COURSE: **Engineering Physics(PHY110)**

Semester: **1st (2022-2023)**

Name of Project: **Anti-lock Braking System (ABS)**

Submit ted by**Manish Kumar**

Reg No: **12201560**

Date of submission: 27.10.2022

EVALUATION

Filing/ Binding	**10 %**	
Contents/Research	**40 %**	
Discussion, Conclusion	**20 %**	
Presentation	**30 %**	
Overall Mark		

Table of Contents

FIGURE LIST

ABSTRACT

One of the most important reasons why sudden braking causes the car's imbalance and accidents is that the wheels lose their maneuverability by locking. ABS has been developed to prevent the brakes from being locked. It has greatly reduced fatal accidents. So, it can be called a life-saving system for ABS. ABS is a vital system for the safety of the driver and passengers in motor vehicles. While the car is driven, another vehicle or any person or object may come out in front of the vehicle and the driver may have to brake suddenly. That's where ABS comes into play. In this article, audience will find an opportunity to get to know the ABS braking system more closely. Briefly, this article describes how this system works exactly, what it does in vehicles, and how ABS vehicles different when it is compared to vehicles without ABS.

1. Introduction

ABS (Anti-lock Braking System) is a braking system that ensures full control of the steering wheel by preventing the vehicle from locking the wheels in sudden braking situations in all road conditions and at all speeds. ABS system is developed to prevent the locking of the wheels on motor land vehicles. In the case of ABS braking, the change in the number of revolutions of each wheel is controlled by an electronic control unit which is called Brake Control Module (BCM or EBCM). While driving, it may need to urgently press the brake pedal because of the various obstacles that appear in front of the car. In such cases, both the clutch and the brake or only brake pedal must be pressed at the same time very strongly in order to stop the car. Otherwise, the car might hit the object, or it could lead to an accident that will cause a huge damage.

When the brake pedal is suddenly pressed, the wheels of vehicles that do not have an ABS system lose their connection with the steering wheel and are locked. Therefore, in this case the wheels cannot sense the commands from the steering wheel. These locked wheels reduce the vehicle's maneuverability to zero. However, vehicles with an ABS system do not lock the wheels in sudden braking situations. The driver can easily get rid of the car in a simple maneuver by turning the steering wheel light slightly while the car is skidding.

ABS is a system that does not lose the connection of the wheels with the steering wheel when the brake pedal is pressed. It stops the wheels by sending a command to the wheels with very short intervals, and after a very short time it sends the command again to deactivate squeezed brake calipers. This sequence state is repeated twenty times in a second. The aim is; when a car at high speed it cannot suddenly stops, it cannot stay where it is due to moment of inertia. So, it continues to slide forward suddenly. At this time, passengers inside the vehicle can even jump out of the windshield. However, ABS slows the wheels and stops the car in a controlled way.

In ABS, the system runs under the control of computers. The driver only operates the brake pedal and, if necessary, maneuvers the car by steering wheel. Any inexperienced driver with an ABS vehicle; compared with the experienced drivers- who use the vehicle without ABS, it stops the car in a much safer and more comfortable way and gets rid of it by accident. In the working system of ABS; When the sensors detect that the wheels are starting to slip, it sends a command to the brake to immediately cut the stopping power. Here it is understood that the working formula of the ABS is based on the pressure limitation. Figure 1 shows braking compression between ABS and without ABS car.

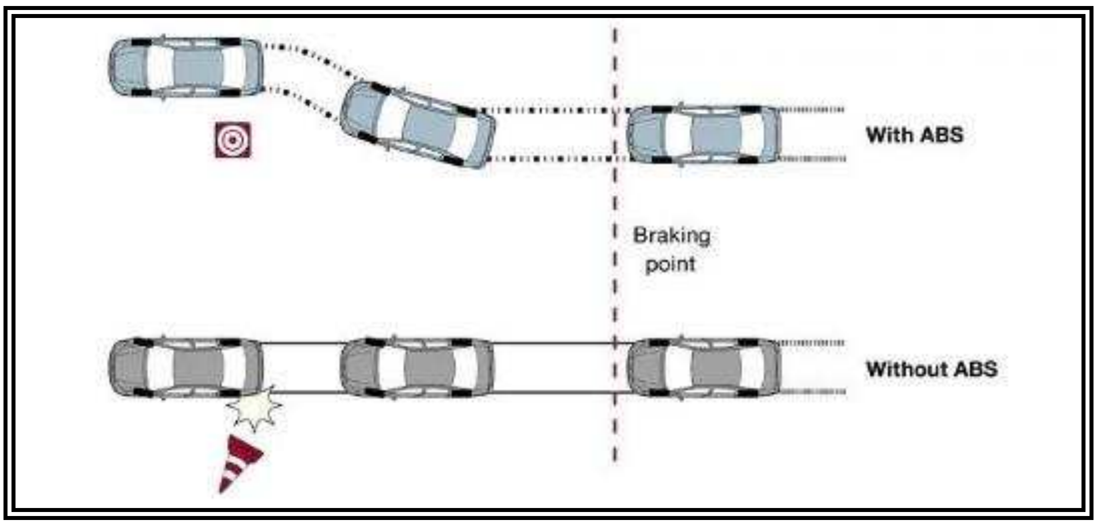

Figure 1.1: With ABS, the car gets better stability and control while braking (Image Source: www.toyota.lk)

Vehicles with ABS stop at a shorter distance than other vehicles, more stable and safe. Especially there is a vital importance of ABS when sudden entry into curved roads and emergency braking is required. The vehicle with ABS can safely brake and maneuver because of its maneuverability, but in the same situation the vehicle without ABS is at risk of being thrown out of the road. Because the vehicle with ABS continues to be under the control of the driver in curved roads.

2. History of ABS

Ever since the first motor vehicles were developed in 1769 and the first driving accidents took place in 1770, engineers have been determined to reduce driving accidents and increase the safety of vehicles [1]. It is clear that, the efficient design of the brake systems reduces accidents. The first patented system was invented by German engineer Karl Wessel in 1928, however Wessel could not develop a working model of ABS [2]. Engineers developed this field with the invention of the first mechanical anti-lock braking system (ABS) system designed and manufactured in the aviation industry in 1930, the first ABS used in Boeing's B-47 bomber aircraft in 1945 to prevent the tires from blowout during braking. Afterwards this braking system were widely used on other aircrafts in the 1950s [3, 4]. With the arrival of the 1960s, ABS began to be tested on cars only to control the rear wheels [5]. With the rapid progress of computer and electronic technology, this system started to spread in cars in 1980s [6]. Today, ABS can be found on most of the latest car models on both wheels and even on some motorcycles.

When looking at the history of ABS in cars; in the 1960s fully mechanical ABS started to be used experimentally for the first time in the *Ferguson P99* race car. When it came to 1970's, Chrysler and Bendix Corporations started using this system in the *Imperial* model with the name "*Sure Brake*" [7,8]. A few years later, Ford marketed this system in 1975 with the name of "*Sure-Track*" [9]. Also, in these years General Motors began using this technology under the name of "Trackmaster" only for rear-wheels and was offered as an option [10]. In the same year, the Japanese Denso company, which produces automotive parts, developed an electronic locking prevention system under the name of “*EAL*” in Nissan President model [11]. The Italian automotive company Fiat started using ABS in trucks for the first time in 1971 [12]. The American company WABCO, which developed the ABS system on the heavier vehicles under the name "*EBS*" and carried this technology to the market in 1986 [13].

