefficient for emergency braking where large brake force is needed at once.

Lastly, the vibration and discomfort experienced by drivers from the brake pedal because they are part of the transmission line when ABS sets in also contributes to the prolong stopping distance

associated with ABS and SBC. Simulation results carried out at DaimlerChrysler's Berlin driving simulator [7] has revealed that almost two thirds of all drivers are startled when ABS pulsation sets in and are even prone to taking their foot off the brake pedal for a short while, thereby lengthening the stopping distance of their vehicle by an average of 2.10 metres during ABS braking from 60 km/h on a snow-covered road surface. The Electronic Stability Program (ESP) used in both ABS and SBC are limited at sharp cornering by laws of Physics and dynamics of masses which will not make their calculating formulae to hold at extreme conditions.

2. MATERIALS

The materials used in the development of EBS include the following while some of them are briefly discussed in the subsections below:

❑ **Mechatronic Stability Program (MSP):** This program is embedded in the Micro-controller (along side with the System Utility Assessment Program (SUAP) for fault diagnosis) which coordinates brake and suspension management.

❑ **Braking detector:** This sensor detects the driver braking commands and is attached to the brake pedal.

❑ **Gyroscope:** This sensor detects the direction taken by the car and measures the lateral acceleration of the car.

❑ **Steering wheel angle sensor:** This sensor detects and measures the intending direction taken by the driver.

❑ **Wheel speed sensors:** There are four wheel speed sensors, one on each wheel to measure the speed of the wheels

❑ **Distronics sensor:** It detects the presence of objects up to 100 feet ahead in a fog or cloudy weather.

❑ **Parktronics sensor:** It measures visually and audibly the relative distance between the vehicle and an obstruction.

❑ **Electromagnetic Anti-lock Braking System (EABS):** It consists of four eddy current brakes one on each wheel. EABS works in a relatively cool condition and satisfy all the energy requirements of braking at high speeds, completely without the use of friction. The working principle of the Electromagnetic Anti-lock Braking System (EABS) is based on the creation of Eddy currents within a metal disc [2] rotating between two electromagnets, which set up a force opposing the rotation of the disc according to Fig 2.1. If the

electromagnet is not energized, the rotation of the disc is free and accelerates uniformly. When the electromagnet is energized, the rotation of the disc is retarded and the energy in the wheel is absorbed.

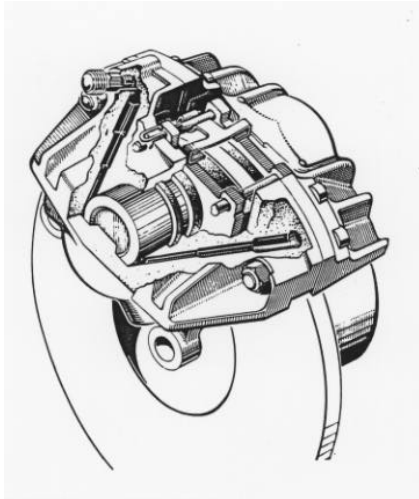


Fig 2.1 Electromagnetic Anti-lock Braking System (EABS)

3. THE SYSTEM DESIGN

The method employed in EBS involves the use of microcontroller embedded with Mechatronic stability Program (MSP) to control car wheels using Electromagnetic Anti-lock Braking System. One of the areas of Electromagnetic Brake-by-wire System as an Artificial Intelligent System has been the development of techniques that allow modeling of information from sensors at higher levels of abstraction and provides perfect stability

and balance for automobiles regardless of the extremity of the driving situation at hand. EBS is a branch of computer engineering that tries to endow computers with intelligence that enable the computer to solve complex driving problems that involve human expertise (Expert system) [12].

EBS as the only surviving hope of automobile field is to mimic human problem solving abilities which borrows characteristics from human intelligence thereby applying them as Artificial Neural Networks in a complex friendly and precise manner. It is a science that simulates within specialized mechanics and sophisticated computronics - Mechatronics. It is highly intelligent, incorporated with self learning ability, handling of complex and perplexing situations, ability to think and reason, reading quickly from sensors and applying correctly to a situation [3]. EBS therefore proactively responds to its environment through these building blocks shown in Fig 3.1.

