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Institute of Traffic Safety
Department Safety Research
and Development

CITA RESEARCH STUDY PROGRAMME
ON ELECTRONICALLY CONTROLLED SYSTEMS ON VEHICLES

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Report

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Testing of existing AntiLock Braking systems (ABS)

Report as defined in Article 4 of the agreement

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34		

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1. Introduction

Modern motor vehicle drive systems are characterised by a multitude of complex control and regulating systems optimally adapting the drive characteristics to the respective driving condition. Known systems are electronic devices for regulating the brake system to obtain increased safety by means of automatic slip regulation when braking (ABS, ESP etc.) or accelerating. Anti Lock Braking Systems (ABS) became a standard device in all actual vehicles. At present a high rate of vehicles equipped with ABS with ages up to ten or twelve years are on the road.

The existing information about the availability and reliability of these systems is insufficient. Furthermore, it is not defined, how these systems can be effectively checked on their correct function. At present, the efficiency of these systems is only tested after the production of the car and no further tests or periodic checking occur during it's whole lifetime. Only self-checks are done by the systems self diagnosis routine and the results are documented in the fault memory. It is unknown, whether these self checks are sufficient to cover most of the failures which appear in the system, or if additional efficiency tests are necessary.

Nevertheless, this information is necessary for the estimation about the influences of these systems on traffic safety.

Therefore, in this study the functional behaviour of older ABS systems is examined with a four wheel ABS Test Bench from TUEV Rheinland. A large number of vehicles (>250) is tested to ensure the correctness of the statistics. The vehicles for the tests are acquired during the periodical inspection tests at the TUEV Kraftfahrt testing facilities. A test sequence for the four wheel test bench is defined to make the detection of failures and discrepancies of the ABS possible. After data collection, a detailed evaluation of the data is carried out. The result of the evaluation determines the rate of defective ABS.

The functional behaviour during the efficiency test is analysed and the appeared failures are compared with the fault memory content before and after the efficiency test on the test bench. Herewith, important information of the failure detection rates of the two test types is generated. Furthermore, it is investigated, if the implementation of the tests in the given procedure of the periodic testing is practicable.

2. The ABS

2.1. Historic Development of the ABS

Anti-lock braking was originally designed for trains in the early 1900s, and was later developed for jet aircraft. In the late 1960s, car manufacturers began to adapt ABS for use in luxury automobiles. However, early prototype systems were severely limited by mechanical and analog technologies of the time. Advances in electronics technology allowed car manufacturers to develop highly reliable anti-lock braking systems that can be economically installed in a wide variety of vehicles.

Modern Anti Lock Braking Systems (ABS) were introduced in the upper class vehicles the first time in 1978. In the early 90s, ABS found spreading at a high rate in middle and lower class vehicles. Today, ABS is a standard feature of nearly all new cars being on the market.

2.2. Basic Function

The basic function of the ABS is prevention of wheel lockup and thus maintains both, steerability and vehicle stability assuring at the same time shorter stopping distances as compared to locked-wheel braking on most road surfaces. Malfunction caused by aging of the ABS components or insufficient maintenance of the vehicle can result in a loss of braking power. A sufficient braking capability is one of the most important qualities a vehicle must have.

2.3. ABS Components

ABS use a combination of electronic and hydraulic systems to modulate the brakes individually to prevent them from locking.

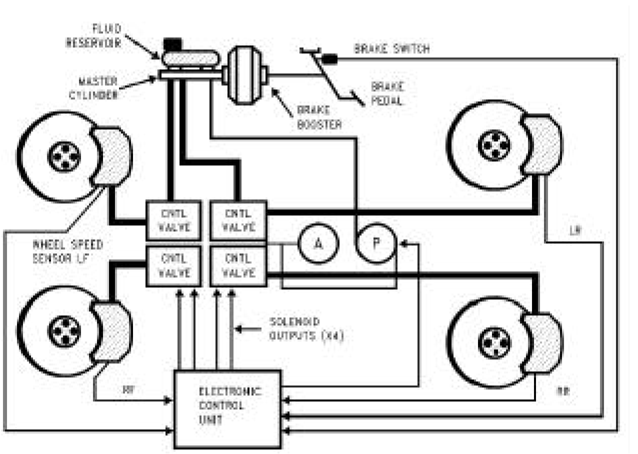


Figure 2.1

Antilock systems basically consist of the following major components [Lit 1] (see also Figure 2.1):

- Wheel Speed Sensors:
  They measure wheel-speed and transmit information to an electronic control unit.

- Electronic Control Unit (ECU):
  This receives information from the sensors, determines when a wheel is about to lock up and controls the hydraulic control unit.

- Hydraulic Control Unit (HCU):
  This controls the pressure in the brake lines of the vehicle.

- Valves:
  Valves are present in the brake line of each brake and are controlled by the hydraulic control unit to regulate the pressure in the brake lines.

While braking, the electronic control unit (ECU) reads signals from electronic sensors monitoring wheel rotation. If a wheel's rate of rotation suddenly decreases, the ECU orders the hydraulic control unit (HCU) to reduce the line pressure to that wheel's brake. Once the wheel resumes normal operation, the control unit restore pressure to it's brake. Depending on the system, this cycle of pumping can occur at up to 15 times per second. Anti-lock braking systems use different schemes depending on the type of brake in use: Four channels, four sensors ABS; three channels, three sensors ABS; two channels, two sensors ABS.

2.4. 3-channel ABS versus 4-channel ABS

In a **3-channel ABS,** hydraulic pressure is supplied to the front brakes individually and is supplied to both rear brakes as if there were only one, although wheel speed may be measured at all four wheels separately. This system is less complicated and cheaper to build but it does not provide as much safety and control as a 4-channel ABS. In a **4-channel ABS,** hydraulic pressure is supplied to all four brakes individually, wheel speed is measured at all four wheels individually. Wheel lockup can be controlled and prevented on all four wheels separately. This system architecture improves safety and control compared with a 3-channel ABS.

3. ABS Test Bench of TÜV Rheinland

Conventional one axle power test benches and/or conventional brake test benches are inadequate for developing and testing complex drive systems like ABS as here testing conditions are created that only inadequately simulate the collective load occurring during driving and the dynamic operating conditions. So far testing equipment coming close to reality has consisted of costly two axle flywheel mass test benches or of very expensive electronically controlled drive test benches. Such test benches have been designed to simulate the same forces as they occur at the tyre or wheel during braking or accelerating on the road. The complex slip conditions between tyres and road not only ask for a costly electronic control system for a simulation closely corresponding to reality but there have also high driving powers to be installed in the test bench due to the dynamic processes to be taken into consideration with the effective moments of inertia in the drive. Therefore, the expenditure for test bench simulation of a road must be assessed as relatively high.

3.1. ABS Testing Possibilities

But there are many applications that do not always require a test bench allowing the simulation of all operating conditions that may occur in the drive and brake. The prime objective of this work carried out at the Institute for Traffic Safety at the TÜV Rheinland (Rhineland Technical Inspection Agency) has been to create low-cost testing equipment for slip-regulating systems, e.g. for series testing of vehicles, also allowing development work to a limited extent. A market analysis of the test bench concepts currently offered for this purpose has revealed that these are unsuitable for ABS testing for at least one of the following reasons:

- Conventional brake test benches costing up to 30,000.00 € do not allow ABS testing as the test speeds of less than 5 km/hr are too low; there is not jet any ABS regulation!
- Test benches costing up to approx. 250,000.00 € drive the vehicle wheels corresponding to a speed of about 20 km/hr to obtain a speed signal of the sensors. By this and by means of a test programme ABS electronics testing is carried out. These test benches are installed at the end of an assembly line at the manufacturers for a final checking. This is a type-specific testing procedure that is only of limited suitability as generally applicable solution.
- Test benches costing up to about 500,000.00 € are usually based on the flywheel mass concept and allow type-independent ABS testing by measuring and evaluating the wheel speeds. In this case, ABS regulating cycles are demonstrable.
- The most expensive test benches are equipped with 4 speed controlled d.c. motors with outputs exceeding 40 kW/wheel. These test benches cost more than about 1 million €.

Tests on plate test benches with the plates constructed so as to allow a complete ABS regulating cycle to be demonstrated on them have not been successful. It can be concluded that according to current information a low-cost test bench for ABS testing was not jet available on the market.

3.2. A new Test Bench Concept

This situation finally resulted in a low-cost test bench concept being essentially based on three considerations:

- Simulation of the braking operation on an inclined icy surface
- Shifting the slip between tyre and road or roll resp. to a test bench element establishing the same relation between torque or coefficient of friction resp. and slip as the tyre/ice combination
- Combination of slip element and drive

The application of these considerations in a practicable test bench equipment is examined in detail below.

3.3. Braking on Ice

When braking a wheel, a torque M_B is initiated via the brake that must be counteracted in stationary condition by an equally high torque M_R being transferred from the road in the tyre contact area.

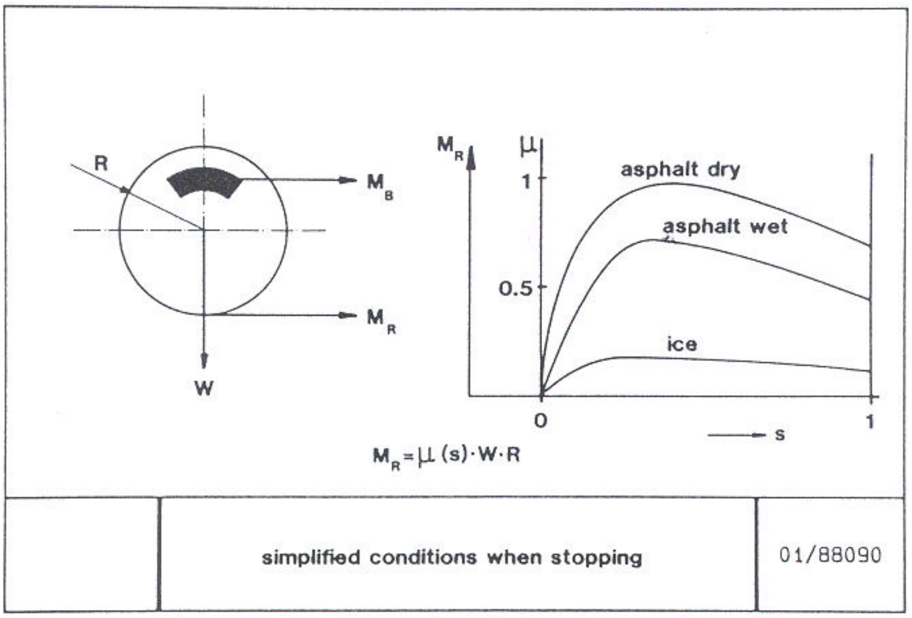


Figure 3.1

This torque depends in its known manner on the slip characteristics of the respective tyre/road combination, on the wheel load W and on the dynamic wheel radius R. Due to the slip dependence of the coefficient of friction, the torque M_R transferred from the road to the wheel is also slip-dependent. Therefore, a simulation of the road on a test bench requires the test bench drive to have the same torque slip characteristics as the road. Assuming that an icy road is to be simulated on the test bench, only low driving powers are to be installed in the test bench. This considerably reduces the test bench expenditure. Moreover, this is a difficult operating condition for the ABS as the high pressure introduced by the driver into the system via the brake pedal must be reduced to a low pressure corresponding to the road “ice”.

3.3.1. The Slip Element

The wheel forces transferred when braking produce a tyre slip causing the tyre wear occurring during braking. This can be minimized by obtaining slip-free transfer of forces between tyres and roll (in the optimum case, tyres and roll mesh as two gear wheels do) and shifting the wear-producing slip to a separate slip element, as shown in Figure 3.2.

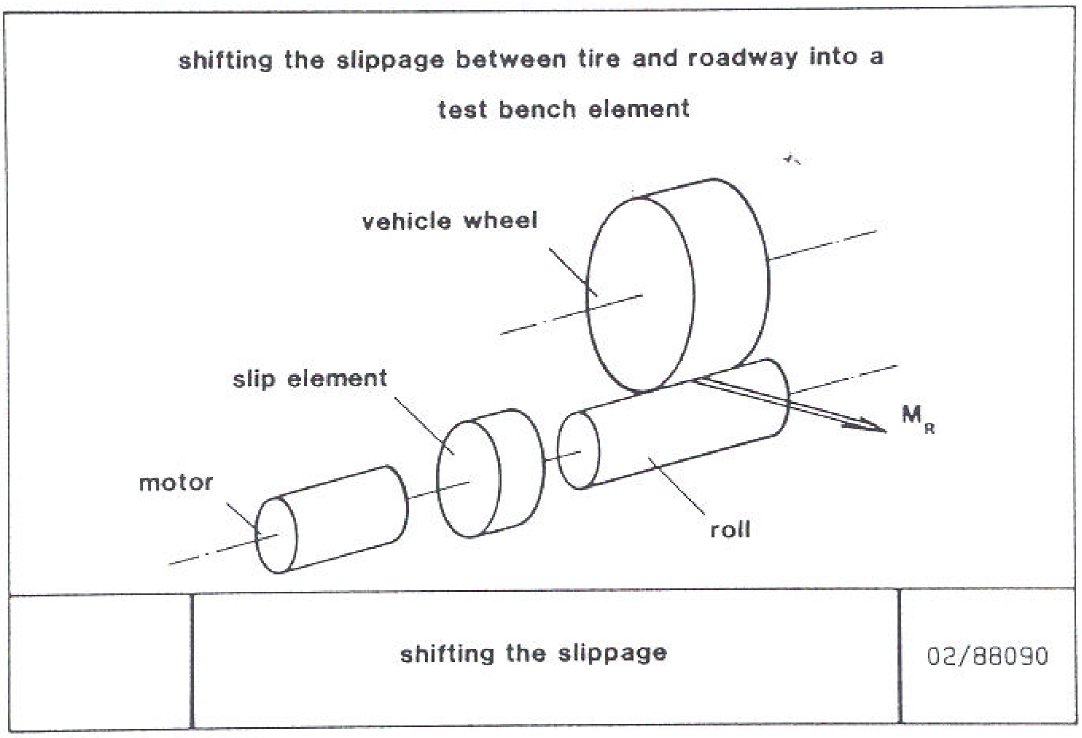


Figure 3.2

There are different types of this slip element possible, such as regulated friction couplings, fluid coupling or magnet couplings, the prerequisite always being that this element establishes the same relation between torque and slip as it is done by the tyre/ice friction combination. The application of a separate friction element makes the measured value independent of the respective tyre/roll combination. Therefore, it is of no importance whether the tyre on the test bench is wet or dry; it must only be ensured that the torques produced in the slip element can actually be transferred at the tyre/roll contact point. Thus the ABS regulator always acts on a reproducible regulating section

3.3.2. Drive and Slip Element

The additional cost of the slip element, increased construction and energy requirement, have resulted in the search for a drive combining the driving and slip functions. This must be a drive featuring the relation between motor torque and slip or speed resp. specified in Figure 3.1 as working characteristic. A suitable drive is a special type of three-phase asynchronous motor with squirrel-cage rotor whose torque/speed characteristic has been influenced so as to correspond to the coefficient of friction/slip curve of tyres on ice. Consequently, the torque M_R to be produced by the road during driving is on the test bench produced by the asynchronous motor. In principle, the motor can directly drive the wheel hub (without wheel and tyre) as the slip usually occurring between tyre and roll on conventional test benches is shifted to the rotating field slip of the asynchronous motor in the concept described here. In the asynchronous machine, the slip constitutes the difference between the speed of the stator field and the rotor in the air gap between both and is here completely wear-free. Moreover, there is no necessicity for any control electronics as the required relation between torque and slip is in a way integrated in the asynchronous machine. Figure 3.3 shows an example of the basic torque characteristic depending on the speed or rotating field slip resp. of such an asynchronous machine. Parameters are idling or synchronous speed resp. and the so-called pull-out torque M_S .