In 1978 Mercedes-Benz was the first company to produce a four-wheel controlled anti-lock braking system with Bosch [14]. In 1988, BMW started using this technology on motorcycles for the first time on the BMW K100. In 1993, American Lincoln firm took the marketplace by making ABS a standard feature for all four wheels [15].

3. Theory and Principles of ABS

As already mentioned, the improvement of the ABS is to stop the vehicle as quickly as possible in a controlled manner when the intended braking is applied. When non-ABS vehicles are braked, one or more than one wheels can be locked, resulting in a longer brake distance, losing steering wheel control and in the worst scenario case, there could be a fatal accident.

There are many parts that make up ABS. This system receives information from the sensors and then effects the hydraulics of the brakes. When a rapid lock is detected, the anti-lock system reduces the hydraulic pressure in the brake cylinders, releasing the brakes and preventing the wheels from locking. The master cylinder controls the hydraulic pressure in the brake cylinder. The hydraulic system connects to the master cylinder with brake cylinder. The hydraulic fluid must pass through a chamber to reach master cylinder and brake cylinder. When the brakes are in normal use, the valve is open and the pressure in the reservoir is the same as the pressure in the main cylinder and in this case the anti-lock braking system does not work since there is no rapid braking.

When the sensor detects sudden braking, the control valve moves. The control valve determines the pressure in the gap in front of the actuator. Larger pressure in the chamber upstream of the actuator causes back slip and closes the valve between the master cylinder and chamber. As the actuator slides backwards, the volume of fluid in the reservoir increases. This reduces the pressure of the hydraulic fluid and releases the brakes which prevent locking.

3.1 Physics of ABS

The force of the weight of the vehicle: $\mathbf{F_N}$

The side force generated by steering effect: **Fs**

The traction force generated by the engine: **Fv**

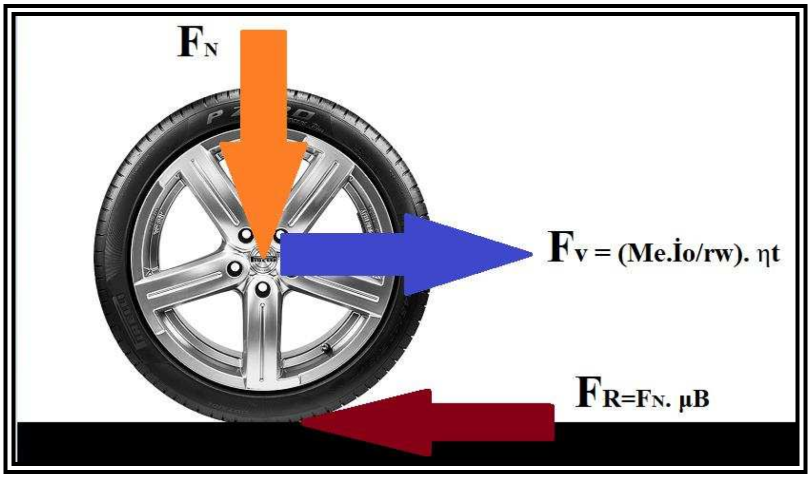

Figure 3.1.1: Forces acting on tire during drive.

If $\mathbf{F_V} > \mathbf{F_R}$ wheel-spinning occurs which is shown in Figure 3.1.1.

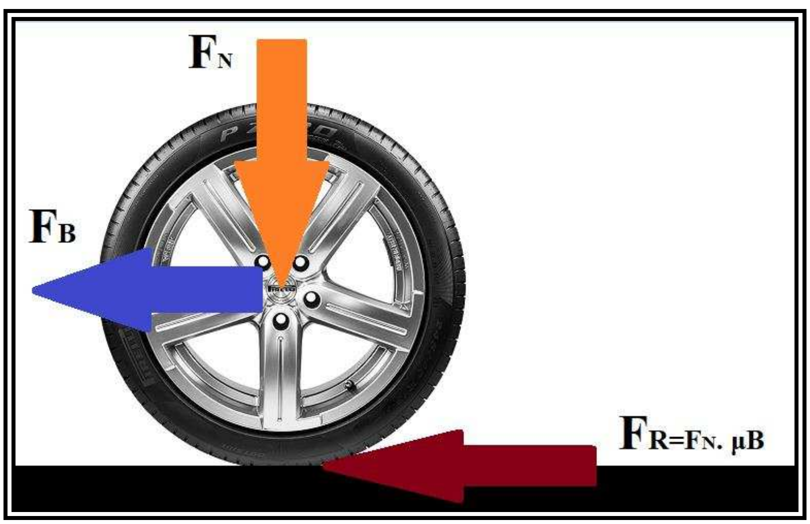

Figure 3.1.2: Forces acting on tire during braking.

If, $\mathbf{Fv_B} > \mathbf{F_R}$ is wheel-spinning

$\mathbf{Fv_B} >> \mathbf{F_R}$ locking which is shown in Figure 3.1.2.

Assuming a vehicle with a weight of 9810 N, the grip force of this vehicle on the icy and dry road will be as follows (μ_B = 0.07 on ice, μ_B = 0.9 on dry road and the axle distribution is equal and the safe slip limit is assumed to be 20%);

For icy road:

$\mathbf{F_R}$ = (9810/4) **.** 0.07 = 171.675 N

$\boldsymbol{\lambda}$= (F_V -F_R) / F_V

$\mathbf{F_V}$ = F_R / (1 - $\boldsymbol{\lambda}$) = 171.675 / 0,8 = 214.5937 N

For dry road:

$\mathbf{F_R}$ = (9810/4) **.** 0.9 = 2207.25 N

$\boldsymbol{\lambda}$= (F_V -F_R) / F_V

$\mathbf{F_V}$ = F_R / (1 - $\boldsymbol{\lambda}$) = 2207.25 / 0,8 = 2759.0625 N

With these calculations, it can be understood why the braking or accelerator pedal must be pressed less on an icy road.

4. Main Components of ABS

4.1. Hydraulic Control Unit

The hydraulic unit adjusts the brake cylinder pressure of each wheel with commands coming from the engine control unit (ECU). During this adjustment, solenoid valves are used. Where the car's engine is located, the main brake is positioned between the master cylinder and the wheel brake cylinders. Thus, the connections to the brake center cylinders and the links to the wheel brake cylinders are kept short. The hydraulic units have inlet and outlet solenoid valves for controlling each wheel pressure. The ECU plays an important role in this part and fulfills all electronic and electrical tasks with the control functions of the system. Figure 4.1.1 shows location of Hydraulic Control Unite in the car engine.