- * Sensors to obtain features from the environment.
- * A coherent means for storing and processing of useful data (Microcomputer).
- * Adaptive output/ actuation mechanism to

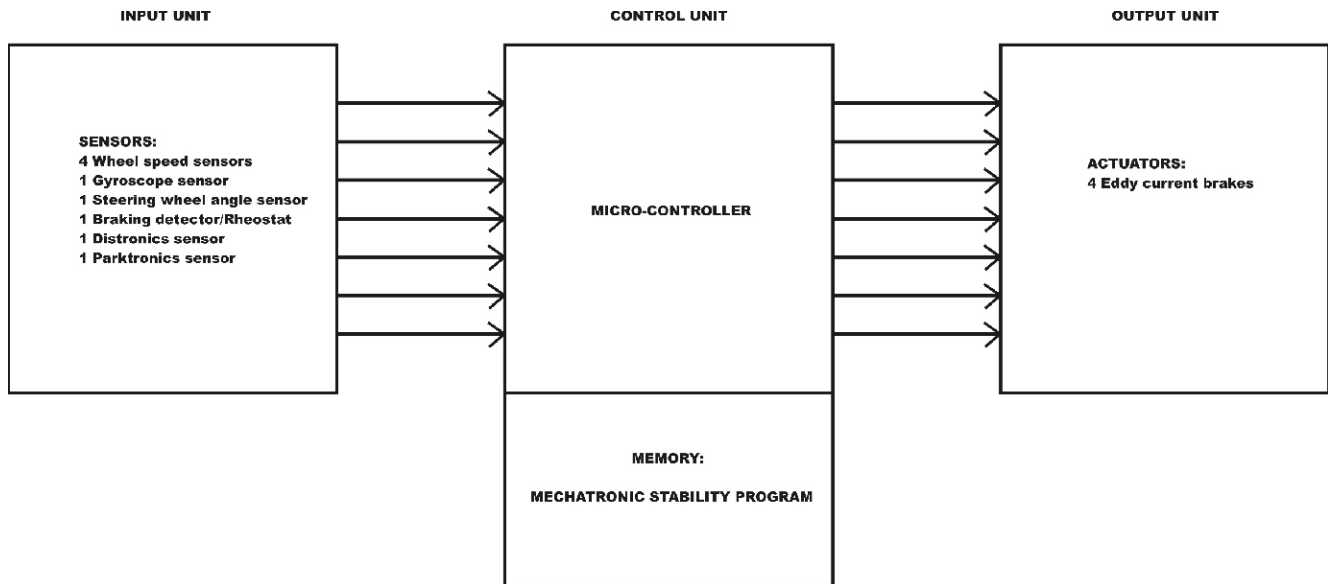


Fig 3.1 EBS CONTROLLER AREA NETWORK ARCHITECTURE MODEL

Moreover, in Electromagnetic Brake-by-wire System, a large number of mechanical components are simply replaced by electronics according to the architecture shown in Fig 3.2. The hydraulic systems, brake cylinder, brake booster, pistons, hydraulic tank in conventional Anti-lock Braking System (ABS) and reservoir of pressure in Sensotronic Brake Control (SBC) (Developed by Mercedes-Benz as the latest braking system) [11] will not be needed again. Instead, EBS through its

artificial intelligence passes these signals to the Electromagnetic Anti-lock Braking System (EABS) which creates Eddy currents within a metal disc rotating between two electromagnets, which sets up a force equal and opposing the rotation of the disc, thereby bringing the car to stop immediately in microseconds, faster and more precise than ABS and SBC due to electric current distribution in the transmission line rather than fluid distribution in the hydraulics of existing ABS and SBC.