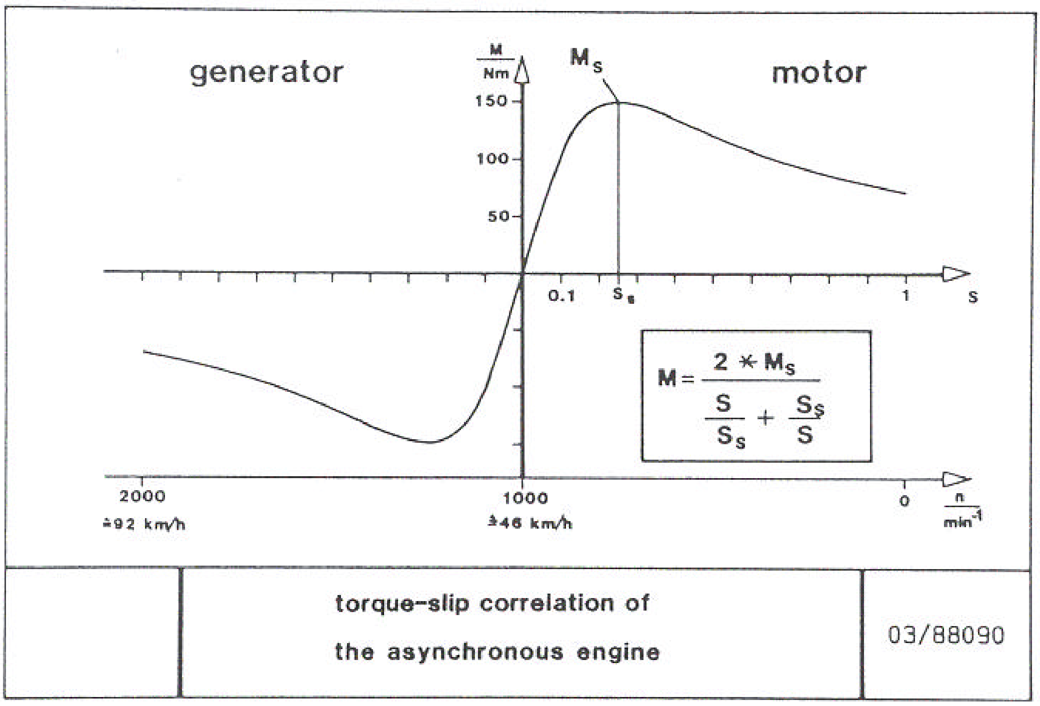


Figure 3.3

Changing the mains frequency (frequency transformer) and the mains voltage allows road surfaces, jumps in the coefficient of friction and different coefficients of friction on the right and on the left to be simulated within certain limits. The road surfaces for drive slip regulator (DSR) development and testing can also be represented without any change as the asynchronous machine can be operated as generator with oversyncronous speeds. Also under these operating conditions, the torque/speed characteristic of the asynchronous motor corresponds to the slip characteristic of a tyre on ice.

3.4. Design of Test Bench Drive

These basic ideas regarding the test bench concept directly reveal the fundamental importance to be attached to the design of the asynchronous machine.
One question is the required relation between coefficient of friction and slip to be represented by the test bench drive. In Figure 3.4 the results of three authors [Lit 2, Lit 3, Lit 4] are listed who determined the dependence of the coefficient of friction on the slip by measurements. For designing the motor, the relation determined in [Lit 3] for ice 0°C is assumed as required characteristic.

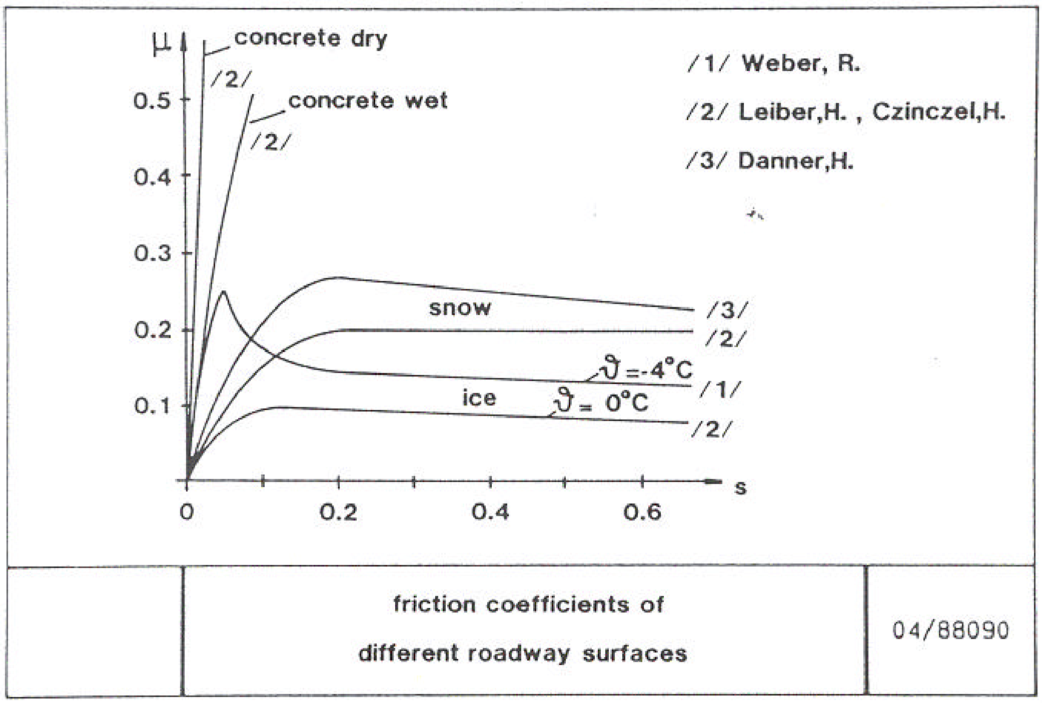


Figure 3.4

3.5. Motor Flanged to Wheel Hub

A motor designed on the basis of this characteristic can be directly flanged to the wheel hub for simulating the brake forces. Taking axle load and wheel radius into consideration, the motor shall produce the same torques as the road. The selected μ-slip curve of ice has its maximum coefficient of friction at $\mu = 0.1$ and slip $s = 0.2$. With the asynchronous machine this corresponds to the pull-out torque or to pull-out slip resp. On the basis of the equation in Figure 3.1 and taking the axle load and wheel diameter into consideration, the required pull-out torque of the motor is obtained. From the construction of the Heyland circle [Lit 5] the ratings of the machine can be obtained for the assumed slip curve. The armature of the motor plus any additional masses constitute the moment of inertia of tyres and rim, thus also allowing a correct simulation of dynamic processes with ABS regulation. This arrangement is suitable for simple development work on the ABS.

3.5.1. Application in Roll Test Benches

A further possibility of applying the functional principle is seen in the use of roll test benches. On roll test benches, the moments of inertia acting on the wheels must be considered for simulating the dynamic regulation processes of the ABS (Figure 3.5).

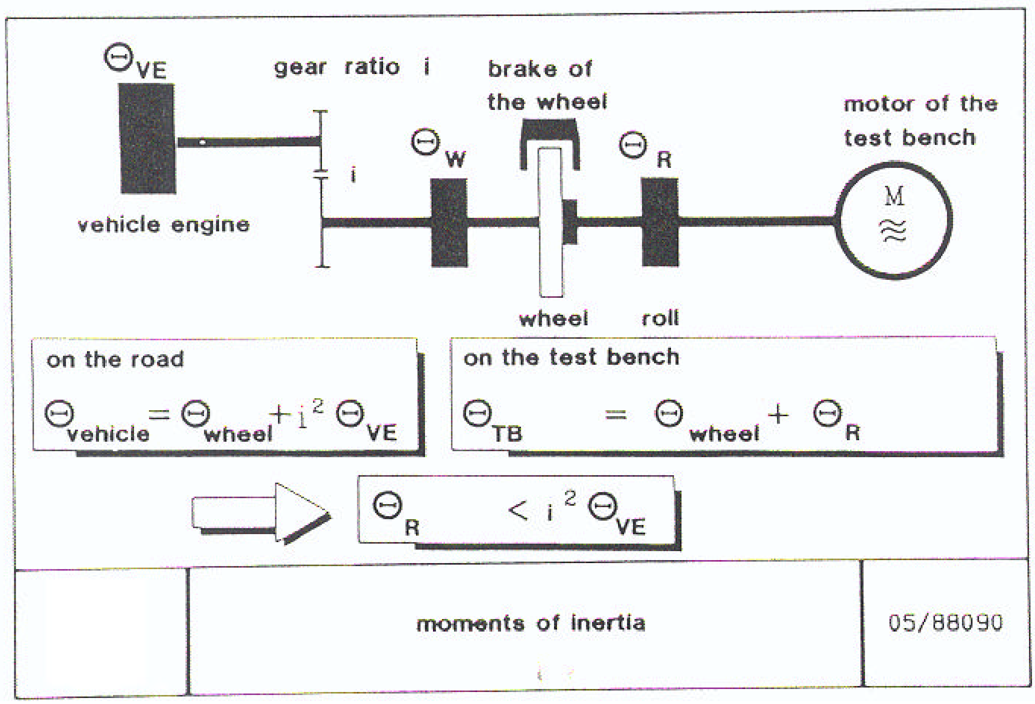


Figure 3.5

Also during actual driving the ABS regulator must cope with changes of the effective moment of the inertia when the effective moment of interia of the engine is engaged and disengaged in the different gear steps. It must be ensured in the test bench design that the moment of inertia of roll and asynchronous motor additionally acting on the wheels is lower than the moment of inertia of the vehicle engine engaged during driving. For the driven axle this requirement can also be fulfilled on the test bench if the tests are carried out with disengaged drive. For the non-driven axle the additional moment of inertia of the roll causes a slightly changed regulation behaviour on the test bench. However, practical tests have releaved that present ABS meet such changes with a sufficiently robust behaviour. A considerably changed behaviour could not be noticed.

The number of poles of the asynchronous machine and the roll diameter are to be adapted to the desired test speed. With a roll diameter of 265 mm and a six-pole machine an idling speed of 46 km/hr can be reached without intermediate gearbox. According to the recommendation in [Lit 6] with this roll diameter and the speed of approx. 50 km/hr the permissible duration of the test is up to 10 minutes. The slip characteristic selected in Figure 3.4 being specified, an asynchronous machine of a rated output of about 5.5 kw will be sufficient as the bench drive for tests on passenger cars.

Asynchronous machines are usually operated in the range between zero torque and rated torque or between synchronous and rated speed resp. In the present application, the motor is braked by the ABS regulator down to speeds of less than the pull-out speed. On account of this, a considerably higher current than the rated current is to be expected. Therefore, monitoring of the motor temperature is advisable during continuous operation. The most important motor data have been derived from the construction of the Heyland circle and represented in Figure 3.6.

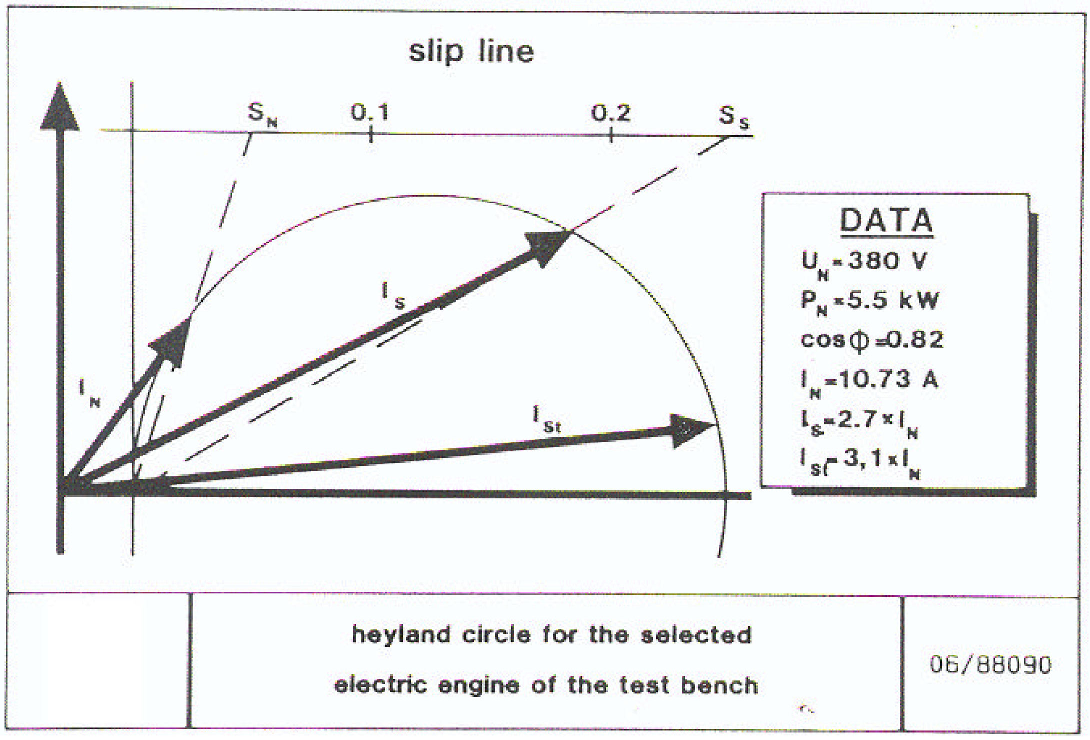


Figure 3.6

3.5.2. Further Applications

The described concept has been based on the application of an asynchronous motor for simulating the moments acting on the vehicle wheel in such a way that the same conditions as on an icy road are obtained for ABS testing. Especially with testing equipment with the motors flanged to the wheel hubs it is conceivable that the concept described here not only an icy road but also roads of higher skid resistance can be simulated with correspondingly stronger machines. By means of frequency transformers, different μ-slip curves can be simulated within certain limits. By simple star-delta change-over of the asynchronous machine, jumps in the coefficient of friction or coefficient of friction varying between the right and the left lane can be simulated.

For ABS simulation the asynchronous machine only acts as motor, i.e. as drive on the brakes. The machine can, however, also be operated as generator, in this case acting as brake (see Figure 3.3). For this purpose the vehicle must drive the wheels in such a way that there will be oversynchronous operating of the asynchronous machine. When for example engaging first gear and accelerating the test bench vehicle, the vehicle engine will bring the asynchronous machine to speeds above the synchronous speed. In this case, the asynchronous machine acting as generator will feed electric power back into the mains. The transition from the motor to generator operating is effected by just increasing the speed, no additional electrical measures being required. The characteristic of the simulated road surface corresponds also in this operating condition to any icy surface. However, the motor output set by means of the accelerator pedal being too high so that the pull-out torque is exceeded, the wheels will spin as they do in reality. In this manner, equipment for regulating the drive slip (DSR) can be tested on the test bench in a very simple way. Coefficients of friction varying between the left and the right lane can be obtained with low expenditure by means of simple star-delta change-over of the asynchronous machine.

With a view to being employed on a four-wheel test bench, the asynchronous machine has been designed with an idling wheel speed of approx. 46 km/hr so that at oversynchronous mode of operation and outputs of one single wheel of about 2 to 4 kW the wheel speed will set to about 50 km/hr. This allows the mechanical load for example for catalyst testing (7 kW at 50 km/hr) to be represented without requiring any additional components. Besides, such a four-wheel test bench has the advantage of allowing catalyst testing also on permanent four-wheel drive vehicles.

3.6. Four-Wheel Test Bench As Built

For demonstrating the functionality of the described concept, a four-wheel test bench has been constructed [Lit 7]. As shown in the diagram in Figure 3.7, this test bench is equipped with three rolls for each vehicle wheel.

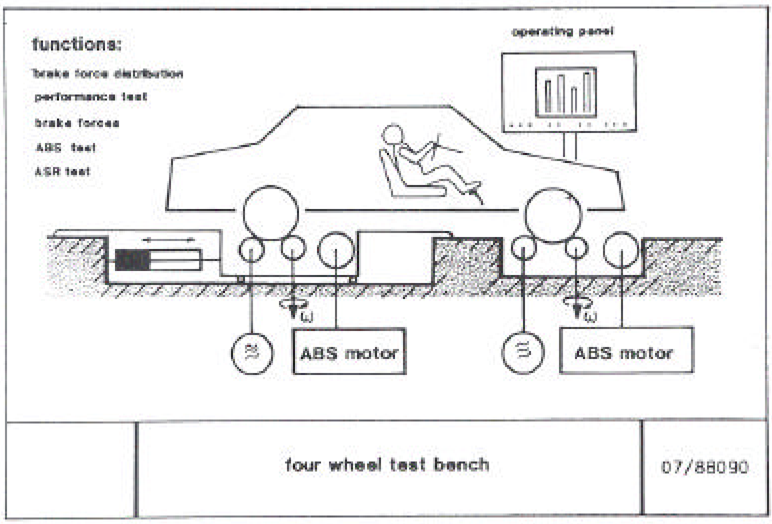


Figure 3.7

The rear rolls rotate at a circumferential velocity of approx.5 km/hr and are used for conventional measurement of the brake forces or the brake force distribution resp.; the central roll serves as supporting roll for the vehicle wheel and is equipped with a revolution indicator for measuring the wheel circumferential velocity; the front roll is directly coupled with the asynchronous motor designed for ABS simulation and is used for simulating the icy road. The motor is mounted on pendulum supports allowing the motor torque to be measured by the supporting force. The wheelbase is adjustable. A computer is provided for controlling the test bench function and ensuring recording, processing and representation of the measured values. Figure 3.7 gives an impression of the test bench put into practice.