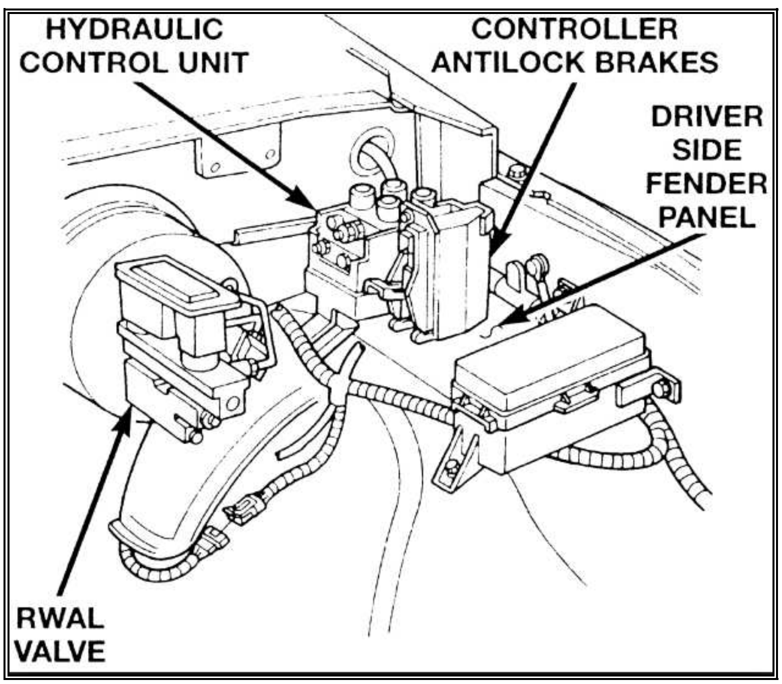

Figure 4.1.1: Location of Hydraulic Control Unit in car engine.

4.2. Wheel Speed Sensor

The ECU, or engine control unit, uses the signals from the wheel speed sensors to calculate the speed of the car's wheels. There are two principles in this regard, active and passive wheel speeds. Whether active or inactive, both speeds measure the speed of the wheels with the magnetic field, without touching the wheels. Today more active sensors are used. Active sensor variants can control both the direction of rotation of the wheels and the speed of the wheels. Figure 4.2.1 shows location of wheel speed sensors in car.

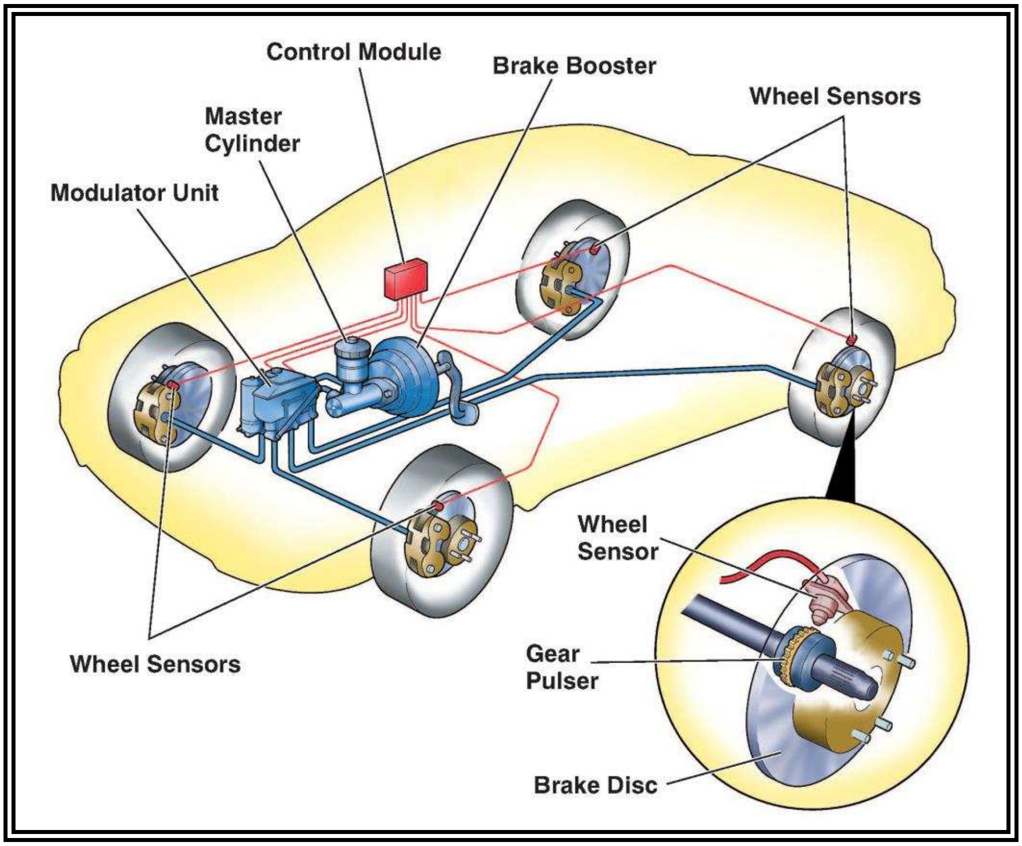

Figure 2.2.1: Location of wheel speed sensors, Master Cylinder, Control module in car.

4.3. Deceleration Sensor

During braking on four-wheel-drive vehicles, it detects the vehicle's deceleration rate and sends these signals to the ECU. The ECU uses these signals to determine precisely the road surface conditions and make the required control measurements. The deceleration speed sensor is located in the luggage compartment in passenger cars and in the engine compartment in other vehicles. Deceleration sensor contains two pairs of LEDs (light emitting diode) and one channel with photo transistor plate and a signal conversion circuit.

When the vehicle's deceleration rate changes, the channel plate is rocked along the longitudinal direction of the vehicle in accordance with the deceleration rate. Channels on the channel plate open and close the photo transistor by cutting off the light coming from the photo-transistor from the LEDs. The rate at which these transistors turn on and off is divided into four levels, which are signaled to the ECU.

4.4. Valves

The Hydraulic Control Unit controls these valves which are continuously active in the system.

The main tasks of valves are;

In the first position, valve open; the pistons in the caliper are braked by giving full power to them.

In the second position cuts the valve line; it cuts off the hydraulic flow on the line leading to the piston and no power is transmitted even when the pedal is pressed.

In The third position, half open; in this mode a certain amount of hydraulic is allowed to pass and pressure is applied to the pistons while the brake force is kept under control so that the line is not completely opened.

4.5. Hydraulic Pump

When the flow of the valve line is stopped, the hydraulic pressure is released from the pump to regain the lost pressure. This process is repeated every time when the hydraulic pressure decreased due to opening of valves. It is located on the hydraulic unit. In the fault condition, the ABS is deactivated and the ABS warning lamp lights up.

4.6. ABS Control Module

ABS Control Module is a microprocessor that evaluates the information transmitted by the wheel speed sensors and with this information it controls the ABS system by giving the necessary commands to the actuators. Generally, it is located under the hydraulic unit. In some vehicles the hydraulic unit may have been mounted at a different location. In the event of a fault, the ABS and the connected systems are disabled, some failures may cause problems with other systems, and the ABS warning lamp is turn on.

5. Types of ABS

5.1 Four-wheel ABS and Rear-wheel ABS

The aim of the four-wheel ABS is to provide maximum stability in the car's stopping conditions and maneuverability of the driver. On vehicles with ABS on all four wheels, the braking systems of the cars prevent the wheels from locking on all four wheels. The driver can control the vehicle better and it is easier to keep the vehicle under control. At this time, the braking pressure required for braking is set. If only the rear two wheels have ABS; this situation is usually found in trucks, minibuses and sports cars. The car is prevented from locking only on the rear wheels.