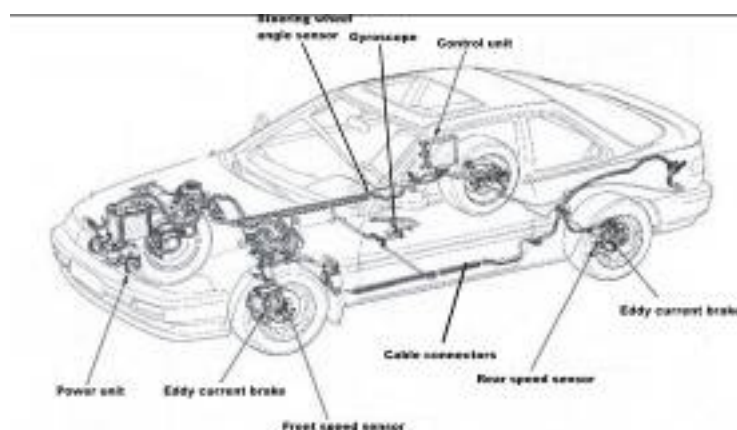


Fig 3.2 EBS VEHICLE ARCHITECTURE

3. THE SYSTEM OPERATION

The EBS microcomputer (central control unit) is the centerpiece of the sensoelectromechanical brake. This is where the interdisciplinary interaction of mechanics and electronics provide its greatest benefits - the microcomputer, stability program and sensors, work together and allow total novelty and highly dynamic brake management according to Fig 4.2. EBS detects the condition each wheel finds itself (slippery, snowy, cornering, bending, flooding), calculates and applies the right amount of brake force needed to each wheel depending on the driving condition at hand thereby maintaining a relative and uniform speed for the car [7][8].

Electromagnetic Brake-by-wire System works electronically, and thus faster and more precisely, than a conventional hydraulic braking system. As a case in point, if the car is moving on a snowy road. As soon as the driver presses the brake pedal according to Fig 4.1 and the sensors (which include the braking detector sensing the driver's braking command, the speed wheel sensors detecting the

speed of each wheel, the steering wheel angle sensor detecting the direction taken by the driver, the gyroscope detecting the direction taken by the car and the displacement sensors detecting the displacements of each wheel according to the road surface) identify the driving conditions around the car, the microcomputer performs simultaneous logical operations and commands functions which are hitherto mechatronically controlled by high-performance microcomputers and electronically controllable actuators that provide control and stability for the car. This is achieved by the MSP detecting the wheels that are slipping (according to the signals received from the wheel speed sensors) on the snow and increasing the brake force on them so that they turn slowly while the wheels that are locked, MSP reduces the brake force on them so that they turn faster like other wheels. As a result, EBS offers even greater active safety than conventional brake systems when braking in a corner or on a slippery surface. This allows EBS to critically reduce stopping distances.

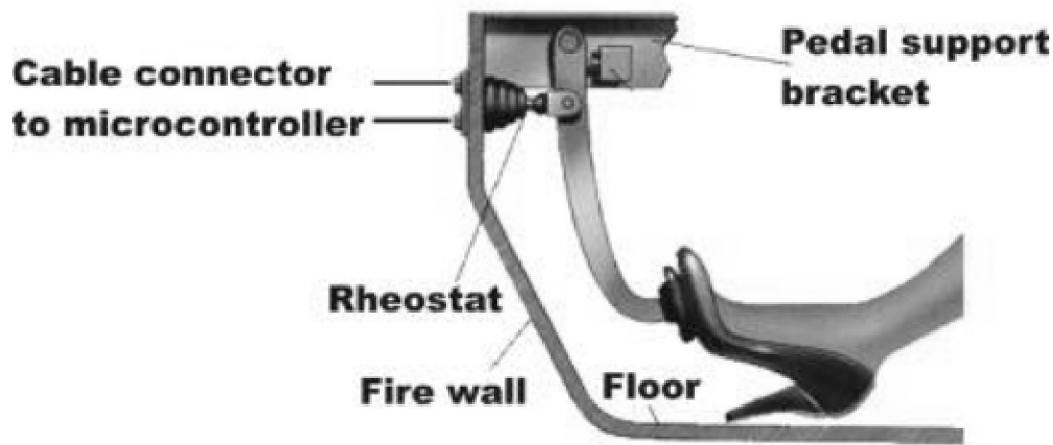


Fig 4.1 MSBC BRAKE-BY-WIRE

During braking in EBS, the car wheels are exposed to a magnetic field from an electromagnet, generating Eddy Currents in the wheels [2]. The magnetic interaction between the applied field and the Eddy Currents acts to slow the wheels down. The faster the wheels are spinning, the stronger the effect meaning that the faster the car, the easier to slow it down thereby producing a smooth stopping motion. All the kinetic energies of the spinning wheel are trapped instantly by the