3.7. Test Bench Adaptation for the CITA-Study

To allow efficient testing, an automatic wheel base adjustment and robust data management has to be adapted to the test bench. Therefore the development of a hard- and software layout is done in this study first. The interfaces have been defined and the necessary I/O-cards for the test bench controller are selected.

A new measurement system for wheel speed measurement at all four wheels is constructed.

3.8. The Measurement System

3.8.1. Sensors

The measurement of the circumferential velocity of the measuring rolls is done with four analog tachogenerators. These precision rotary speed measurement devices are driven via a torsionally stiff with flexible coupling to the axle of the rollers. For the realisation of this measurement system, DC tachogenerators TDP 0,99 LT - 2 (Figure 3.8) from Huebner, Berlin are used. Advantages of these generators are:

- Temperature compensation of the tachogenerator output voltage
- Extremely short response time due to low time constant
- The magnetic system is screened against external field influence
- The generators are maintenance free for more than 10^9 revolutions.

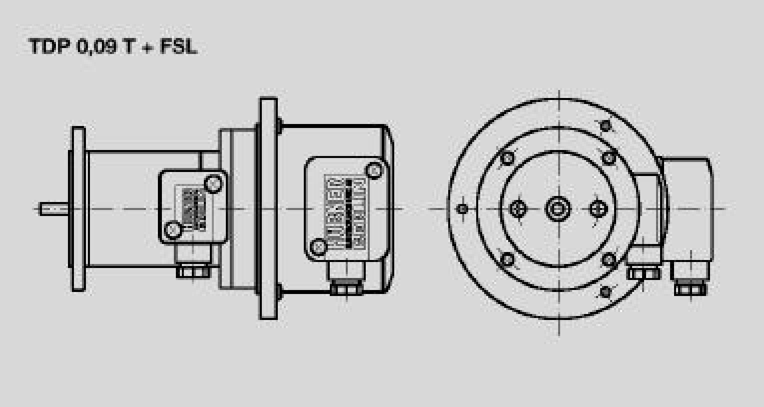


Figure 3.8

3.8.2. Signal Conditioning and Data Recording

The analog signals from the rolls are conditioned with 4 wide bandwidth strain gate signal conditioner circuits 1B31AN from Analog Devices on an AC 1222 mounting card.

The data acquisition is realised with a common industrial personal computer. This computer is fitted with the multifunctional ISA measurement card MFB 51 from Kolter electronics with following features:

- 16/8 A/D Input, 1.25us, s&h
- single / diff. ended,
- uni.-bipolar
- 4 D/A Output, 12 bit, je 50 mA
- 24 TTL I/O, programmable
- 3 x 16bit Timer, interrupt
- G = 1,2,4,8 PGA
- G = 10, 100, 200, 500 INA
- U / I Inputs with Resistor-Arrays

This card contains an ADS7810 as a complete 12-bit sampling A/D converter. The ADS7810 is specified with a 800kHz sampling rate guaranteed over the full temperature range.

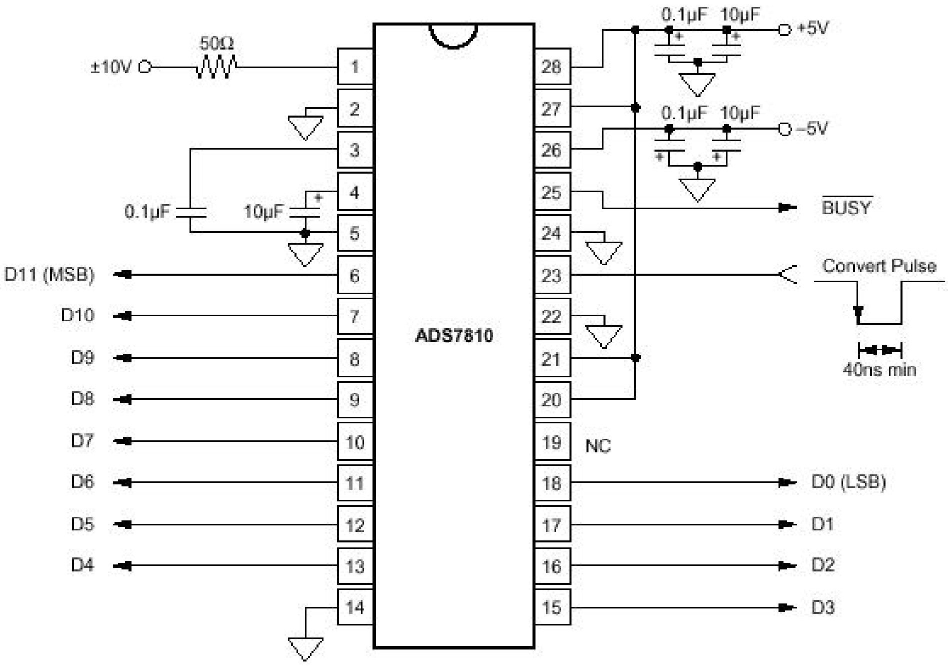


Figure 3.9

For data recording, a self-written Turbo Pascal program with a Real Time Kernel is used. With this program, the data measured of each test is written to the harddisk in separate ASCII files. The program also allows a simple visual presentation of the measurement results (wheel speed, brake force, brake force distribution for all 4 wheels). The steering of the test sequence (wheelbase adaption, information signals for the test driver, start of the test procedure, switching of the friction coefficient) is also controlled from this program and a digital Input/Output card with opto-couplers is used for controlling the test bench.

3.8.3. Data Evaluation

The evaluation of the data collected and the production of several graphic presentations for each test are made with an office personal computer using DIAdem version 7.0 from Gfs in Aachen. All measurement plots in this report are depicted with DIAdem.

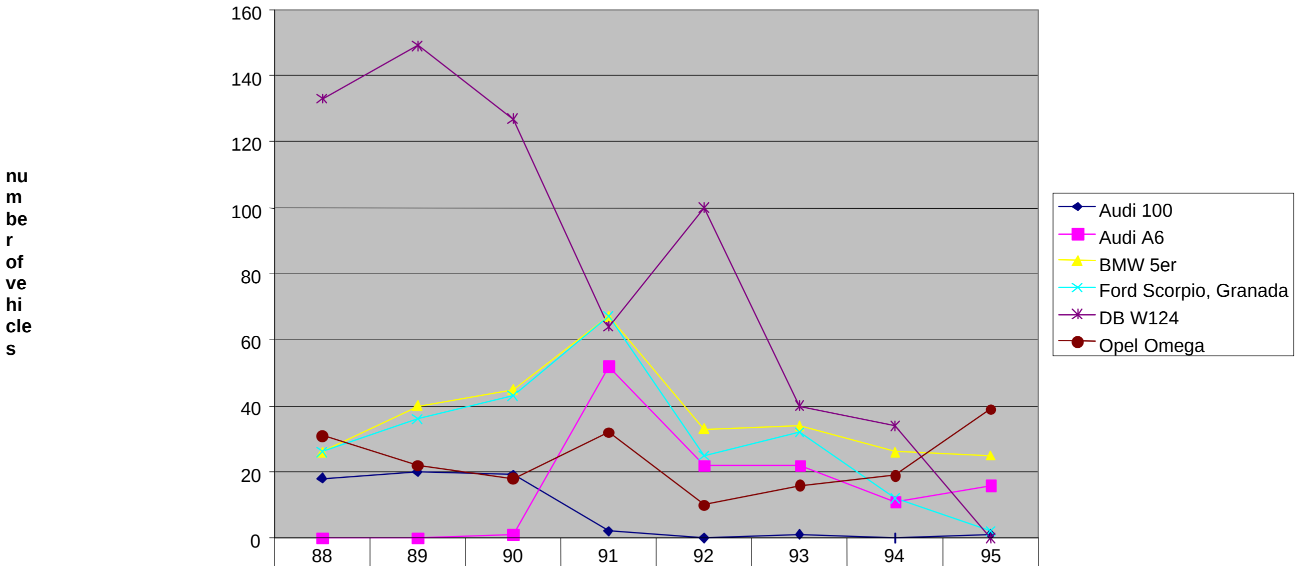
3.9. Instruction of Test Staff

The test staff at Cologne-Muelheim proofing ground is instructed to do the test runs. Due to extensive automation of the test process, the test staff working there daily can do the tests additionally to the periodical inspection. The additional fault memory scans are done by supplementary personal, because the scanning procedure needs much time (searching the connector, scanning the fault memory, documentation of the results etc.) and was not integratable in daily work of the present periodical inspection.

4. ABS Tests

4.1. Vehicle Type Selection

For the study, six vehicle types possibly coming to the periodical vehicle inspection at the location Cologne-Muelheim in the years 2000 and 2001 are selected. Therefore, a huge database from all proofing grounds with various types and ages of vehicles is analysed and six types are filtered (Figure 4.1). The filtering criteria are influenced by ABS as standard equipment of a specific type and the number of vehicles being probably available at the specific proofing ground. Another criteria is the availability of diagnosis tools for scanning the fault memory of the cars to be analysed.



	88	89	90	91	92	93	94	95
Audi 100	18	20	19	2	0	1	0	1
Audi A6	0	0	1	52	22	22	11	16
BMW 5er	26	40	45	67	33	34	26	25
Ford Scorpio, Granada	26	36	43	67	25	32	12	2
DB W124	133	149	127	64	100	40	34	0
Opel Omega	31	22	18	32	10	16	19	39

year of construction

Figure 4.1

Following six vehicle types are selected:

- AUDI 100
- AUDI A6
- BMW 5series
- DAIMLER BENZ W124
- FORD Scorpio
- Opel Omega

During the data collection, it has been found out, that not as much cars as expected would be available at Cologne-Muelheim. To reach the proposed number of tests, additional vehicle types have been added. As an additional action, the limits for the age of the vehicles included in the tests were slightly amended. The tests now include cars with a construction year ranging from 1988 to 1998. This was also necessary, because the proposed analysis of the failure memory of the vehicles is only possible for a small subgroup of the older cars (year of construction before 1995).

The study finally includes following car types:

- Audi 100
- Audi A6
- VW Passat since 1993
- BMW 5 series (models E 34 and E 39) or
- BMW 3 series (model E 36)
- Mercedes Benz E-Class (models W 124 or W 210) or 190 series or C-Class
- Ford Scorpio
- Opel Omega

In the presentation of the results, the car types are anonymized and presented as "type A - type G"

4.2. Definition of Test Sequence and Graphic Representation

The test procedure and the test criteria must be defined before the start of the tests. With the test-bench, braking force and wheel speed can be measured at all four wheels. The test procedure simulates a situation driving downhill on a snowy or icy road with constant velocity. The friction coefficient μ can be switched from approx. 0.1 (ice) to approx. 0.2 (snow) and back.

As a result of the test runs in which no switch of the friction coefficient was done, we decided to realise the following test sequence:

Period 1:	0 s	-	8 s	:	$\mu \approx 0.2$
Period 2:	8 s	-	9.5 s	:	$\mu \approx 0.1$
Period 3:	9.5 s	-	13 s	:	$\mu \approx 0.2$

During this time, the driver has to initiate and continue full braking. A "failure" is recorded if a wheel locks for more than 1 second. This definition of failure matches the requirements of ECE-R 13, which allows "short wheel locking". Once a wheel has locked for more than 1 second, the motors of the test bench are switched off to avoid tyre damage.

To appraise the ABS systems, the development of graphical and/or mathematical or statistical methods for failure detection is needed. Therefore, we decided to realise two interpretation forms: **time course (wheel speed, brake force)** and **brake force distribution.**

4.2.1. Time Course: Wheel Speed

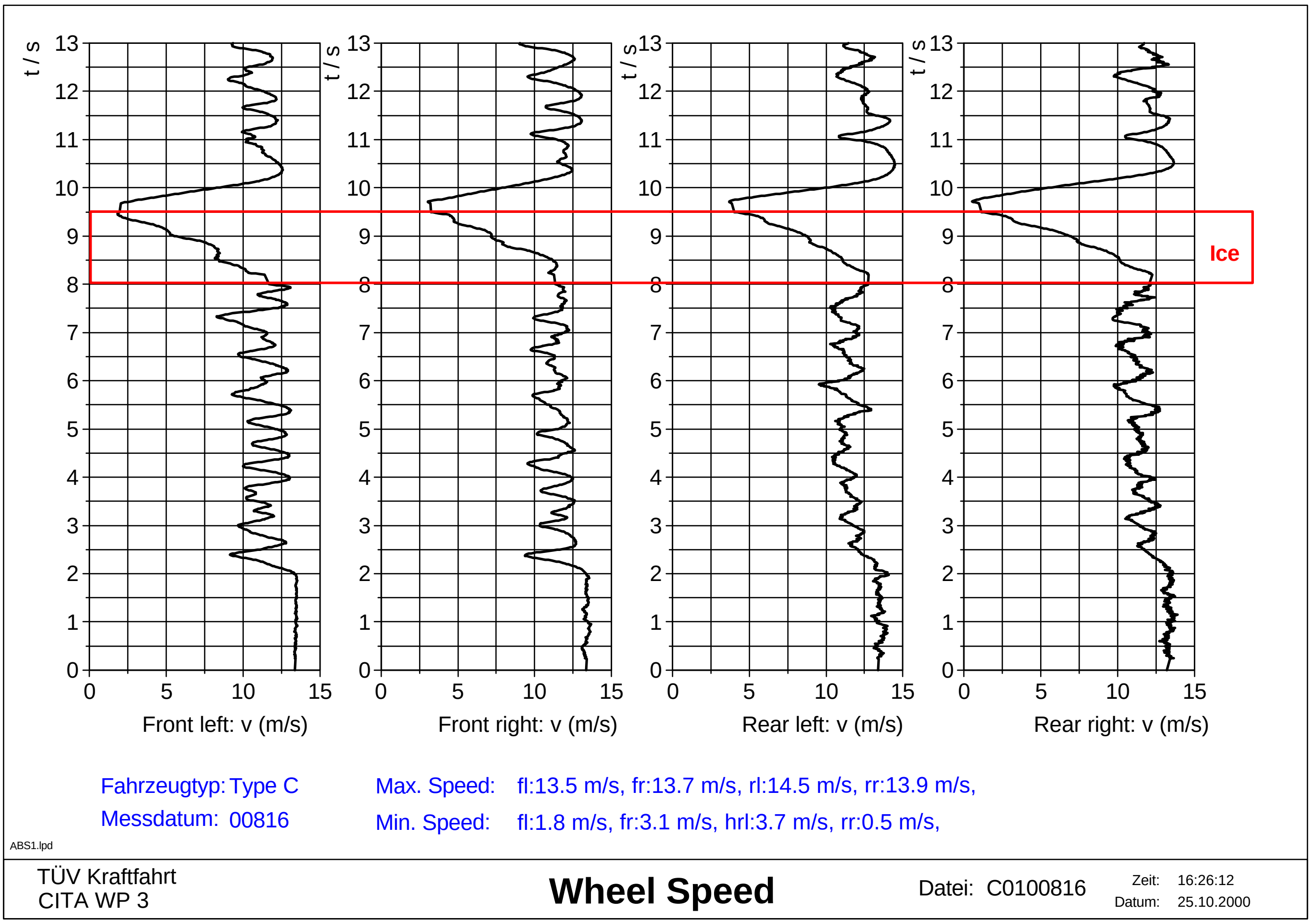


Figure 4.2

Figure 4.2 depicts the time course of the wheel speed (in m/s) for all four wheels during the complete test sequence. While doing the test, following reactions of the ABS can be visible in the plot:

- **First phase (SNOW, 0s - 8s):**
  - The rolls and wheels idle.
  - Test bench simulates a friction coefficient of approx. 0,2.
  - Full braking is initiated by the driver at 2 seconds.
  - After the first minimum, the speed oscillates round a mean value.
- **Second phase (ICE, 8s - 9,5s):**
  - The friction coefficient is switched to approx. 0,1.
  - The speed of all four wheels decreases.
- **Third phase (SNOW 9,5s - 13s):**
  - The friction coefficient is switched back to approx. 0,2.
  - The wheel speed increases.
  - A comparison with first phase shows: system needs more time until exact regulation.