If only the rear two-wheel ABS system is available; If the driver is press on the brake pedal and locks the wheels, the driver must know that the braking system is not as effective as the four-wheel ABS. In this case, the driver must manually adjust the pressure on the brake pedal. Thus, the driver can conveniently orient the car in the desired direction and provide safe driving. Figure 5.1.1 shows differences between Four-channel, Three-channel and One-channel ABS.

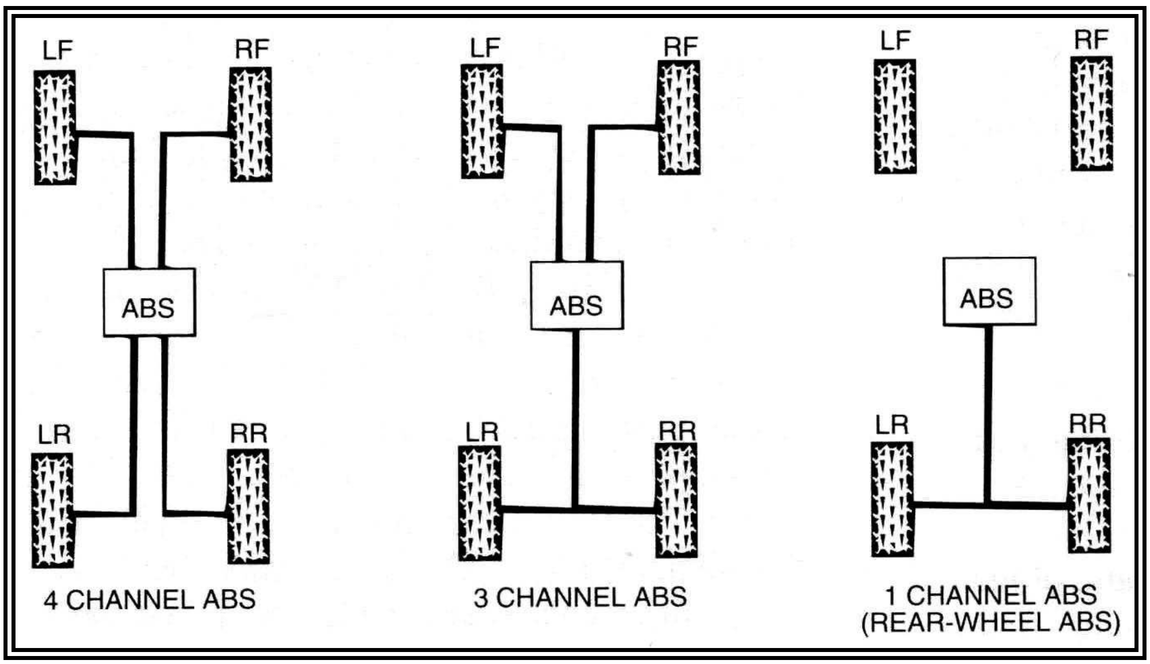

Figure 5.1.1: Four-channel, Three-channel and One-channel ABS.

5.2. Four-channel Four-sensor ABS

This type has four-wheel sensors and four hydraulic control channels. Each wheel is controlled independently. Steering safety and stopping distance on all road conditions are protected. In front-wheel drive vehicles, most of the weight is on the front wheels due to engine and transmission system located in front of the vehicle. Front wheels control almost 70% of the brake force. The remaining 30% of the braking force provided on the rear wheels is very important for the protection of the stability of the vehicle. The yawing moment that causes the speed difference on the wheels on the rear axle on different road surfaces can cause the vehicle to be out of balance. For this reason, vehicles with four-channel ABS have a low-logic choice on the rear wheels to maintain the balance of the vehicle in the majority.

5.3. Three-channel Three-sensor ABS

The three speed sensors measure the number of revolutions of both the wheel and differential sun gear. The braking force on the front wheel is adjusted separately by solenoid valves. The braking force of the rear wheels is regulated by a single solenoid valve. This type hydraulic units are used in parallel brake circuits.

5.4. Two-channel ABS

This type of hydraulic unit is used on heavy vehicles or on vehicles such as trucks. Only the rear two wheels are controlled.

5.5. One-channel One-sensor ABS

This type of anti-lock system is usually found in SUVs in VANs and pickups. There is only one valve and one sensor, which controls the rear wheels. It is similar to the three-channel ABS system for the way of operation. The distinctive feature of the system is that there is no independent speed sensor for each wheel.

6. ABS Failures and Signs

If the warning light of the ABS brake system does not extinguish within three seconds of applying the voltage, or if the lamp lights up during driving, there is a fault and the system is switched off. Figure 6.1 shows ABS and Brake system warning lights.

Figure 6.1: ABS and Brake system warning lights**.**

The vehicle must be checked to make the ABS brake system functional again. In the meantime, the normal operation of the brakes remains unaffected. The investigation of the faults is extremely easy with the diagnostic facility. Faults are detected according to the fault code appropriate to the fault type. Determination of the fault location in the faulty line can also be done by conventional methods.

If the ABS warning light is on;

In order to provide separate testing of the parts in the system, this diagnostic method is divided into stages. In any kind of fault diagnosis, the test should be started from the first stage until the fault is corrected.

- The voltage of the electronic module should be checked,
- whether reservoir warning and pressure warning switches are operating should be checked,
- The resistance of the sensor should be checked,
- Main valve operation should be checked,
- The inlet and outlet valves should be checked for resistance,
- Electronic modules must be replaced.

If the ABS warning light is on after the engine has started, sensor cables and isolations should be checked. All sensor cabling in the system and their insulation should be checked one by one.

If the ABS warning light comes on after the vehicle has been in motion; If the fault still cannot be rectified as a result of inspections of the sensor cables and their insulation made after individual control of the parts in the system, the following checks are possible:

- Sensor resistance control,
- Wheel sensor operation and sensor track control.

The ABS and brake warning lamps are on, or the pump is running long;

It is possible to investigate the fault in this situation at various stages. First, the system's members should be tested one by one, then complaints should be followed up to the developer. The following check are;

- Outside leakage control,
- Pump motor control,
- Pressure increase time control,
- Operation of the pressure sphere,
- Pressure warning function control,
- Internal leak check of the hydraulic center unit.

If the ABS warning lamp lights up intermittently;

It is also possible to investigate the fault in this case again at various stages. First, the system elements must be tested one by one, then these operations should be followed:

- Improper connection check in the installation plugs,
- Hydraulic reservoir cover operation and pressure warning operation control,
- Sensor resistance check.

If only the brake warning light is on;

Once the system components have been checked individually, the following test sequence should be followed:

- Check the parking brake lamp operation,
- Check brake hydraulic level warning lamp operation,
- Check for external leaks,
- Check the operation of reservoir and pressure warning lights.

Parking brake lamp operation check;

The ignition is switched off, the brake pedal is pumped at least 20 times and the ignition is switched on, waiting until the engine has stopped. The handbrake is released; if the light remains on, the hand brake setting is checked.

Hydraulic level warning lamp operation check;

The ignition is switched off, the pedal is pumped at least 20 times. The ignition is switched on and the hydraulic level is checked immediately when the engine has stopped running; It should be between 'max' and 'min' lines.