Eddy Current. By Lenz's law, the Eddy Current swirls in such a way as to create a magnetic field equal and opposite to the current producing it or the induced Eddy Current exerts a force equal and opposite to the motion producing it [2], because of the tendency of Eddy Currents to oppose, Eddy Currents cause energy in the spinning wheel to be lost. It strips off the spinning wheel its entire kinetic energy (in microseconds) in a jiffy and steady manner.

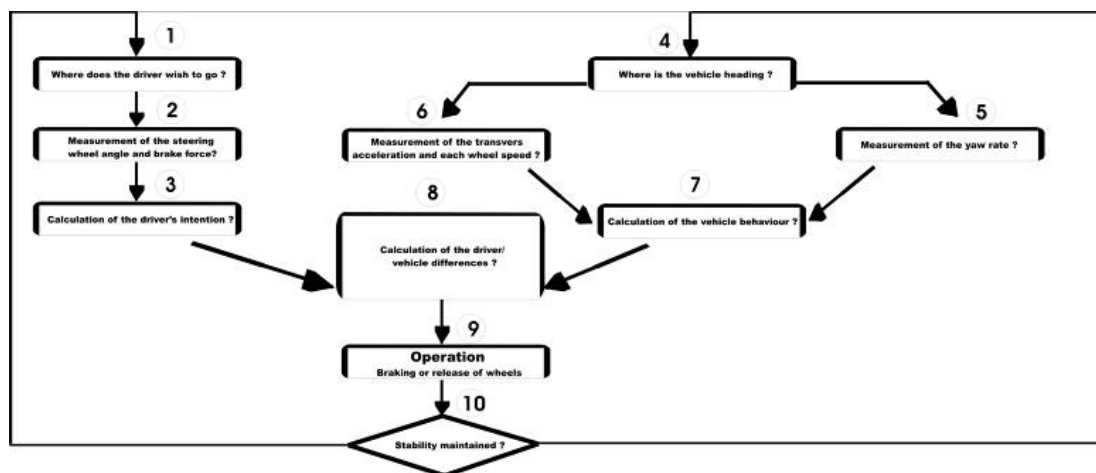


Fig 4.2 EBS OPERATION FLOW CHART

4.1 EBS flow chart description

Stage 1. Where does the driver wish to go? :

This include the driver's intention in changing direction to either left, right or maintain a straight direction and either braking (decelerate) or accelerating.

Stage 2. Measurement of the steering wheel angle and brake force: MSP takes the readings of the driver's degree of change in direction from the steering wheel angle sensor and the extent of braking from the braking sensor.

Stage 3. Calculation of the driver's intentions: The driver's intentions concerning direction and braking are determined.

Stage 4. Where is the vehicle heading? : This include the direction taking by the car and its speed

Stage 5. Measurement of yaw rate: The readings of the vehicle's direction are taking from the gyroscope sensor

Stage 6. Measurement of transverse acceleration and each wheel speed: MSP takes the readings of the vehicle's acceleration from the acceleration sensor and each wheel speed is taking from the wheel speed sensors.

Stage 7. Calculation of vehicle's behavior: The vehicle's behavior concerning speed and direction are determined.

Stage 8. Calculation of driver's/ vehicle's

behavior differences: MSP checks if the driver's intentions and the vehicle's behavior corresponds to each other from the readings taking from the sensors

Stage 9. Braking or release of wheels: MSP therefore determines if the stability of the vehicle has been compromised and brake or release the wheels affected.

Stage 10. Stability maintained: MSP continues to repeat this cyclic process within microseconds to constantly maintain stability of the vehicle.