4.2.2. Time Course: Brake Force

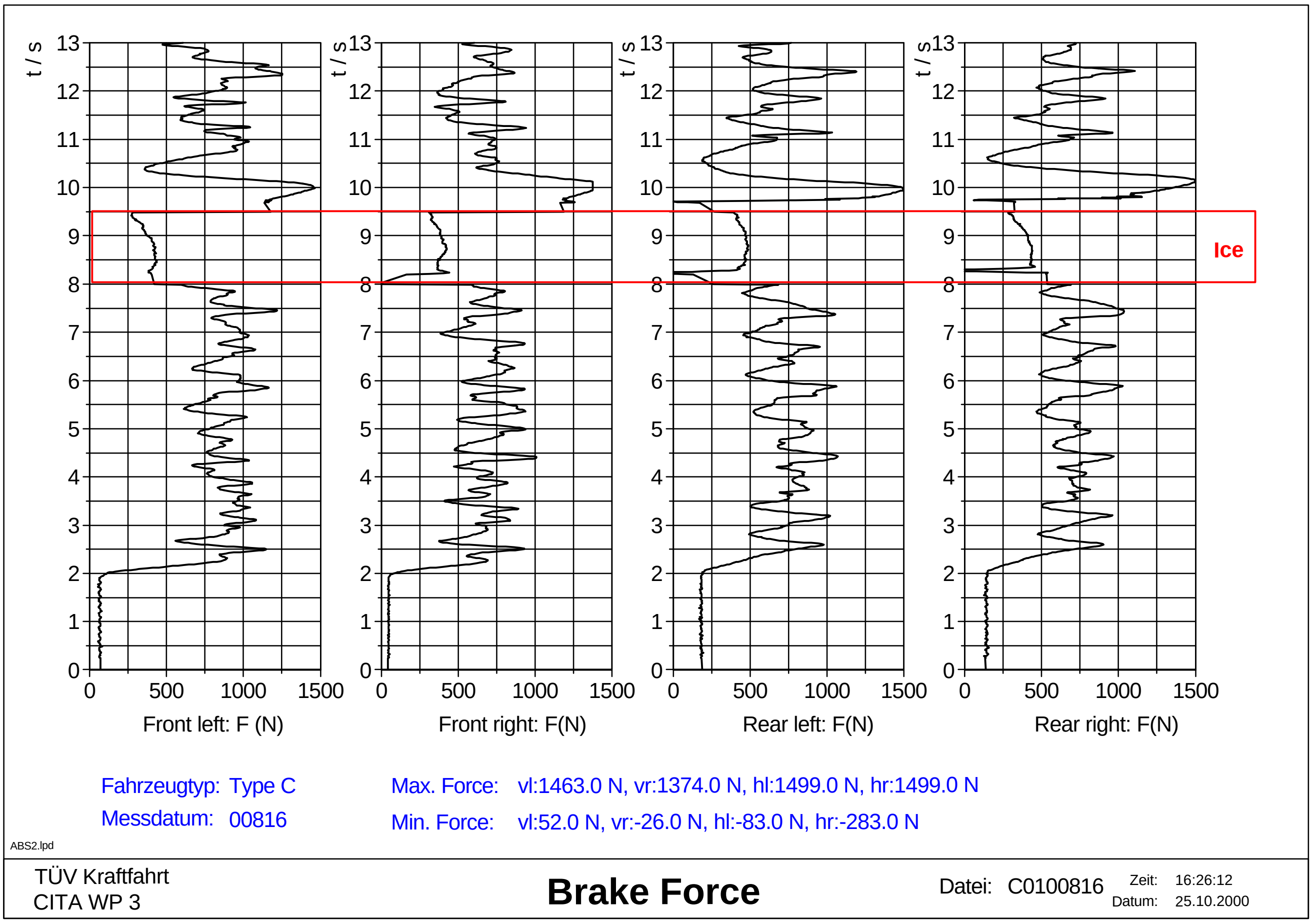


Figure 4.3

This figure shows the time course of the brake force (in N) for all four wheels, also passing the three-phase test sequence:

- **First phase (SNOW, 0s - 8s):**
  - 0 - 2 s: The plot shows the rolling resistance, no braking is done.
  - Braking is initiated by the test driver at 2 seconds.
  - After the first maximum: the brake force oscillates like the speed.

- **Second phase (ICE, 8s - 9,5s):**
  - The brake force decreases rapidly
  - and stays nearly constant at 400 N.
  - This is the maximal transferable force in this operating condition.

- **Third phase (SNOW 9,5s - 13s):**
  - The brake force increases immediately at front wheels.
  - It increases with a delay (1/2 s) at the rear wheels!
  - This behaviour is typical for all ABS tested in this study.

4.2.3. Brake Force Distribution

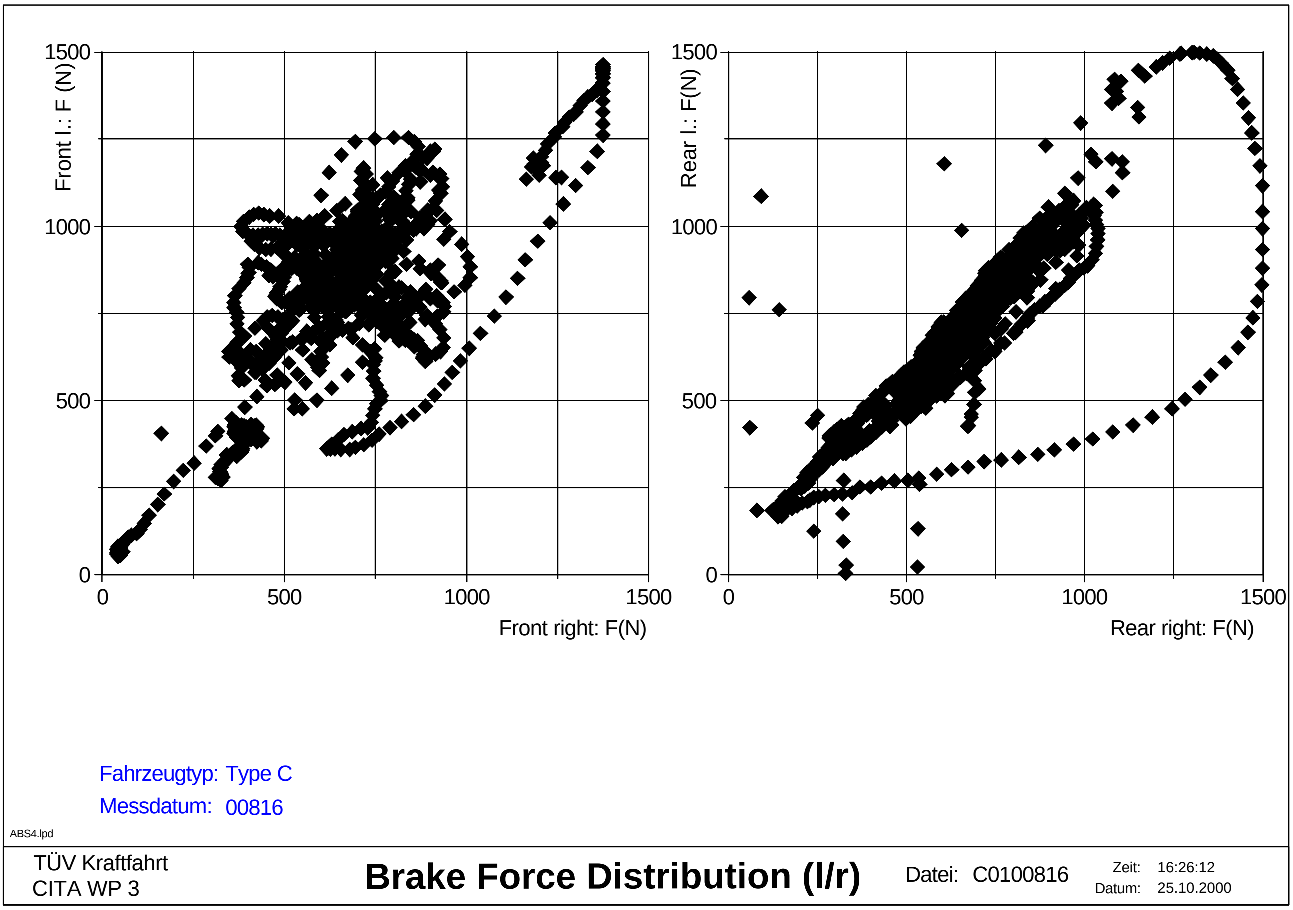


Figure 4.4

The brake force distribution between the left and right wheels is of great interest for the vehicle dynamic behaviour and is displayed in Figure 4.4

- **Criteria for the brake force distribution:**
  - The German STVZO demands max. 30 % deviation of the brake force between the left and the right wheels.
  - This level is not created for ABS systems, but it gives an orientation for the analysis.

- **Front axle:**
  - The brake force distribution shows a “nearly” symmetrical distribution.

- **Rear axle:**
  - Some datapoints are completely asymmetric.

4.2.4. Brake Force Distribution, splitted

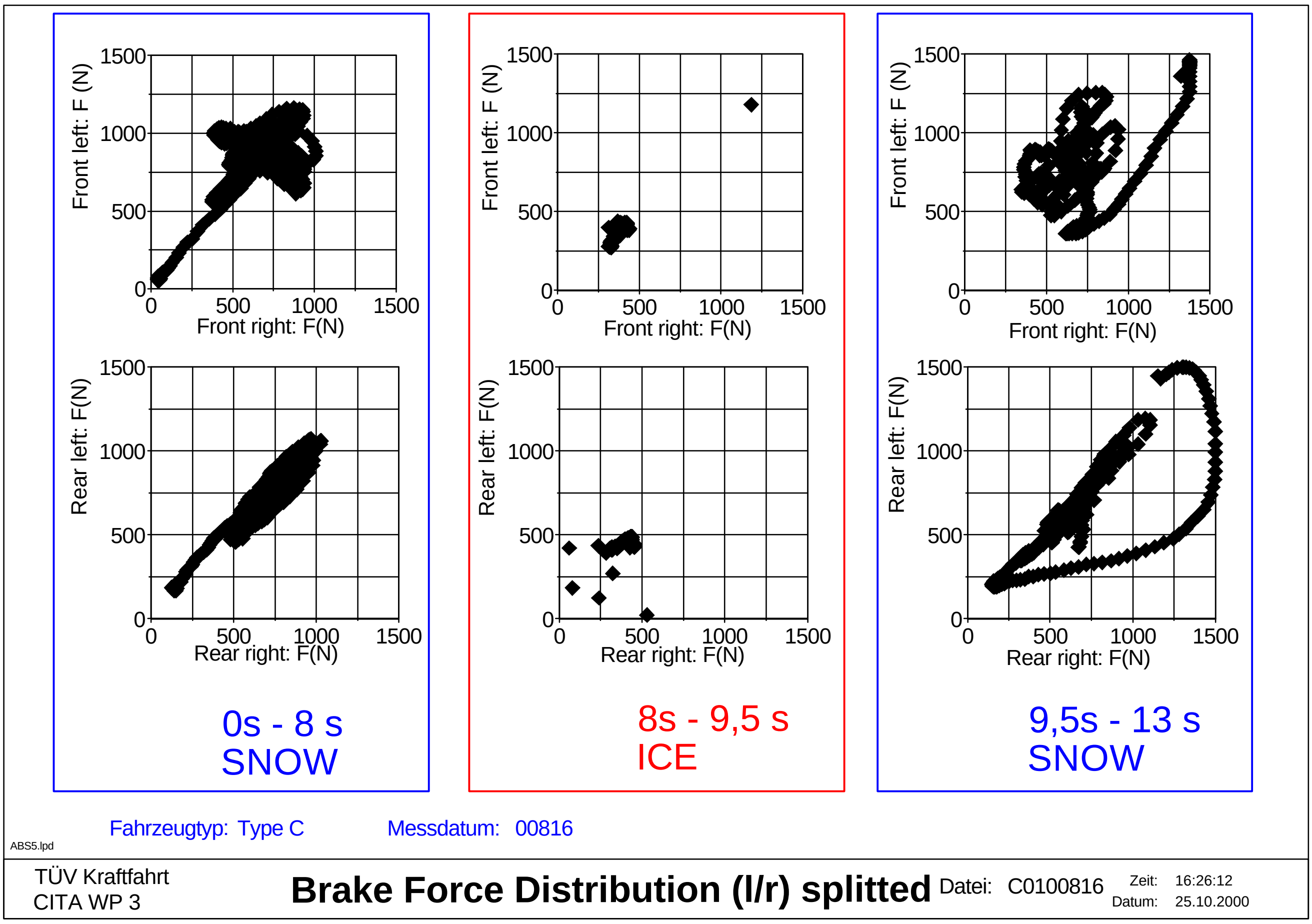


Figure 4.5

For detailed analysis, the three timesteps are depicted separately. They are shown in Figure 4.5:

The last interval respectively the change in the friction coefficient between the ICE and the SNOW phase seems to be very difficult for ABS.

The brake forces range between 500 N 1500 N at the front wheels and between 200 N and 1500 N at the rear wheels. The brake force distribution is completely asymmetric for the rear wheels.

Of course the brake force distribution between the front and the rear axle can also be investigated and assessed according eg. to the ECE - R 13. This is not done in this paper.

4.3. Test Runs

Test runs are done with different cars. In these test runs, the change of the friction coefficient was not enabled.

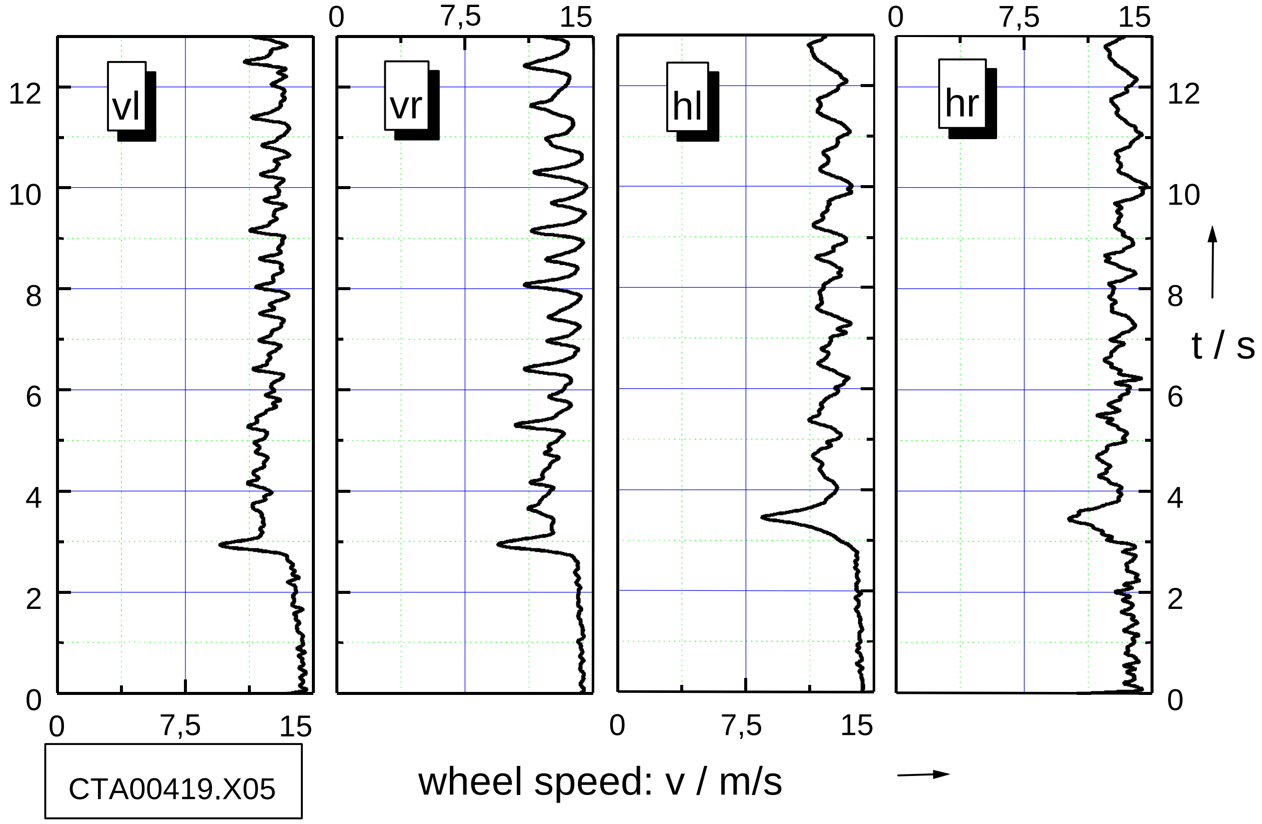


Figure 4.6

In Figure 4.6, the measurement results of a car with modern ABS-system (2 years old) are shown. Figure 4.7 shows the results of an older car. Recorded is the wheel speed in meters per second for all four wheels.