Outside leakage control;

- The brake hydraulic pipes are checked,
- Check central pump low and high pressure hydraulic pipes,
- Near the reservoir, leaks are checked at felts and joints,
- Leak under the carpet at the entrance to the central pump of the push rod with brake pedal control is done,
- The necessary actions are taken, and the fault is corrected.

If the ABS warning light is not lit at all;

All the recommended operations are performed so that all parts in the system can be tested one by one. If the ABS warning light is not lit at all, fuses, light bulbs and wiring should be checked.

If the brake pedal goes too deep (While ABS warning light is off);

After all the parts in the system have been checked, external leaks are checked, and air is taken from the system. Central pump internal hydraulic leaks are also checked, and necessary actions and changes are performed.

If the brake pedal travel increases when the ABS system is running;

If the pedal travel increases when the ABS system is switched on, all parts are first tested in the system, then the system is checked for leaks and air is taken from the brake system. This operation is followed by electrical control of the main valve.

If the operation of ABS is weak;

After all elements are checked in the system, diode operation control is performed. Then an external leak check is carried out and air in the system is removed. After that, resistance control of the inlet and outlet valves is performed, and the hydraulic duty controls of the inlet and outlet valves are performed. As a result of the checks made, necessary actions are taken.

7. Advantages and Disadvantages of ABS

7.1. Advantages of ABS

The advantage of the anti-lock braking system is that the vehicle under all kinds of braking conditions; stabilize and ensure optimum braking without losing control of the steering wheel. Optimum braking means optimizing the braking distance by achieving maximum road holding, thus bringing it to the optimum distance. If emergency braking is necessary, must be able to avoid an obstacle, lose dominance during bends, and lose steering dominance even if the wheels have different levels of grip.

In addition to reducing the brake distance, the most important advantage of the ABS braking system is that steering is not lost during emergency braking.

7.2. Disadvantages of ABS

Under certain circumstances, vehicles with ABS provided an open superiority in braking compared to a non-ABS vehicle. In gravel, loose and wet snowy roads, this is the opposite. Vehicles with ABS have a longer stopping distance. If ABS is thought to give the driver steering control, it will be understood that the stopping distance is not a parameter that shows the braking performance alone.

8. Discussion and Conclusion

8.1. Discussion

This study describes the impact of ABS on driving dynamics and driving safety. Vehicles with and without ABS have been compared. Although ABS is known to improve driving dynamics, vehicle control and comfort at the time of braking, statistics are still given in the appendix. According to the research published in 1996 (Hertz et al, 1996) ABS vehicles have less accidents than non-ABS vehicles and mortal accident rates of vehicles without ABS are very high [16]. According to another research published in 2001 (Farmer, 2001), ABS reduces accident numbers but there is no direct evidence that ABS increases the overall vehicle safety alone [17].

8.2. Conclusion

This study has attempted to assess how the ABS system works, its history, the duty of ABS parts, the solutions of system errors, and the advantages/disadvantages of ABS. As a vehicle travels at a constant speed, the speed of the car and the speed of the wheels are the same. When the driver presses the brake, the speed of the wheels gradually decreases and reaches a speed that is different from the speed of the vehicle, which is still under the influence of mass. When the difference between the wheel speed and the speed of the vehicle is too big, it slips between the tires and the road surface. In such unintentional sliding wheel braking situations, the ABS ECU calculates the changes in the rotational speeds and speeds of the wheels. From here, the vehicle speed is determined and according to this, the brake pressure is supplied to the wheels in the required amount to provide a safer driving.

ABS is a system that provides both safety and comfort by automatically performing all these complex operations without waiting for anything from the driver. In addition, ESP, TCS, EHB, EBD and BAS, such as integration with a number of systems to move the current level of safety to a more reliable level is pioneered.

References

1. P. M. Hart, “Review of Heavy Vehicle Braking Systems Requirements (PBS Requirements),” Draft Report, 24 April 2003.
2. Jon Lawes (31 January 2014). Car Brakes: A Guide to Upgrading, Repair and Maintenance. Crowood. pp. 207–. ISBN 978-1-84797-675-8.
3. A. G. Ulsoy and H. Peng, “Vehicle Control Systems,” Lecture Notes, ME 568, 1997.
4. P. E. Wellstead, “Analysis and Redesign of an Antilock Brake System Controller,” IEEE Proceedings Control Theory Applications, Vol. 144, No. 5, September 1997, pp. 413-426. doi: 10.1049/ip-cta:19971441
5. S. Yoneda, Y. Naitoh and H. Kigoshi, “Rear Brake Lock-Up Control System of Mitsubishi Starion,” SAE Paper, Washington, 1983
6. H. Takahashi and Y. Ishikawa, “Anti-Skid Braking Control System Based on Fuzzy Inference,” U.S. Patent No. 4842342, 1989
7. "Directory Index: Chrysler_and_Imperial/1972 Chrysler/1972_Imperial_Press_Kit". Oldcarbrochures.com. Retrieved 2014-08-26.
8. 1973 Chrysler and Imperial Data Book and Car Selector - Page 49. (n.d.). Retrieved from http://imperialclub.org/~imperialclub/Yr/1973/Data/49.htm
9. 1970 Lincoln Continental Brochure. (1973). Retrieved from http://www.oldcarbrochures.com/static/NA/Lincoln/1970_Lincoln/1970 Lincoln Continental Brochure/1970 Lincoln Continental-15.html
10. First Automotive Anti-lock Brake System (ABS). (1972). Retrieved from https://history.gmheritagecenter.com/wiki/index.php/1972,_First_Automotive_Anti-lock_Brake_System_(ABS)
11. Society of Automotive Engineers in Japan, Inc. (n.d.). 240 Landmarks of Japanese Automotive Technology. Retrieved from http://www.jsae.or.jp/autotech/data_e/5-4e.html, Electro antilock system (installed in Nissan President)
12. FIAT, C. (2013, December 11). Sistema antislittamento Sicurezza frenata. Retrieved from https://www.youtube.com/watch?v=JbpmalG8VUE, "Sistema

antislittamento Sicurezza frenata - Centro Storico FIAT - Archivio Nazionale del Cinema d'Impresa, 1971".

13. WABCO. (n.d.). 150 Years of WABCO. Retrieved from http://www.wabco-auto.com/about-us/wabco-at-a-glance/our-history/, First electronic braking system (EBS)

14. Mercedes-Benz. (2017, June 30). Mercedes-Benz W 116 350 SEL. Retrieved from https://www.mercedes-benz.com/en/ats_vehicle/mercedes-benz-w-116-350-sel/

15. Lincoln, T. (2007, July 15). 1993 Lincoln safety ad. Retrieved from https://www.youtube.com/watch?v=wMJSXyTnOhI

16. Hertz, Ellen, Hilton, Judith; and Johnson, Delmas Maxwell, "Analysis of the Crash Experience of Passenger Vehicles Equipped with Antilock Braking Systems". ESV Paper Number 96-S9-O-03, May 1996.

17. C. M. Farmer (2001). The Long-Term Effect of ABS in Passenger Cars and LTVs. Springfield, Virginia: National Highway Traffic Safety Administration.