4.2 EBS INNOVATIVE MECHATRONIC FUNCTIONS PERFORMED

* Slippery and snowy roads: The microcomputer calculates the right amount of brake force needed by each wheel to maintain relatively uniform motion for the car thereby maintains a perfect stability without swerving on a slippery road. The microcomputer constantly monitors the rotational speed of each wheel using the signals from each wheel speed sensors, and when it detects a wheel rotating significantly slower than the others a condition indicative of impending wheel lock it actuates EABS to reduce brake force at the affected wheel, thus the wheel then turns faster like others; when the

microcomputer detects a wheel is turning significantly faster than the others, brake force is increased on that wheel thereby turning slower like others.

* Corner: The microcomputer detects this and applies more brake pressure at the two inside wheels and maintains high stability for the car so as to maintain its trajectory around the circle and work against under-steering or over-steering unlike other vehicles by comparing the values of the signals from the gyroscope sensor and that of the steering wheel angle sensor. It also increases the height of the suspensions at the outside wheels to maintain a uniform circular motion against centrifugal force.

* Emergency obstruction: Something remains annoyingly beautiful about EBS, it cannot hit any obstruction, even if the driver is asleep, drunk or unconscious, the car slows down at every 3 feet to any obstruction and brakes in emergency at 2 feet to any obstruction with the use of parktronic sensor.

* Fog or Cloudy weather: The Distronic sensor is in the EBS emblem because of its emergency functionality. If the driver is in the fog or cloudy weather and he cannot see 100 feet ahead of him. If the Distronic distance sensor

detects a slower moving vehicle directly ahead, the vehicle speed will be reduced so that the driver follows that vehicle at a preset distance. Anyone that has driven in a deep fog will appreciate the efficacy of Distronics in EBS.

5 SIMULATION

The simulation was carried out on the EBS simulator developed and was embedded with the EBS Mechatronic Stability Program (MSP) which displays digital analysis of the activities of the system. MSP is an artificial intelligent system that is programmed at higher level of programming abstraction. The aim of the simulation is to test the efficiency, reliability and potentials of its intelligence under different driving conditions.

5.1 EBS Simulator Input Interface Description

Section 1: This section inputs the readings of the braking sensor into the simulator for MSP calculations

Section 2: This section inputs the speed from the wheel speed sensors for each of the four wheels into the simulator

Section 3: This section inputs the displacement values from the displacement sensors for the four suspensions