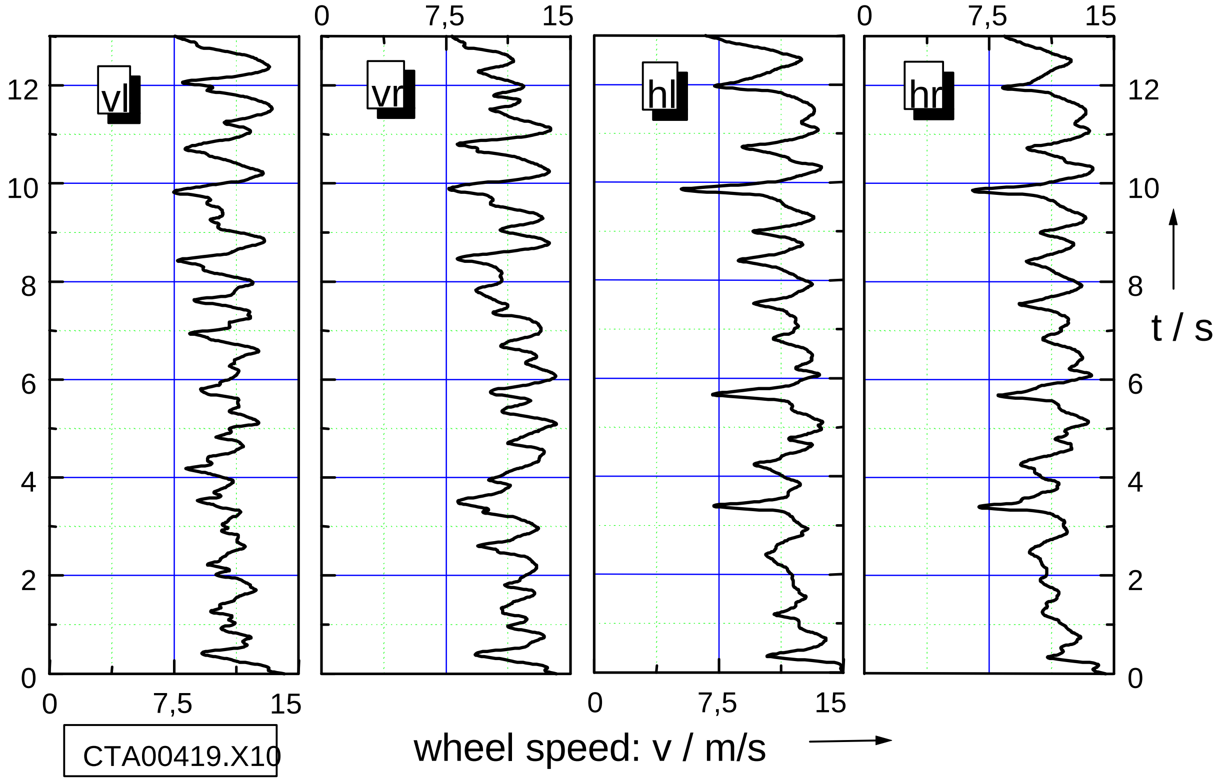


Figure 4.7

As first result, these test runs represent differences between the controlling strategy and ability of both systems. The controlling of the older ABS-system is not as exact as in the modern one. But both systems operate correctly, there is no tendency for wheel blocking.

4.4. Implementation of Tests and Data Collection

The implementation of tests and data collection was done between August 2000 and August 2001. The number of tests was increased by inviting owners of the selected car types from the TUEV customer database by mail.

At the end of the test phase, 262 cars had come to Cologne Muelheim proofing ground for the ABS test.

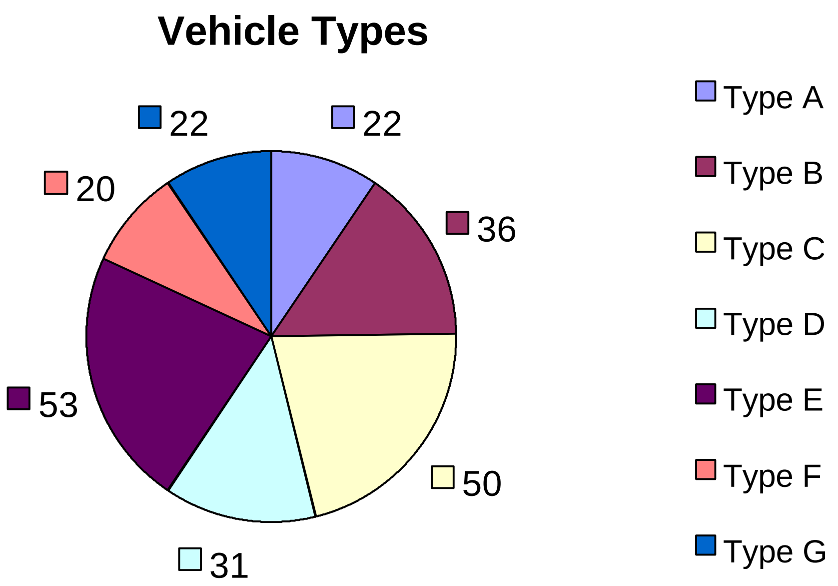
In two of these cars, the *complete originally equipped ABS was removed by someone*. These cars were of course not tested on the test bench.

The first analysis step is the identification of valid datafiles. This means, that measurements must be sorted out when

- no braking
- too late braking
- vehicle has no ABS
- measurement problems

occurs. The result was the identification of 234 valid datasets, which will undergo the further analysis.

Figure 4.8 describes the number of cars (splitted into sections of the selected vehicle types) which were tested.



Type A	**22**
Type B	**36**
Type C	**50**
Type D	**31**
Type E	**53**
Type F	**20**
Type G	**22**
TOTAL	**234**

Figure 4.8

Figure 4.9 shows the number of tested cars sorted by the distance driven of the cars.

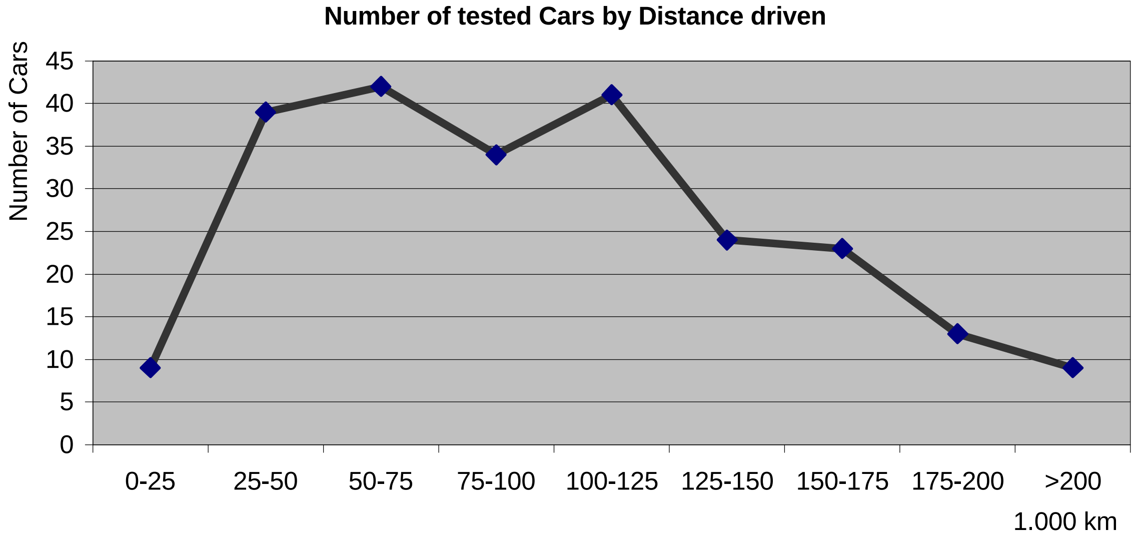


Figure 4.9

Approximate the same number of cars with distance driven between 50 and 150 thousand kilometres are tested. The number of cars more than 175 thousand kilometres is very small, because of this no significant analysis can be done for these years of construction. The number of tested cars sorted by the year of construction are indicated in Figure 4.10.

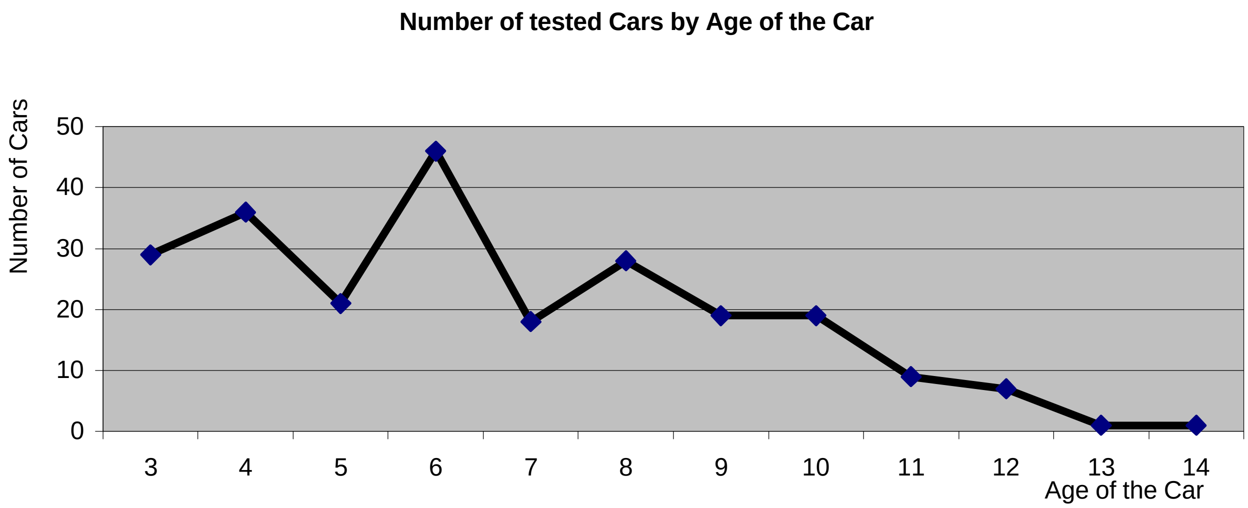


Figure 4.10

A sufficient number of tested cars with an age up to 10 years is reached.

4.5. Fault Memory Scans

4.5.1. Diagnosis tool

The availability of diagnosis tools for scanning the fault memory of the cars is discussed with the test system manufactures SNAP-ON and BOSCH, both being involved in this CITA research project. SNAP-ON lend at the beginning of 2000 test systems for Audi, BMW, Ford and VW. BOSCH supplied a test system for DB W124.

4.5.2. Test Procedure with Fault Memory Scan

For the comparison of the results of the fault memory scan and the efficiency test on test bench, it is necessary to document only the fault memory entries which occur during the test procedure on the test bench. Therefore following test sequence is used for the fault memory scan:

1. Scan of fault memory before test on test bench
2. Documentation of existing fault memory entries
3. Deletion of the fault memory
4. Efficiency test on test bench
5. Scan of fault memory after test
6. Documentation of new fault memory entries

4.5.3. Problems and Specialities

For some cars, mostly depending on the car type, the fault memory scans are not successful. A further analysis of this problem is given in (5.4.2 ff).

5. Evaluation of the Test Results

5.1. Overview

The Evaluation of the collected data is divided into 3 steps:

A. Definition of test criteria

B. Evaluation of all efficiency tests on test bench

Failure analysis by different parameters:

- Car type
- Year of construction
- Kilometrage

C. Evaluation of all efficiency tests on test bench with <u>additional</u> fault memory scans

Investigation of the number of successful fault memory scans:

- Successful scans for each car type.
- Reasons for unsuccessful scans.
- Unsuccessful scans distinguished by year of construction of the car.

Scan result analysis by:

- Car type.
- Fault memory entry (fault type).
- Investigation of the correlation between fault memory scan results and tests on test-bench.

5.2. Definition of Test Criteria

After the analysis of the first collected data, following main failure types are selected:

- Blocking of the wheels during the test procedure, divided into blocking in the "snow" phase and blocking in the "ice" phase (main failures).
- Significant deviation between the measurement results of an individual tested car and the collective results of the same vehicles after statistic analysis (further failures).

5.2.1. Main Failures

For the main failures which mean blockage of the wheels during the test procedure two examples are given in this chapter.

Figure 5.1 shows a totally failure of the ABS, which has no function in this test. Immediately after the beginning of the braking, the wheels block early in the snow phase.