APPENDICES

APPENDIX A: Statistical Data

Table A1. Driver injury severity by ABS presence and vehicle model

	ABS Not Fitted			ABS Fitted			
	Injury Severity			Injury Severity			
Vehicle Model	Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	Total
A	7	1	8	1		1	9
AA	407	105	512	15	3	18	530
AAA				15	2	17	17
BBB	7	3	10	14	2	16	26
CCC				1		1	1
D	74	24	98				98
DDD				3		3	3
EEE				1		1	1
F	456	147	603	341	123	464	1067
GG	136	33	169				169
H	25	17	42				42
HH	11	5	16	5		5	21
I	33	11	44	1	2	3	47
J	365	117	482				482
JJ	14	4	18	6	1	7	25
K				6	3	9	9
KK		1	1	9	3	12	13
L	622	210	832	375	122	497	1329
LL	7	3	10	21	17	38	48
MM				1		1	1
NN	6	1	7	3		3	10
O	8	5	13	13	9	22	35
P	2	1	3				3
PP	157	49	206	5		5	211
Q	529	144	673	425	114	539	1212
QQ	4		4				4
R	46	29	75				75
RR	492	141	633	45	12	57	690
S				1	1	2	2
SS	10	2	12	4	2	6	18
TT	8	1	9	1		1	10
UU	50	11	61	1		1	62
V	2		2				2
VV	44	11	55				55
WW	128	55	183	1		1	184
X	122	42	164				164
XX	10	4	14	1		1	15
Y	33	12	45				45
YY	7	3	10				10
Z	5	1	6				6
ZZ	1		1				1
Total	**3828**	**1193**	**5021**	**1315**	**416**	**1731**	**6752**

Table A2.	Driver injury risk by ABS presence and vehicle model						
	ABS Not Fitted			ABS Fitted			
Vehicle Model	Not Injured	Injured	Total	Not Injured	Injured	Total	Total
A	23	8	31	7	1	8	39
AA	2457	350	2807	110	9	119	2926
AAA				127	15	142	142
BBB	55	10	65	72	15	87	152
CCC				7	1	8	8
D	398	74	472				472
DDD				5	3	8	8
E	1		1				1
EEE				22	1	23	23
F	3510	506	4016	2632	391	3023	7039
GG				1		1	1
GG	809	133	942	2		2	944
H	224	34	258	2		2	260
HH	91	11	102	29	4	33	135
I	198	34	232	26	1	27	259
II				13		13	13
J	1349	414	1763				1763
JJ	146	12	158	83	2	85	243
K				29	7	36	36
KK	17		17	107	10	117	134
L	4478	718	5196	2585	413	2998	8194
LL	95	8	103	162	25	187	290
M	6		6	1		1	7
MM				7	1	8	8
NN	49	4	53	23	3	26	79
O	106	11	117	90	17	107	224
P	6	3	9				9
PP	828	156	984	27	2	29	1013
Q	3649	529	4178	2838	411	3249	7427
QQ	12	4	16				16
R	637	75	712	1		1	713
RR	3368	483	3851	274	38	312	4163
S	17		17	9	2	11	28
SS	90	10	100	21	5	26	126
T				1		1	1
TT	37	6	43	2	1	3	46
UU	224	44	268	1	1	2	270
V	3		3				3
VV	374	48	422	2		2	424
WW	926	151	1077	1		1	1078
X				2		2	2
XX	17	5	22				22
Y	185	27	212				212
YY	55	10	65				65
Z	92	5	97				97
ZZ	2	1	3				3
Total	**24534**	**3884**	**28418**	**9321**	**1379**	**10700**	**39118**

Table A3. Driver injury severity by crash DCA and ABS presence

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted			ABS Fitted			Total
		Injury Severity			Injury Severity			
		Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	
Ped near side. ped hit by vehicle from the right	100	1		1				1
Far side. ped hit by vehicle from the left	102	2		2				2
Any manoeuvre involving ped not included in DCAs 100-108	109	1		1	1		1	2
Cross traffic(intersections only)	110	246	68	314	58	21	79	393
Right far (intersections only)	111	25	1	26	3		3	29
Left far (intersections only)	112	4	5	9				9
Right near (intersections only)	113	123	37	160	32	11	43	203
Two right turning (intersections only)	114	1	1	2	2		2	4
Right/left far (intersections only)	115	1		1				1
Left near (intersections only)	116	14	3	17	5	1	6	23
Two left turning (intersections only)	118	1		1				1
Other adjacent (intersections only)	119				1		1	1
Head on (not overtaking)	120	105	95	200	41	21	62	262
Right through	121	231	60	291	48	15	63	354
Right/left. one veh turning right the other left	123	2		2				2
Other opposing manoeuvres not included in DCAs 120-125	129	2		2	3		3	5
Rear end(vehicles in same lane)	130	377	39	416	106	11	117	533
Left rear	131	56	3	59	11		11	70
Right rear	132	97	10	107	28	2	30	137
Lane side swipe (vehicles in parallel lanes)	133	9	4	13	4	1	5	18
Lane change right (not overtaking)	134	13	5	18	3		3	21
Lane change left (not overtaking)	135	15	4	19	3		3	22
Right turn sideswipe	136	25	5	30	5	1	6	36

Table A3. Continued

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted: Injury Severity: Minor Injury	ABS Not Fitted: Injury Severity: Severe Injury	ABS Not Fitted: Total	ABS Fitted: Injury Severity: Minor Injury	ABS Fitted: Injury Severity: Severe Injury	ABS Fitted: Total	Total
Left turn sideswipe	137	3	2	5				5
Other same direction-manoeuvres not included in DCAs 130-137	139	2	1	3	1		1	4
U turn	140	27	9	36	10	3	13	49
U turn into fixed object/parked vehicle	141	1		1				1
Leaving parking	142	10		10		1	1	11
Entering parking	143	1		1				1
Reversing in stream of traffic	145	4		4	1		1	5
Reversing into fixed object/parked vehicle	146	1		1				1
Vehicle strikes another veh while emerging from driveway	147	45	5	50	8	1	9	59
Other manoeuvring not included in DCAs 140-148	149	1		1	2		2	3
Head on (overtaking)	150	12	6	18	2	1	3	21
Out of control (overtaking)	151	13	10	23	9	3	12	35
Pulling out (overtaking)	152	7	2	9	3	1	4	13
Cutting in (overtaking)	153					1	1	1
Pulling out -rear end	154	4		4				4
Other overtaking manoeuvres not included in DCAs 150-154	159	2		2	2		2	4
Vehicle collides with vehicle parked on left of road	160	21	8	29	7	3	10	39
Double parked	161		1	1				1
Accident or broken down	162	8		8	2		2	10
Permanent obstruction on carriageway	164	3		3		1	1	4
Temporary roadworks	165	4		4				4
Struck object on carriageway	166	9	6	15	3	2	5	20
Struck animal	167	9	7	16	8	2	10	26