Section 4: This section inputs the readings of

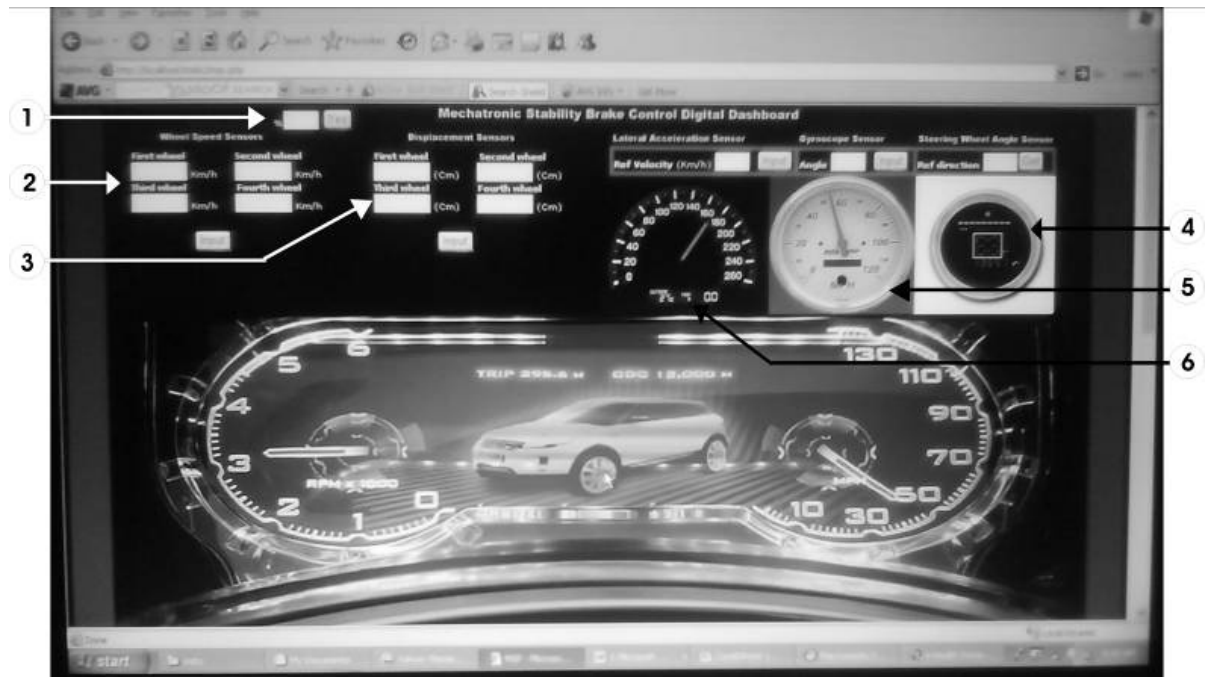


Fig 5.1 EBS SIMULATOR INPUT INTERFACE

the steering wheel angle sensor into the simulator
 Section 5: This section inputs the readings
 from the gyroscope sensor

Section 6: This section inputs the readings
 from the lateral acceleration sensor

Mechatronic Stability Program (ESP) Digital Analysis

Driver's intentions				Lateral Acceleration Sensor	Gyroscope Sensor	Steering Wheel Angle Sensor
Maintain direction	Straight	Accelerating	++1, acceleration	120 km/h	10 degrees	10 degrees

.....Driving situation at hand.....

Individual car wheel	Wheel speed	Brake force/Current	Status	Wheel condition	Suspension height	Displacement sensor readings	Suspension status
Wheel 1	34 km/h	0	Locked	Gravel, slower	0	12	Pothole
Wheel 2	67 km/h	0	Locked	Gravel, slower	0	5	Bumps
Wheel 3	120 km/h	0	Slipping	Wet, snowy, raining	0	10	Uniform
Wheel 4	212 km/h	0	Slipping	Wet, snowy, raining	0	8	Bumps

.....Mechatronic Stability Program Adjustments.....

Individual car wheel	Wheel speed	Brake force/Current	Status	Wheel condition	Suspension height	Suspension action	Suspension current
Wheel 1	120 km/h	-1	Regulated	Gravel, slower	12	Extended	1
Wheel 2	120 km/h	-1	Regulated	Gravel, slower	5	Retracted	-1
Wheel 3	120 km/h	1	Regulated	Wet, snowy, raining	10	Maintained	1
Wheel 4	120 km/h	1	Regulated	Wet, snowy, raining	8	Retracted	-1

The Mechatronic Stability Program is up and running, good luck

Fig 5.2 EBS Simulator showing the digital analysis of the simulation results

5.1 Simulation Method

EBS Simulator is a web-based software developed using Pre Hypertext Processor (PHP) program and MySql Server for the database. The simulator has both input interface as shown in Fig 5.1 and the digital display output as shown in Fig 5.2. Simulation was carried out on the system using different driving conditions which were snowy or wet road, gravel or sandy road and sharp cornering. Cornering driving condition was also chosen for the suspension.

The input interface consists of inputs for the speed

wheel sensors of the 4 wheels, braking detector, gyroscope, lateral acceleration sensor, displacement sensors for the 4 suspensions and steering wheel angle sensor as shown in Fig 5.1.

The digital display output interface consists of the display of the results of the simulation under different driving conditions as shown in Fig 5.2.

5.2 Simulation Results and Discussion

Table 5.1 shows Simulation result for snowy or raining driving conditions.