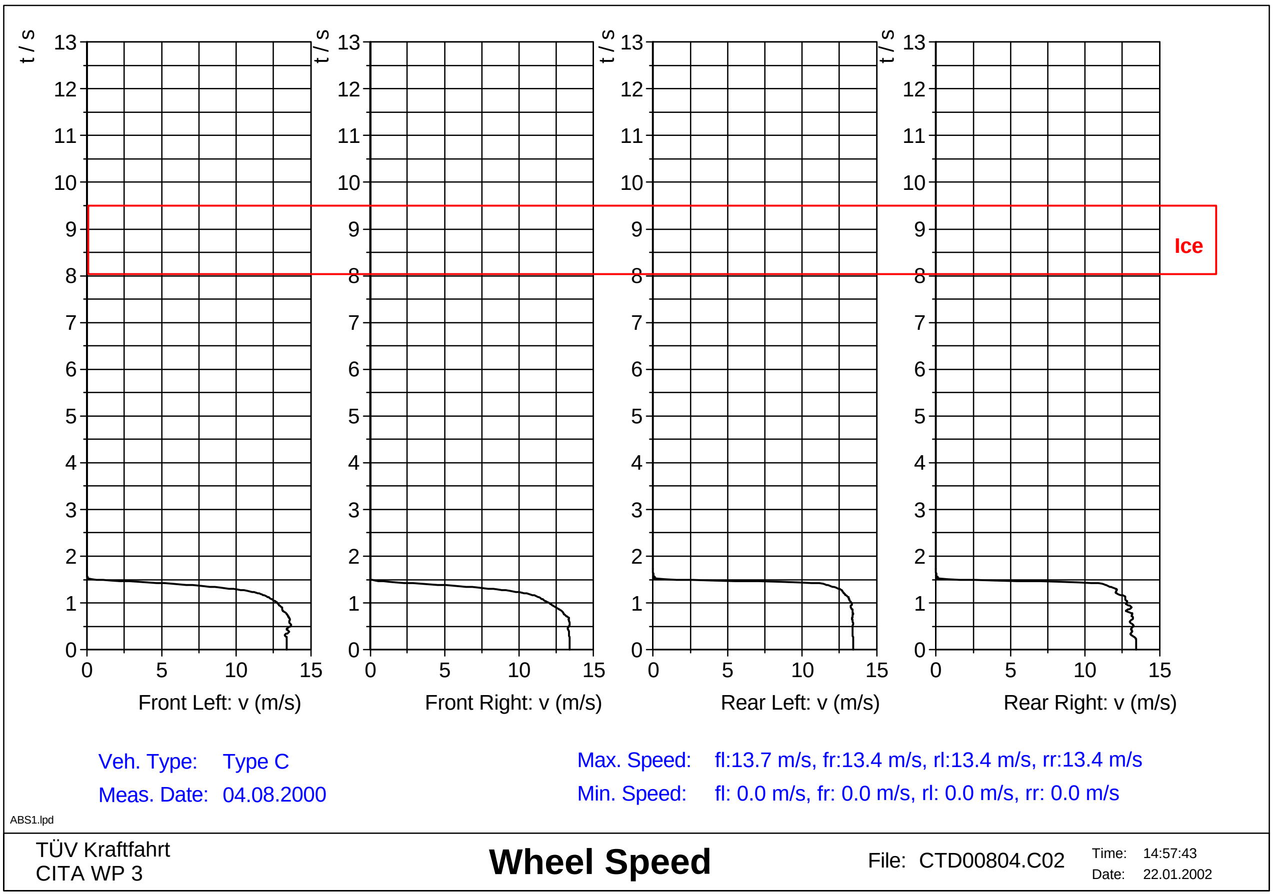


Figure 5.1

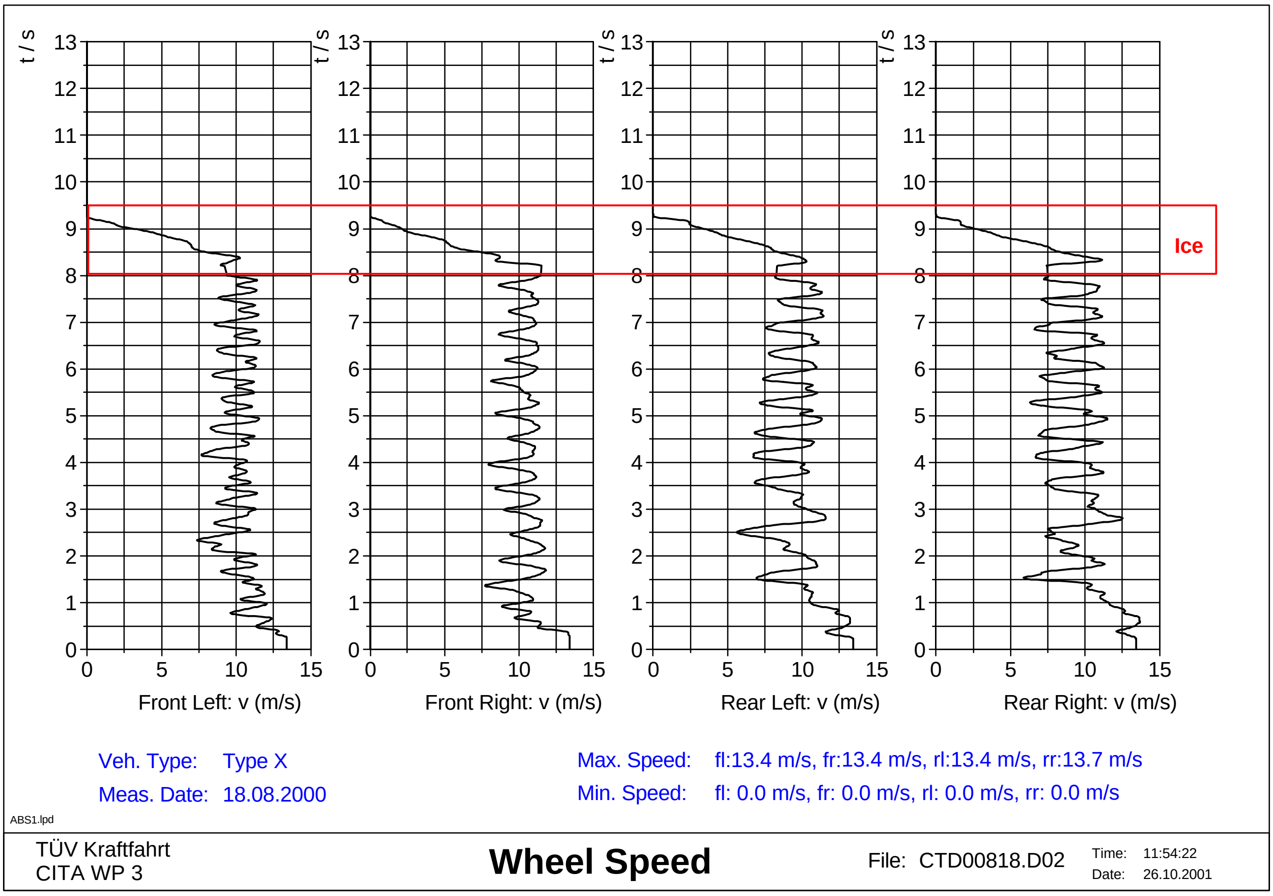


Figure 5.2

No complete failure, but controlling problems of the ABS which also lead to wheel blockage are depicted in Figure 5.2. The car passes the snow phase without blocking, but the rear wheels show relative large regulation amplitudes for the wheel speed. After the change of the friction coefficient to the ICE simulation, the wheel speed decreases continuously and the wheels block at approx. 9s. This failure is not so severe as the failure shown in Figure 5.1, but it leads also to uncontrollable steering behaviour of the car in the ice phase. This problem may be caused by: sensor damage, dirt accumulation etc.

5.2.2. Further Failures

Further failures mean significant variation between the measurement results of an individual tested car and the collective results of the same vehicles after statistic analysis. In this chapter such failures are presented and described. The results of the measurement are presented in the appendix.

Measurement No. CTD 10402.D03:

These plots show a vehicle with extreme rough regulations of the wheel speed. The speed is oscillating with amplitudes. At the minimum values, all 4 wheels are near blockage. The oscillation frequency is approx. 0,4 Hz. (T = 2,5 s).

In spite of the rough speed regulation, the brake force distribution is nearly symmetric.

Measurement No. CTD10427.B08:

This car has a quite normal speed regulation in the first snow phase and in the ice phase. After the ice phase (snow again), a normal regulation takes place for the front wheels, but there is no regulation at the rear wheels.

Measurement No. CTD 10606.F13:

The brake force at the rear wheels is at the same range as at the front wheels. High brake force amplitudes, but symmetric for both wheels. The test driver remarks that the car bounces extremely up and down.

Measurement No. CTD10620.A20:

Great regulation amplitudes for the wheel speed and the brake force. Extreme brake force peak at both rear wheels in the ice phase.

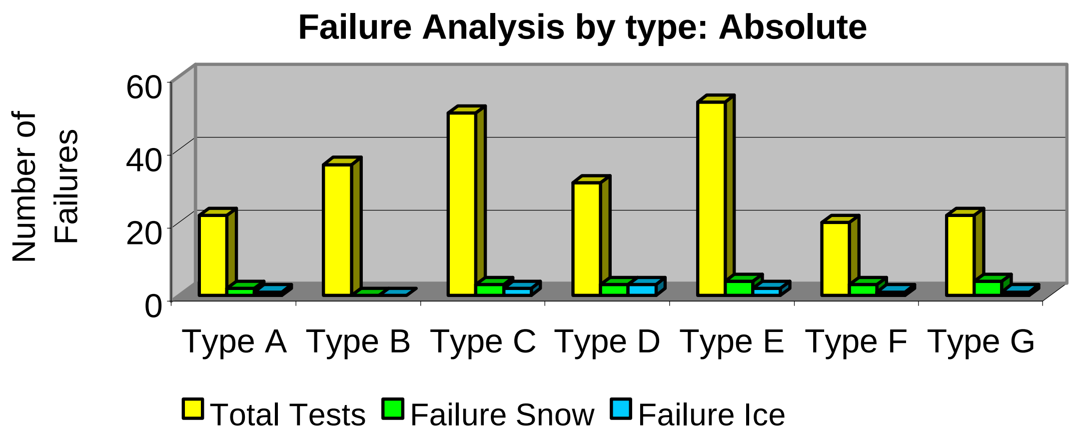
Measurement No. CTD 10705.D06:

Extreme minimum direct after the beginning of braking, nearly blockage at front-right wheel. Later very small and high frequent regulation.

5.3. Evaluation of the Collected Data: All Tests (on Test Bench)

5.3.1. Failures Distinguished by Car Type:

The first analysis is the representation of the appeared failures as found by the type of the car. This analysis will give a good overview about the test results and an orientation for the further analysis of the tests. Figure 5.3 shows the absolute number of failures created by the different car types and distinguished into failures in the snow phase and in the ice phase.



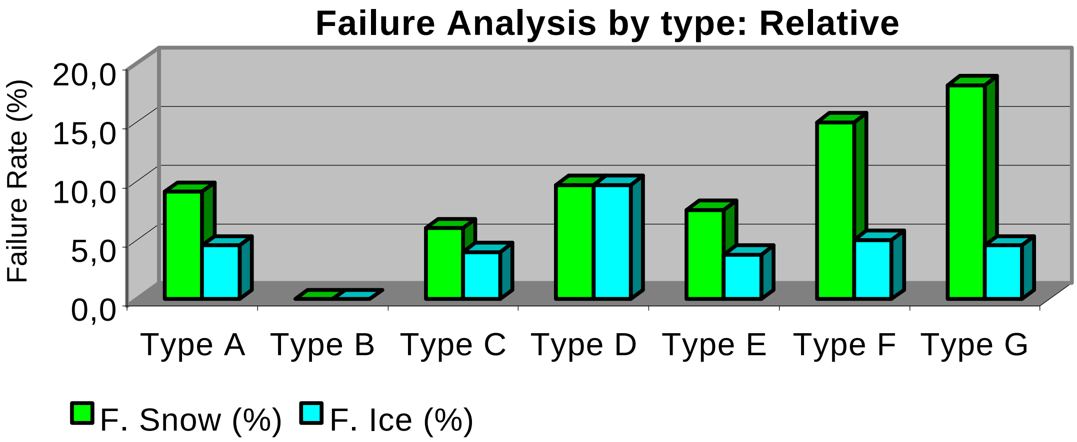
	Type A	Type B	Type C	Type D	Type E	Type F	Type G	TOTAL
Total Tests	22	36	50	31	53	20	22	**234**
Failures Snow	2	0	3	3	4	3	4	**19**
Failures Ice	1	0	2	3	2	1	1	**10**
								29

Figure 5.3

In total, of 234 valid tests 19 failures in the snow phase and 10 failures in the ice phase occur. The failure rate in the snow phase is between 0 and 4 failures, the failure rate in the ice phase between 0 and 3 failures. Ostentatious behaviour in comparison with the other car types shows type B, because it has neither a failure in the snow phase nor in the ice phase.

It is necessary to take the number of total tests for each car type into account. Therefore, the result is better interpretable when it shows the relative failure rates for each car type.

Figure 5.4 shows the relative failures by car type distinguished into failures in the snow phase and failures in the ice phase. Notable is again type B without any failure. Except from type B, the failure rate in the snow phase ranges between 6,0 % (type C) and 18,2 % (type G). In the ice phase, between 4,5 % (type A and G) and 9,7 % (type D) have a blockage during the tests.



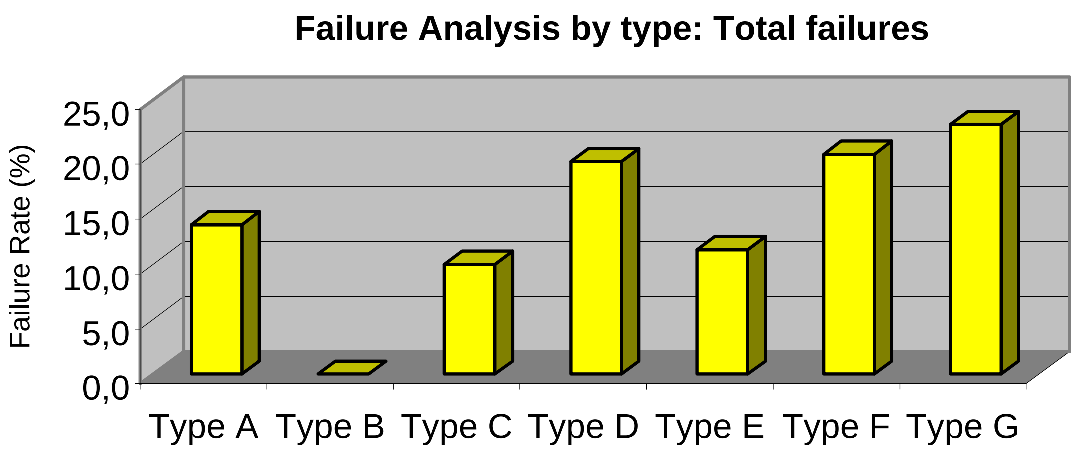
	Type A	Type B	Type C	Type D	Type E	Type F	Type G	TOTAL
R. F. Snow (%)	9,1	0,0	6,0	9,7	7,5	15,0	18,2	**8,1**
R. F. Ice (%)	4,5	0,0	4,0	9,7	3,8	5,0	4,5	**4,3**
								12,4

Figure 5.4

The total failure rate is 8,1 % for failures in the snow phase and only 4,3% for failures in the ice phase. The reason of this difference can be that most of the ABS-failures will lead to a blockage in the snow phase (which already means a high stress for the ABS-system) so that these cars of course don't reach the ice phase. Only 4,3 % of the cars have failures, which don't lead to blockage in the snow phase but cause blockage in the ice phase with the severest stress for the ABS-System ($\mu \approx 0,1$).

When the difference between snow failures and ice failures is investigated, an inhomogenous distribution can be seen. For type A, C, D and E the failure rate in snow and ice is not very different. Type F and G have a much grater failure rate in snow than in ice.

In the next Figure (Figure 5.5), the failures in snow and ice phase are added to an overall failure rate.



	Type A	Type B	Type C	Type D	Type E	Type F	Type G	TOTAL
R. F. Snow (%)	9,1	0,0	6,0	9,7	7,5	15,0	18,2	**8,1**
R. F. Ice (%)	4,5	0,0	4,0	9,7	3,8	5,0	4,5	**4,3**
R. F. Total (%)	**13,6**	**0,0**	**10,0**	**19,4**	**11,3**	**20,0**	**22,7**	**12,4**

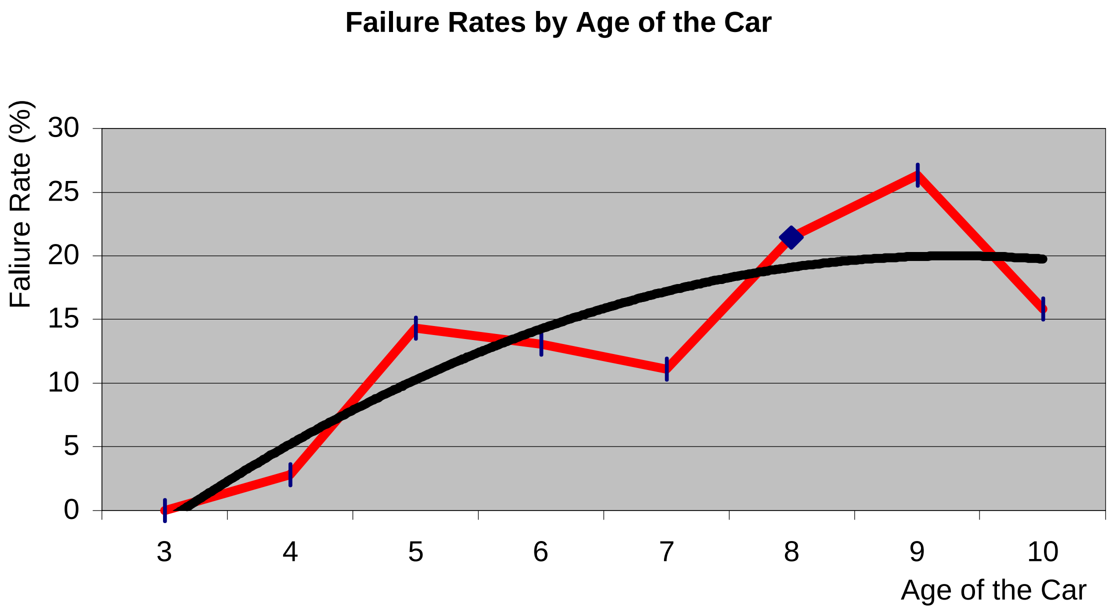
Figure 5.5

It points out, that there is a relative constant number of failures (10 % -19 %) between different car types. Exception is type B without any failure.

For detailed analysis, now the failures are distinguished by other parameters.

5.3.2. Failure Rates by Age of the Car

The age of the car and with it the age of the ABS has influence on the reliability of the system and the availability of the correct system functions. A higher failure rate will occur in older systems. To proof if this trend existed in the collected data of this study, the failure rate now is analysed by the year of construction of the tested cars.



Age of the car	3	4	5	6	7	8	9	10
Total Tested	29	36	21	46	18	28	19	19
R. F. Snow (%)	0,0	2,8	9,5	10,9	5,6	10,7	21,1	10,5
R. F. Ice (%)	0,0	0,0	4,8	2,2	5,6	10,7	5,3	5,3
R. F. Total (%)	**0,0**	**2,8**	**14,3**	**13,0**	**11,1**	**21,4**	**26,3**	**15,8**

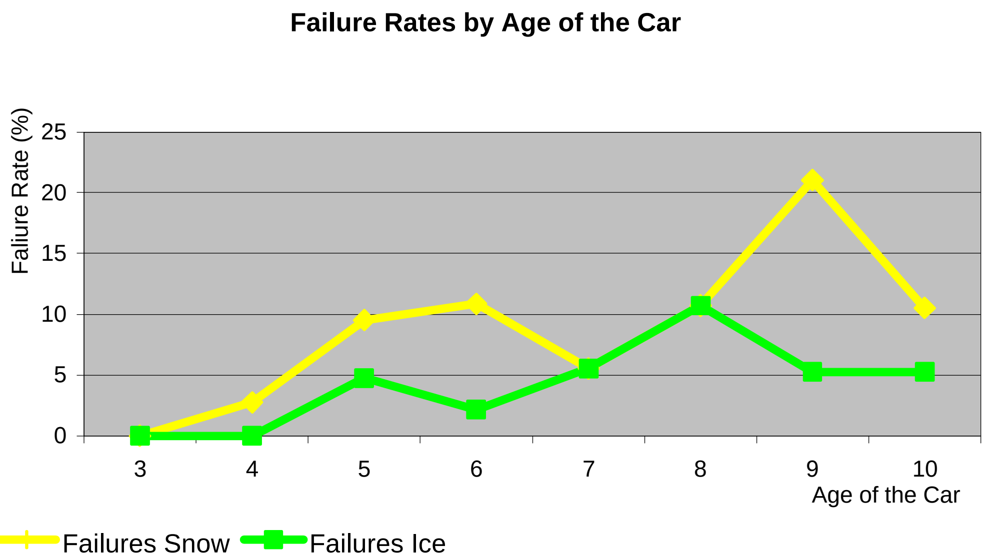
Figure 5.6

Figure 5.6 shows the overall failure rate (snow and ice) depending on the age of the tested cars. The black curve is the trend curve.