Table A3. Continued

Definition for Classifying Accidents (DCA)	DCA No.	ABS Not Fitted			ABS Fitted			Total
		Injury Severity			Injury Severity			
		Minor Injury	Severe Injury	Total	Minor Injury	Severe Injury	Total	
Other on path	169	6	1	7	1	1	2	9
Off carriageway to left	170	27	13	40	9	2	11	51
Left off carriageway into object/parked vehicle	171	86	67	153	42	27	69	222
Off carriageway to right	172	12	16	28	6	6	12	40
Right off carriageway into object/parked vehicle	173	73	55	128	26	22	48	176
Out of control on carriageway (on straight)	174	13	9	22	6	4	10	32
Off end of road/t-intersection	175		1	1				1
Other accidents-off straight not included in DCA+A67s 170-175	179	10	15	25	7	2	9	34
Off carriageway on right bend	180	19	8	27	6	5	11	38
Off right bend into object/parked vehicle	181	56	26	82	28	19	47	129
Off carriageway on left bend	182	10	5	15	3	3	6	21
Off left bend into object/parked vehicle	183	38	24	62	15	9	24	86
Out of control on carriageway (on bend)	184	13	9	22		5	5	27
Other accidents on curve not included in DCAs 180-184	189	16	8	24	5	3	8	32
Fell in/from vehicle	190	3	2	5	2		2	7
Load or missile struck vehicle	191	1	2	3	2	3	5	8
Struck train	192	4	2	6	2		2	8
Struck railway crossing furniture	193	2		2				2
Parked car run away	194		1	1	1	1	2	3
Other accidents not classifiable elsewhere	198	1	2	3				3
Total		**1928**	**663**	**2591**	**573**	**215**	**788**	**3379**

Table A3.1.	Chi-squared analysis of crash distribution for ABS and non-ABS equipped vehicles: Victoria and Queensland			
DCA		**Not Fitted**	**Fitted**	**Total**
Pedestrian	Count	4	1	5
	Expected Count	3.833975	1.166025	5
Vehicle Adjacent	Count	530	134	664
	Expected Count	509.1518	154.8482	664
Vehicle Opposing	Count	495	128	623
	Expected Count	477.7132	145.2868	623
Vehicle Same Direction	Count	670	176	846
	Expected Count	648.7085	197.2915	846
Manoeuvring	Count	104	26	130
	Expected Count	99.68334	30.31666	130
Overtaking	Count	56	22	78
	Expected Count	59.81	18.19	78
On Path	Count	83	30	113
	Expected Count	86.64782	26.35218	113
Off Path on Straight	Count	397	159	556
	Expected Count	426.338	129.662	556
Off Path on Curve	Count	232	101	333
	Expected Count	255.3427	77.6573	333
Passenger and Miscellaneous	Count	20	11	31
	Expected Count	23.77064	7.229358	31
Total	**Count**	**2591**	**788**	**3379**
	Expected Count	**2591**	**788**	**3379**

Chi-square Tests			
	Value	**Degrees of Freedom**	**Asymptotic Significance (2 Sided)**
Pearson Chi-Square	32.24342	9	0.000181
Likelihood Ratio	31.30462	9	0.000262
Linear-by-Linear Association	29.1924	1	6.55E-08
N of Valid Cases	3379		

Note: 2 cells (10%) have expected count less than 5. The minimum expected count is 1.17.

Table A4. Driver injury severity by RUM Code and ABS presence

		ABS Not Fitted			ABS Fitted			
		Injury Risk			Injury Risk			
Road User Movement (RUM)	RUM Code	Not Injured	Injured	Total	Not Injured	Injured	Total	Total
Ped nearside	0	3		3				3
Ped emerging	1	1		1				1
Ped far side	2				2		2	2
Ped playing	3	1		1	1		1	2
Ped on footpath	6				1		1	1
Cross traffic	10	272	54	326	111	15	126	452
Right far	11	15	4	19	4	1	5	24
Left far	12	4		4	2		2	6
Right near	13	102	31	133	41	9	50	183
2 right turning	14	1		1				1
Left near	16	8	3	11	3		3	14
Other adjacent	19	1		1				1
Head on	20	163	89	252	42	33	75	327
Right through	21	235	55	290	80	16	96	386
Rear end	30	364	49	413	139	14	153	566
Left rear	31	18	3	21	1		1	22
Right rear	32	76	13	89	25	1	26	115
Lane sideswipe	33	10	2	12	3	3	6	18
Lane change right	34	18	4	22	8	2	10	32
Lane change left	35	11	5	16	4		4	20
Right turn sideswipe	36	4	1	5	3		3	8
Left turn sideswipe	37	5	1	6	1		1	7
Other same direction	39	1	1	2	1		1	3
U turn	40	40	8	48	17	1	18	66

Table A4. Continued

Road User Movement (RUM)	RUM Code	ABS Not Fitted			ABS Fitted			Total
		Injury Risk			Injury Risk			
		Not Injured	Injured	Total	Not Injured	Injured	Total	
U turn into object	41	3		3				3
Leaving parking	42	11	2	13	3		3	16
Reversing	45	1	1	2	5	1	6	8
Reversing into obj	46	4		4	2		2	6
Emerging from drive	47	23	4	27	2		2	29
Other manoeuvring	49	2	2	4	2	1	3	7
Head on (overtake)	50	4	5	9	2		2	11
Out of control otake	51	3	1	4		1	1	5
Overtake turning	53	9	1	10	1	1	2	12
Cutting in	54	1		1	1		1	2
Pulling out rear end	55		1	1				1
Other overtaking	59	1		1				1
Parked	60	21	5	26	12		12	38
Double parked	61	1		1	1		1	2
Accident	62	11	2	13	2		2	15
Vehicle door	63	3		3				3
Perm obstruction	64	1		1				1
Temp road works	65	1		1		1	1	2
Object on road	66	2		2	1		1	3
Struck animal	67	10	3	13	5	2	7	20
Other on path	69	3		3				3
Off road to left	70	17	9	26	5	3	8	34
Off road left => obj	71	126	47	173	48	26	74	247
Off road to right	72	14	8	22	8	2	10	32

Table A4. Continued

Road User Movement (RUM)	RUM Code	ABS Not Fitted			ABS Fitted			Total
		Injury Risk			Injury Risk			
		Not Injured	Injured	Total	Not Injured	Injured	Total	
Off road right => obj	73	62	21	83	32	16	48	131
On road-out of cont.	74	4	1	5	4	1	5	10
Off end of road	75	1	2	3	4	1	5	8
Off left/right bend	80	14	8	22	8	2	10	32
Off left/right bnd=>obj	81	76	33	109	38	23	61	170
Off right/right bend	82	6	3	9	1	3	4	13
Off right/right bnd=>obj	83	18	17	35	30	7	37	72
Off right/left bend	84	5	5	10	2	2	4	14
Off right/left bnd=>obj	85	42	8	50	17	5	22	72
Off left/left bend	86	5	3	8	1	1	2	10
Off left/left bnd=>obj	87	20	9	29	11	4	15	44
Out of control on bend	88	12	5	17	3		3	20
Object struck veh	91	2	1	3	1		1	4
Struck train	92	2		2		2	2	4
Parked veh runaway=>obj	93	1		1	1		1	2
Parked veh runaway=>veh	94	1		1				1
Alighting/boarding	95	1		1				1
Other	98	1		1				1
Total		**1898**	**530**	**2428**	**742**	**200**	**942**	**3370**