Driver's intention: Braking detector= 0, Steering wheel angle sensor= 0 degrees (Straight direction), Lateral acceleration sensor= 120 Km/h

Driving situation at hand				Mechatronic Stability Program(MSP)		
				Adjustments		
	Speed (Km/h)	Condition	Wheel status	Speed (Km/h)	Brake force	Wheel status
Wheel 1	140	Snowy/raining	Slipping	120	++1	Regulated
Wheel 2	120	Snowy/raining	Normal	120	0	Normal
Wheel 3	130	Snowy/raining	Slipping	120	++1	Regulated
Wheel 4	120	Swowy/raining	Normal	120	0	Normal

In this scenario of Table 5.1, wheel 1 and 3 are turning essentially faster than others while wheel 2 and 4 are turning properly according to the reference speed (120 Km/h). This driving condition is dangerous because wheel 1 and 3 are slipping

which would make the vehicle swerve and skid off the road. Therefore, MSP corrects this by increasing the brake force on wheel 1 and 3 so that they turn at the same speed as others, thus maintaining a uniform speed, stability and control

for the vehicle.

Table 5.2 shows Simulation result for Gravel or sandy driving conditions.

Driver's intention: Braking detector= 0, Steering wheel angle sensor= 0 degrees (Straight direction), Lateral acceleration sensor= 120 Km/h

Driving situation at hand			Mechatronic Stability Program(MSP) Adjustments			
	Speed (Km/h)	Condition	Wheel status	Speed (Km/h)	Brake force	Wheel status
Wheel 1	60	Gravel/sandy	Locked	120	- -1	Regulated
Wheel 2	140	Gravel/sandy	Slipping	120	++1	Regulated
Wheel 3	80	Gravel/sandy	Locked	120	- -1	Regulated
Wheel 4	130	Gravel/sandy	Slipping	120	++1	Regulated

In this scenario of Table 5.2, wheel 1 and 3 are turning slower than the others while wheel 2 and 4 are turning faster than the reference speed (120 Km/h). This driving condition is too dangerous because wheel 1 and 3 are locked while wheel 2 and 4 are slipping which will make the car become unstable and lose control. Therefore, MSP corrects this by reducing the brake force on wheel 1 and 3 so that they begin to turn faster and increase brake force on wheel 2 and 4 so that they turn at 120 Km/h, thus maintain uniform speed and stability

for the car.

Table 5.3 shows Simulation result for sharp cornering driving conditions.

Driver's intention: Braking detector= 0, Steering wheel angle sensor= 60 degrees (Turning right), Lateral acceleration sensor= 120 Km/h

Driving situation at hand			Mechatronic Stability Program(MSP) Adjustments			
	Speed (Km/h)	Condition	Wheel status	Speed (Km/h)	Brake force	Wheel status
Wheel 1	120	Gravel/sandy	Under-steered	120	0	Regulated
Wheel 2	120	Gravel/sandy	Under-steered	Below 120	++1	Regulated
Wheel 3	120	Gravel/sandy	Under-steered	120	0	Regulated
Wheel 4	120	Gravel/sandy	Under-steered	Below 120	++1	Regulated

In this scenario of Table 5.3, the car is cornering towards the right but could not maintain its trajectory because wheel 2 and 4 are turning at the same speed as others (120 Km/h). The car would experience under-steering because it could not maintain its trajectory around the sharp corner and will then skid off the road. Therefore, MSP corrects this by intelligently applying brake force on the two inner wheels (wheel 2 and 4), reducing their speed until the two outer wheels (wheel 1 and 3) are allowed to properly turn around the corner thus maintaining the car's trajectory. The MSP will continue to brake wheel 2 and 4 as long as

the angle given by the steering wheel angle sensor and gyroscope sensor are equal, which indicates that the trajectory is maintained, stability is achieved and the car obeys the driver's driving commands. This action displays the efficacies of the intelligence of MSP over all the stability programs that ever exists because it is not using Physics formulae in cornering which are limited by laws of Physics and dynamics of masses.

6. ELECTROMAGNETIC BRAKE-BY-WIRE SYSTEM MODEL

The Electromagnetic brake-by-wire System Model consists of the following components:

❓ A Microcontroller (brake-by-wire manager): It receives the driver's braking commands from the braking detector and performs the braking management by regulating the eddy current brake.