With older cars, the statistic significance of the results decreases because only a small number of such cars could be tested in this study For an age > 10 years, only a small number of cars were tested. Therefore, these years are not depicted in the plot. The result for this years of construction has a smaller significance level than for the modern cars.

The diagram makes clear, that the failure rate is increasing with the age of the car. For cars with an age between 3 years (year of construction 1998) and 7 years (year of construction 1994) the failure rate increases with a great gradient. For older cars, the gradient is less.

In Figure 5.7, the failure rates are splitted into failures in the snow phase (yellow) and failures in the ice phase (green).



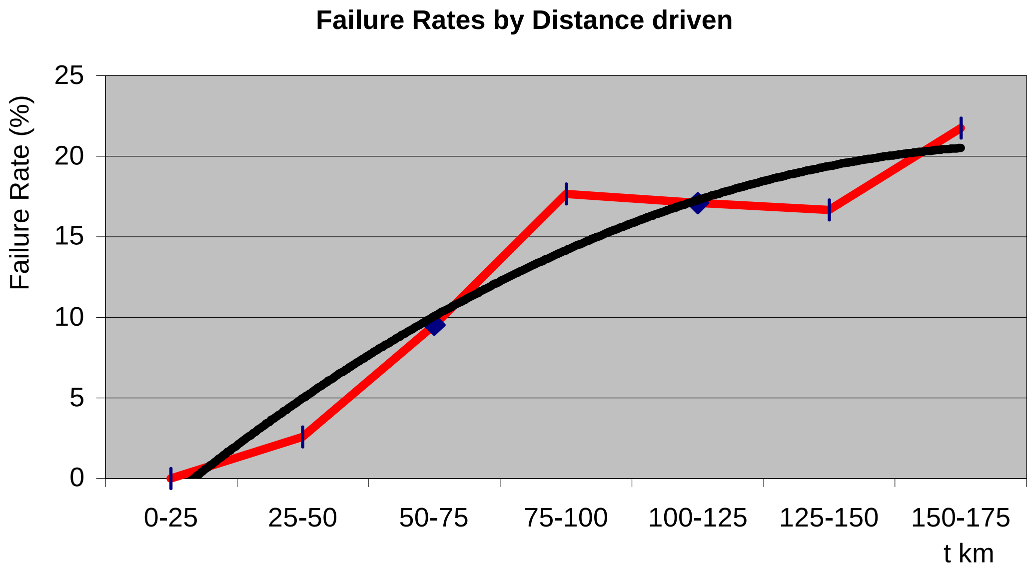
Age of the car	3	4	5	6	7	8	9	10
Total Tested	29	36	21	46	18	28	19	19
R. F. Snow (%)	0,0	2,8	9,5	10,9	5,6	10,7	21,1	10,5
R. F. Ice (%)	0,0	0,0	4,8	2,2	5,6	10,7	5,3	5,3
R. F. Total (%)	**0,0**	**2,8**	**14,3**	**13,0**	**11,1**	**21,4**	**26,3**	**15,8**

Figure 5.7

For cars with an age between 3 and 8 years, a trend for increasing failure rate can be seen. For older cars, especially with an age of 9 and 10 years, a clear trend is not seen due to the small number of tests with these cars.

5.3.3. Failure Analysis by Distance Driven

Another important factor for the availability and reliability of electronic and mechanic systems is the distance driven of the car. Figure 5.8 shows the total failure rate (snow and ice failures added) depending on the distance driven.

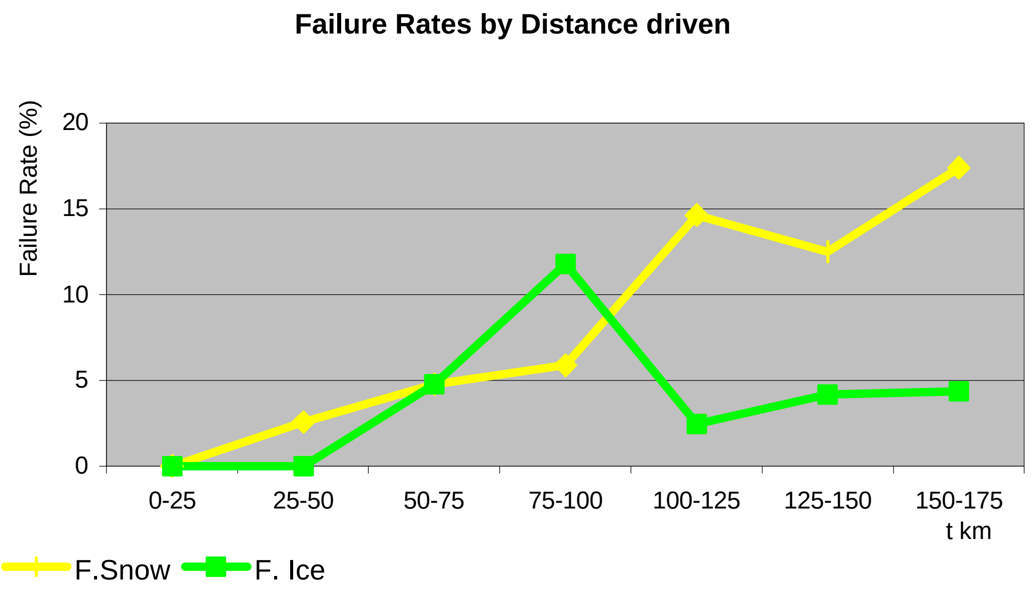


t km	0-25	25-50	50-75	75-100	100-125	125-150	150-175
Total Tested	9	39	42	34	41	24	23
R. F. Snow (%)	0,0	2,6	4,8	5,9	14,6	12,5	17,4
R. F. Ice (%)	0,0	0,0	4,8	11,8	2,4	4,2	4,3
R. Total (%)	**0,0**	**2,6**	**9,5**	**17,6**	**17,1**	**16,7**	**21,7**

Figure 5.8

The failure rate increases with the distance driven of the car for kilometres between 0 and 100 thousand kilometres. Between 100 thousand kilometres and 125 thousand kilometres, the failure rate is nearly constant. It increases again for cars with more than 125 thousand kilometres. For more than 175 thousand kilometres, only a small number of cars (13 between 175 tkm and 200 tkm and 9 with more than 200 tkm) were tested, therefore no relevant analysis can be done for this distance driven.

In Figure 5.9 the failures in the ice phase and in the snow phase are depicted separately.



t km	0-25	25-50	50-75	75-100	100-125	125-150	150-175
Total Tested	9	39	42	34	41	24	23
R. F. Snow (%)	0,0	2,6	4,8	5,9	14,6	12,5	17,4
R. F. Ice (%)	0,0	0,0	4,8	11,8	2,4	4,2	4,3
R. Total (%)	**0,0**	**2,6**	**9,5**	**17,6**	**17,1**	**16,7**	**21,7**

Figure 5.9

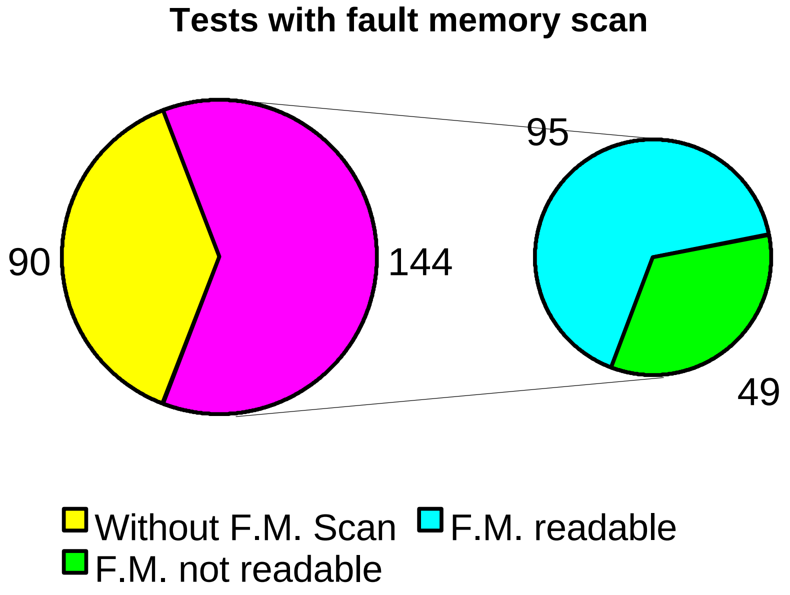
The figure clearly points out, that the number of “ICE” failures is relatively constant or increasing, while the number of “SNOW” failures increases with the distance driven of the car. For the ABS system, it is easier to master the snow phase than the ice phase. The ice phase with the extremely low friction coefficient ($\mu \approx 0,1$) is the severest requirement for the ABS. Therefore, already light technical problems will cause malfunction in this phase. Such failures of the ABS don't seem to be of great dependence from the kilometres of the car.

For blockage in the snow phase, more severe failures are needed, because small deviations in the regulation of the wheel speed may not lead to blockage. Such failures are strongly increasing with the distance driven of the car.

5.4. Evaluation of the Collected Data: Tests on Test Bench with additional Fault Memory Scans

5.4.1. Tests with fault memory scan

The ABS tests on the improved test bench for this study should be done at the Cologne Muelheim proofing ground from the normal stuff, in addition to the periodic inspection. After the beginning of the tests, it was pointed out that the additional scan of the fault memory before and after the test on the test bench are not integratable in the daily work at Cologne Muelheim proofing ground. To do the additional work and to reach the proposed number of tested cars, customers from TUEV Rheinland customer database with car types matching to the selection in this study, were invited by letter and the total test sequence (first fault memory scan, test on test bench, second fault memory scan) was done by staff from the Institute for Traffic Safety of TUEV Rheinland. This chapter presents the results of the test with both, test on test bench and scan of the fault memory.



TOTAL:	234
Without F.M. Scan	90
With F.M. Scan	144
F.M. readable	95
F.M. not readable	49

Figure 5.10

Figure 5.10 points out, that from the total test on test bench with valid recorded datasets (234) a subgroup of 144 tests include both, efficiency test on test bench and scan of the fault memory before and after the efficiency test. From these 144 cars, the fault memory was readable at 95 and the fault memory was not readable at 49 because of various reasons.

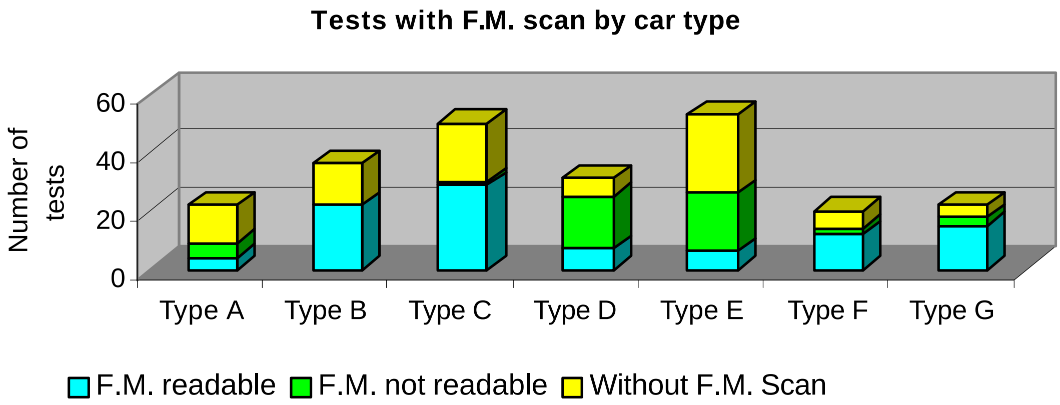
This chapter firstly will figure out the number of successful fault memory scans and the problems with not readable fault memories and will then present the analysis for the test with fault memory scan and efficiency test.

In addition to the fault memory scans, the function of the ABS warning lamp was checked. For the vehicles with failures in snow (n=19), following warning light signals were found out: Only in one vehicle, the warning lamp was alight before the efficiency test. In two cars, the warning lamp was switched on during the failed test (wheel locking) and remain alight until further braking were done on the road. In two vehicles, the warning lamp was only alight while the wheels lock. All failures during the ice phase (n=10) were not signalised by the warning lamp.

5.4.2. Tests with Fault Memory Scan by car Type:

The availability of diagnosis tools for scanning the fault memory of the cars was discussed with the test system manufacturers SNAP-ON and BOSCH, both being involved in the CITA Working Group 7. SNAP-ON offered the use of a test system for the car types A, B, C, D, F and G for this study, BOSCH offered the use of a test system for type E.

Figure 5.11 gives an overview about all tests on the test bench (the whole columns) for each car type. The blue part shows the number of cars with test on test bench and successful scan of the fault memory. The green part depicts the number of cars with a tried but unsuccessful fault memory scans. For the yellow part the number of cars results with exclusive test on test bench, without fault memory scan.



	Type A	Type B	Type C	Type D	Type E	Type F	Type G	**TOTAL**
F.M. readable	4	22	29	7	6	12	15	**95**
F.M. not readable	5	0	1	18	20	2	3	**49**
Without F.M. Scan	13	14	20	6	27	6	4	**90**
Total	22	36	50	31	53	20	22	**234**

Figure 5.11

Many cars of type “E” were not readable. Maybe there was a defect in the Bosch-tester (only used for type E). For the other car types, some fault memories were unreadable too. The only exception is type B, in which all fault memory scans were readable.

As fault memory scans are important and featured kind of vehicle electronic test in future, a further analysis for the appeared problems is given in the next chapters.

5.4.3. Fault Memory not readable by Problem Type

Figure 5.12 names the causes for unsuccessful fault memory scans and shows how often the variant causes occur in this study. Due to the recognised problems with the tester for type E, the most important problem is shown in a separate row (Row 2).