Table A4.1.	Chi-squared analysis of crash distribution for ABS and non-ABS equipped vehicles: NSW			
DCA		**Not Fitted**	**Fitted**	**Total**
Pedestrian	Count	5	4	9
	Expected Count	6.484273	2.515727	9
Vehicle Adjacent	Count	495	186	681
	Expected Count	490.6433	190.3567	681
Vehicle Opposing	Count	542	171	713
	Expected Count	513.6985	199.3015	713
Vehicle Same Direction	Count	586	205	791
	Expected Count	569.8955	221.1045	791
Manoeuvring	Count	101	34	135
	Expected Count	97.26409	37.73591	135
Overtaking	Count	26	6	32
	Expected Count	23.05519	8.944807	32
On Path	Count	63	24	87
	Expected Count	62.68131	24.31869	87
Off Path on Straight	Count	312	150	462
	Expected Count	332.8593	129.1407	462
Off Path on Curve	Count	289	158	447
	Expected Count	322.0522	124.9478	447
Passenger and Miscellaneous	Count	9	4	13
	Expected Count	9.366172	3.633828	13
Total	**Count**	**2428**	**942**	**3370**
	Expected Count	**2428**	**942**	**3370**

Chi-square Tests			
	Value	**Degrees of Freedom**	**Asymptotic Significance (2 Sided)**
Pearson Chi-Square	27.28796	9	0.001253
Likelihood Ratio	26.80922	9	0.001504
Linear-by-Linear Association	17.0208	1	3.7E-05
N of Valid Cases	3370		

Note: 2 cells (10%) have expected count less than 5. The minimum expected count is 2.52

Appendix B: Technical Drawings

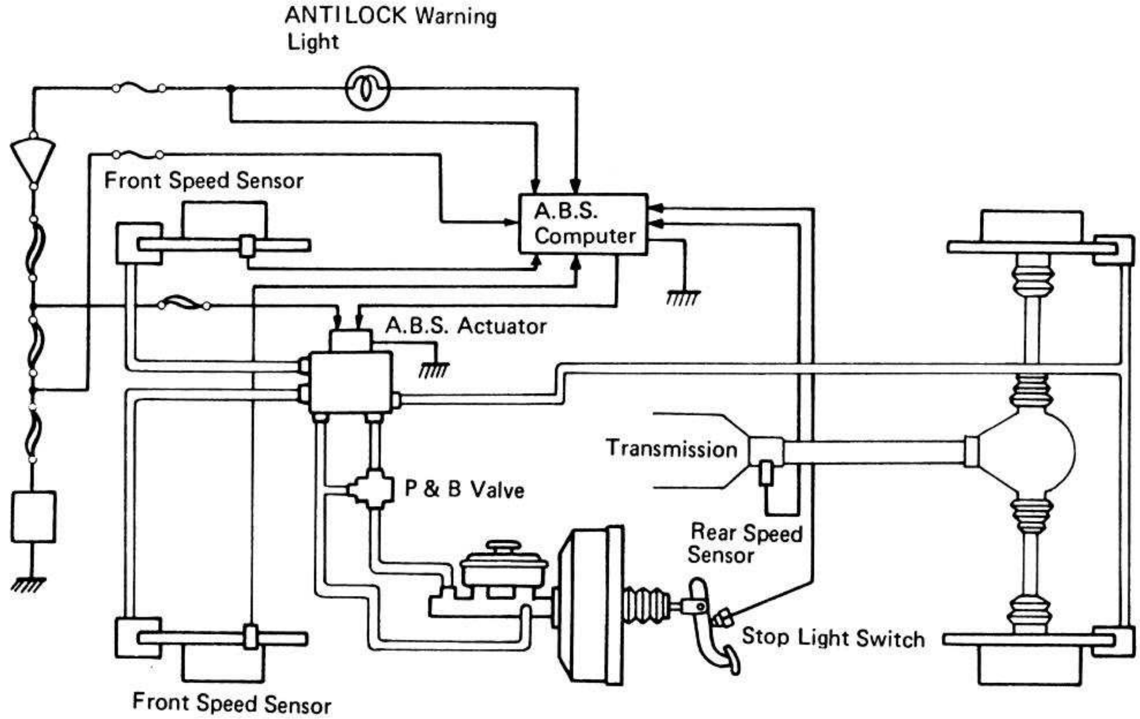

Figure a2: Anti-lock brake system (ABS) schematic-1989-90 Cressida

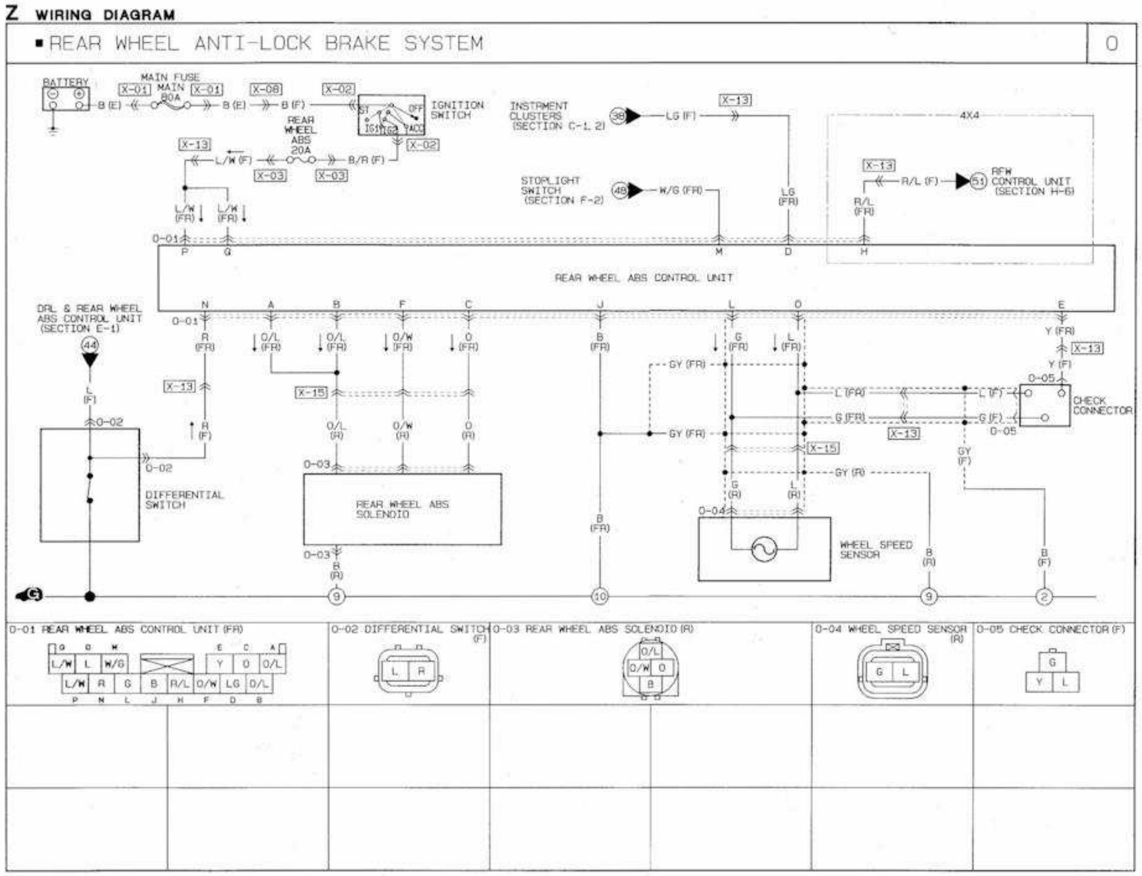

Figure a2.1: 1991 Mazda B2600i Wiring Diagram Rear Wheel Anti-Lock Brakes