❓ Eddy current brake: It generates eddy current to stop the wheel.

❓ Sensor (braking detector): It detects the driver's braking commands.

❓ Transmission line: It consists of the cable connector to transmit braking signals among the components.

❓ Brake pedal: It is the pedal used to input the driver's braking commands into the MSBC brake-by-wire Model.

❓ Accelerator: It is pedal used to control the engine driving the shaft attached to the wheel.

❓ A wheel: This is the turning wheel under the action of the rotating shaft attached to the driving engine of the model.

❓ Driving Engine: It drives the shaft attached to the wheel

BY-WIRE SYSTEM MODEL WORKS?

The driving engine drives the shaft attached to the wheel when the accelerator is pressed by the driver during acceleration. During braking according to Fig 6.1, the driver lifts his/her leg off the accelerator to disengage the driving engine (since the dynamics of automobiles state that you cannot be accelerating and be braking at the same time, this calls for the presence of two pedals) and presses the brake pedal to input his braking intention into the system. The sensor (braking detector) measures the driver's braking commands and transmits it through the transmission line to the Micro-controller (brake-by-wire manager) which then regulates the current in the eddy current brake based on the signals from the driver's braking commands to stop the wheel. All these take place in microseconds to display the efficacies of EBS.

6.1 HOW DOES ELECTROMAGNETIC BRAKE-



Fig 4.1 a and b MSBC brake-by-wire Model

6.2 THE EXPERIMENT

6.2.1 Method

The experiment was carried out on EBS Model to determine its response time at different speeds when the brake pedal is applied completely. The aim of the experiment is to determine the time it takes the microcontroller to receive the braking command from the sensor (Braking detector) and generate eddy current to decelerate the wheel in proportion to the braking commands received.

6.2.2 Apparatus

The apparatus used for the carrying out the experiment include the EBS brake-by-wire Model, a speedometer, a stopwatch, 210-220 V Power supply.

6.2.3 Procedure

When the EBS Model engine was ignited, the speedometer reads 0 Km/h. Then the accelerator pedal was applied to accelerate the wheel until the speedometer reads 40 Km/h. After the wheel accelerates to 40 Km/h, the accelerator pedal was released to disengage the engine (because you cannot be accelerating and be braking at the same time, it is one after the other) and the brake pedal was applied fully, the stoppage time (T) taken for the microcontroller to completely stop the wheel was taken and recorded in Table 6.1.

The procedure was repeated for speeds (Km/h) 60, 80, 100, 120 and the stoppage time (T) was recorded respectively in Table 6.1.

Experimental Results and Discussion

S/N	Wheel Speed (Km/h)	Stoppage Time (T)(Seconds)
1	40	0.08
2	60	0.09
3	80	0.07
4	100	0.08
5	120	0.06

Table 6.1

The experimental results show that the response time is extremely faster (Average Response of 0.07 seconds) than that of ABS and SBC with 1.44 seconds [10]. This consistent fast response (20% faster than ABS and SBC) time under different speeds shows that very large brake is readily available at all speeds and at all time without the presence of reservoir of pressure as in SBC, thus it is more suitable and reliable in emergency braking conditions where large brake force is needed at once. The system is purely sensorless because the braking command could be varied as desired with the presence of the braking detector and the transmission is without hydraulics which also accounts for its faster response.

Moreover, the experimental results also show that the isolation of the driver from the transmission line accounts for its braking comfort and reliability because vibration is eliminated. The gripping efficiency is not affected by heat dissipation (is not heat dependent). This makes it more efficient and reliable during prolonged braking where it still maintains its gripping without brake failure like ABS and SBC.

7. CONCLUSION

From the results obtained, Electromagnetic Brake-

by-wire System (EBC) has its efficiency, heat independence, better thermodynamic management, possesses faster response and larger brake force, satisfy all energy requirements, eliminates mechanical systems of hydraulics, eliminates wear and tear, greatly reduces stopping distance and transmission is through current distribution, we can conclude that EBC provides lasting solutions to the long standing conflict of stability and balance in the world of automobiles. However, research work is still going on in this paper.

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