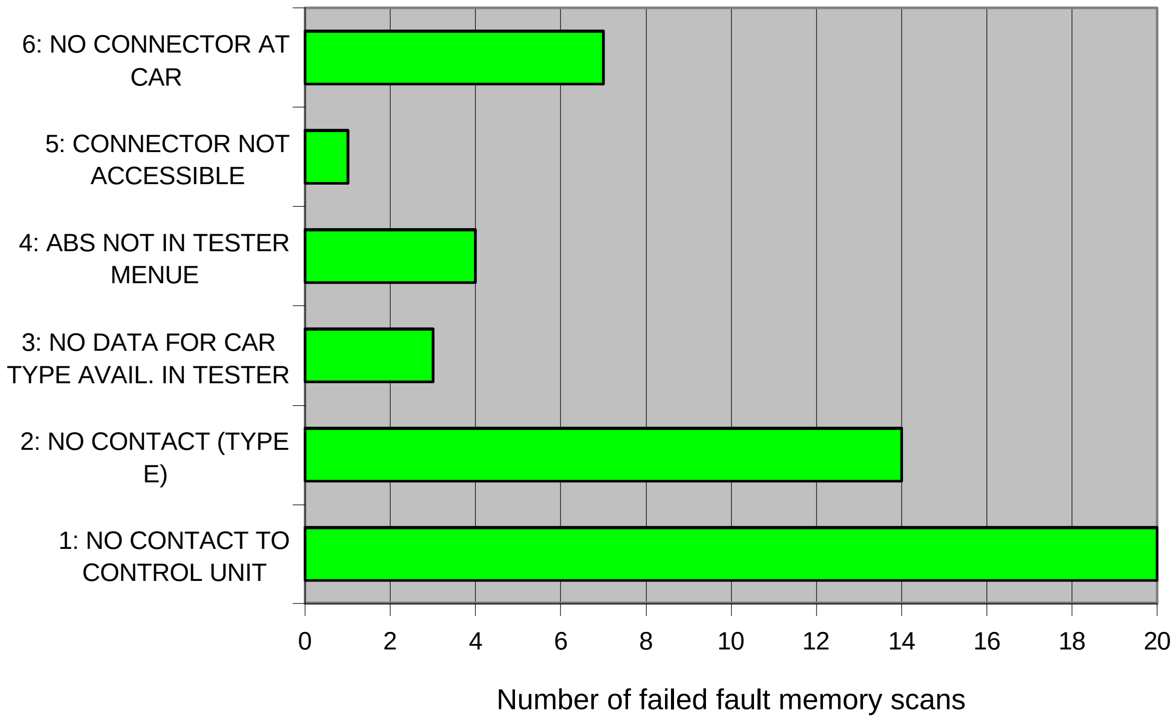
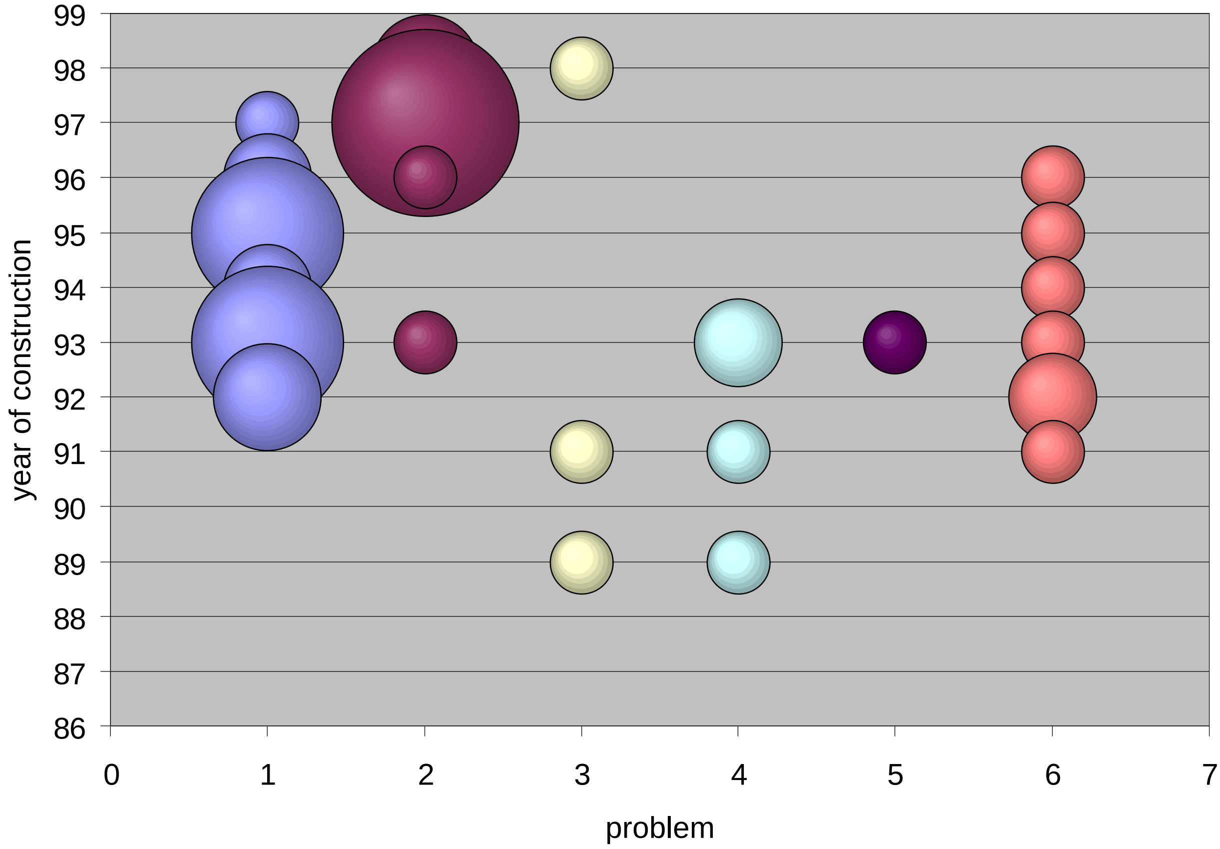


Figure 5.12

Row 1 shows the most common problem: The tester can't get in contact to the ECU control unit, although all electrical connections have been done. This failure appears 14 times for cars of type E and 20 times for the other car types. In 3 cases, the tester had no data to read out the ABS fault memory of the car type (Row 3). For 4 times, the tester could get into contact to the ECU, but the ABS didn't appear in the tester menu and therefore, it couldn't be read out (Row 4). 8 cars didn't have a connector for the diagnosis tool (Row 6). In 1 case, the connector was available but not accessible, because it was covered with the sealing cup of the gearshift leaver, which was not removable without greater effort.

As the age of the car is of great relevance to the stage of the ECU and tester technology, a deeper analysis of the year of construction regarding to the recognised problems is expressiveness.

5.4.4. Fault Memory not readable by Problem and Year of Construction



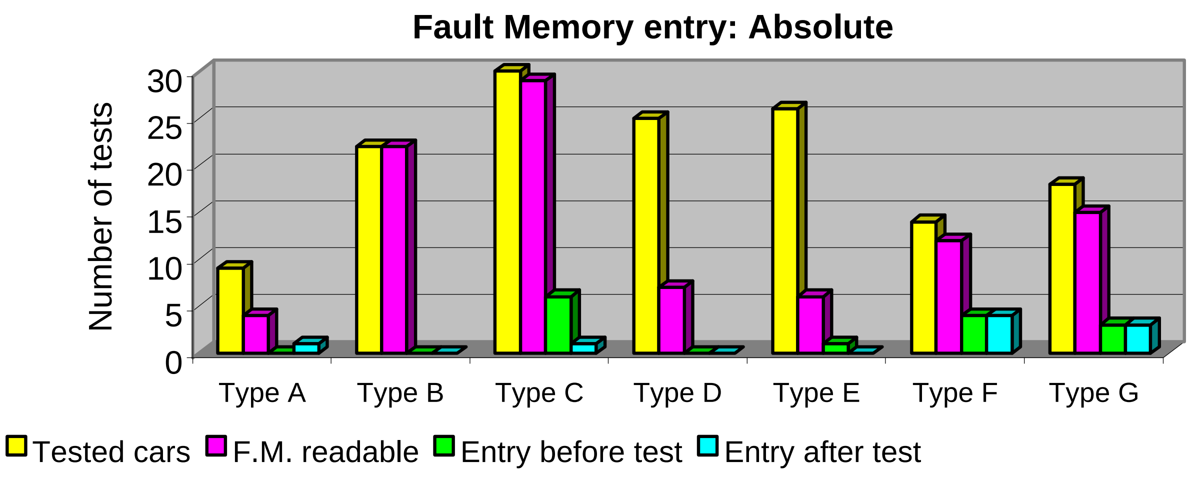
Cause for not readable fault memory:	Number:
1: NO CONTACT TO CONTROL UNIT	20
2: NO CONTACT (TYPE E)	14
3: NO DATA FOR CAR TYPE AVAIL. IN TESTER	3
4: ABS NOT IN TESTER MENUE	4
5: CONNECTOR NOT ACCESSIBLE	1
6: NO CONNECTOR AT CAR	7
Total	49

Figure 5.13

This figure shows causes for not readable fault memories (horizontal axis), the year of construction of the car (vertical axis) and the number of occurrence of the problem (size of the bubbles). Column 2 points out, that many modern cars of type E were not readable confirming the assumption that there was a technical defect in the tester for this car type. For the other car types, a contact to the control unit wasn't possible for cars built between 1992 and 1997 (Column 6). A connector wasn't available for cars with a homogenous distribution of the year of construction between 1991 and 1996.

5.4.5. Analysis: Fault Memory Entries by Car Type

After the explanation of the causes for fault memory scan problems, the found fault memory entries are analysed now. Figure 5.14 gives the complete overview about the fault memory scans sorted by car type. The yellow column shows the number of tested cars with both tests, efficiency test on test bench and fault memory scan, for each car type. The violet column depicts the number of successful fault memory scans. With the green and the blue columns, the rate of failure entries before the efficiency test and after the efficiency test is shown. For the test procedure with fault memory scans, please refer to chapter 4.5.



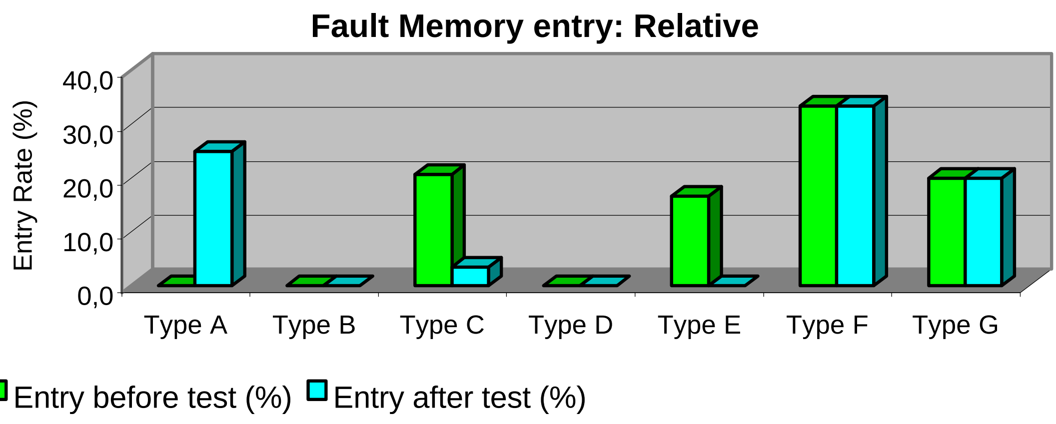
	Type A	Type B	Type C	Type D	Type E	Type F	Type G	**TOTAL**
Tested cars	9	22	30	25	26	14	18	**144**
F.M. readable	4	22	29	7	6	12	15	**95**
Entry before test	0	0	6	0	1	4	3	**14**
Entry after test	1	0	1	0	0	4	3	**9**

Figure 5.14

It is obvious from this figure, that the success of fault memory scan extremely depends on car type: From type B 100% of the fault memories were readable, from type D only 28%. The number of fault memory entries also depends on car type. Type B has neither an entry before the efficiency test nor after the test, type C has more failure entries before the test (6) than after the test (only 1), and type F and G have the same number of fault memory entries before the test and after the test (4 / 3 entries).

A diagram with the relative percentage of fault entries will be more impressive than the diagram with total test/failure rates. Furthermore, an analysis of the different fault entries / fault types is of great interest.

Figure 5.15 gives an impression of the relative fault entry rates.



	Type A	Type B	Type C	Type D	Type E	Type F	Type G	TOTAL
Entry before test (%)	0,0	0,0	20,7	0,0	16,7	33,3	20,0	**14,7**
Entry after test (%)	25,0	0,0	3,4	0,0	0,0	33,3	20,0	**9,5**

Figure 5.15

It is remarkable, that up to 30% of the cars of one type have fault memory entries before test on test bench (type D: 30%, type C and G: 20%, type E: 16,7%). After the deletion of the fault memory entries and the efficiency test on the test bench, for type F and G up to 30% of fault entries recur after test on test bench. More than 20% of type A have failure entries after the test on the test bench

5.4.6. Fault Memory Entry by Fault Type

Most of the fault entries of the cars coming to the ABS tests are faults of *one or more wheel speed signals*. 9 cars have such fault entries. Such faults can be caused from temporary problems with one or more wheel speed sensors in the past, or from current failures. If it is a failure entry because of a temporary problem in the past, the fault will not recur during the following test on the test bench. For 3 of the 9 cars with sensor-related faults, there is no fault memory entry after the test. These 3 of 9 faults are the "historical" part. The majority of 6 faults must currently exist in the ABS-system, because there is a new fault memory entry after the efficiency test on the test bench.

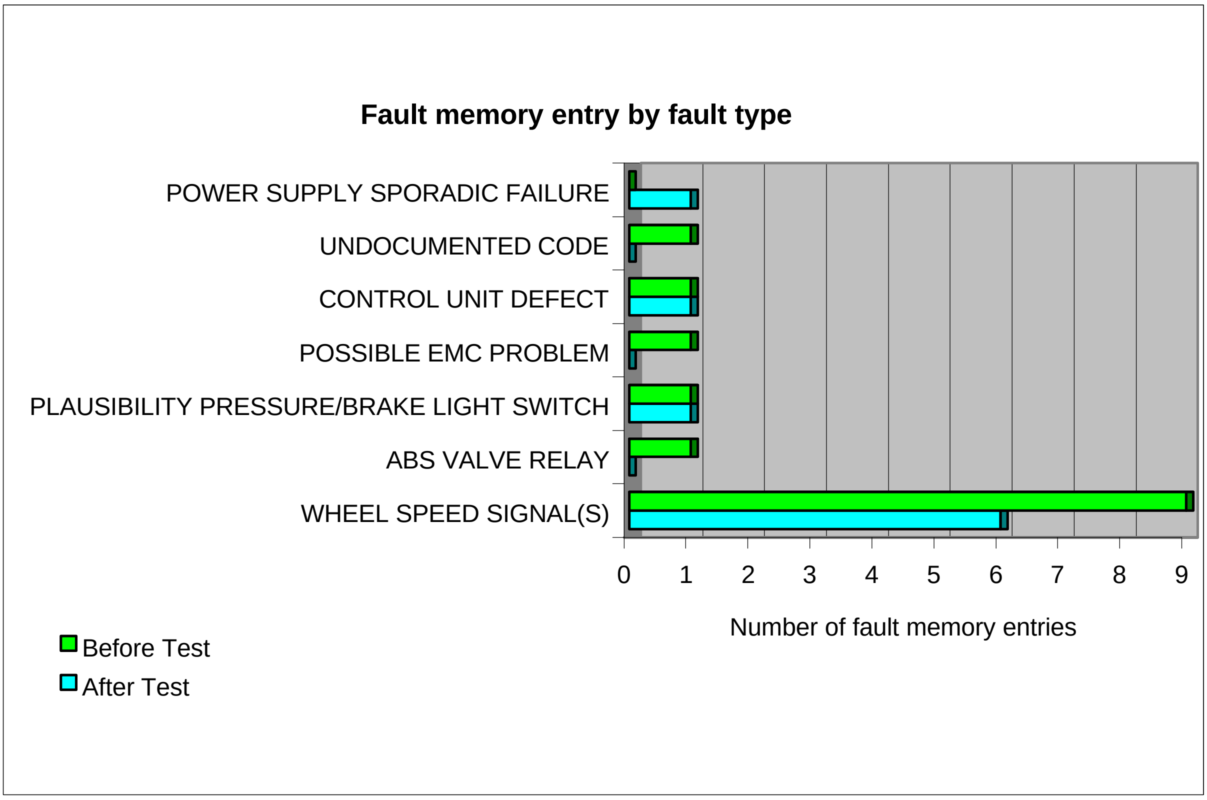


Figure 5.16

Additional, a number of various further fault entries occur. One fault was caused by an *ABS valve relay*. One fault was not analysable by the test tool, this fault was presented as "*undocumented code*". One fault means "*EMC-problems*" of the ABS system. These three fault entries don't recur after the test on test bench.

One car come with a defect ECU (fault memory entry: *Control unit defect*). Of course, this fault recurs during the efficiency test and natural, the efficiency test was not passed.

Another fault before and after the efficiency test was "*plausibility pressure / brake light switch*".

One fault (*power supply sporadic failure*) was not existing in the fault memory of the car coming to the ABS-test, but this fault occurs during the efficiency test sequence. The ABS test sequence of the TUEV Rheinland test bench results in a permanent activation of the ABS system (ECU, valves, sensors...) for 13 s. This fault may be caused by electrical contact problems which lead to an undervoltage of the system during the constant activation of the system, which does not occur while normal street driving on normal surface conditions and without emergency braking. Therefore, this fault didn't occur before the test on the test bench.

5.4.7. Correlation between Fault Memory Scan and Test on Test Bench

As a comprehension, the correlation between the results of the fault memory scans and the efficiency test on the test bench must be further analysed. The aim is to appraise the effectivity of the test via fault memory scan and the efficiency test on the test bench. Therefore, the fault memory entries after the test on the test bench will be related to the results of the efficiency test at first, and from the other point of view the tests on test bench with failures will be related to the fault memory entries belonging to these tests.

5.4.7.1. Fault Memory Entries after Test On Test Bench:

- **9** Fault memory entries
- Results of test on test bench:
  - **5** blocking on snow
  - **0** blocking on ice
  - **4** without failures on test bench

Fault memory entries: (5 blocking on snow and 0 blocking on ice)
3 x WHEEL SPEED SIGNAL(S)
1 x PLAUSIBILITY PRESSURE/ BRAKE LIGHT SWITCH
1 x CONTROL UNIT DEFECT

Fault memory entries: (4 without failures on test bench)
3 x WHEEL SPEED SIGNAL(S)
1 x POWER SUPPLY SPORADIC FAILURE

Figure 5.17

After the efficiency test on the test bench, 9 fault memory entries occur.

For 5 of them, also the test on the test bench was failed (blocking on snow). 3 fault memory entries about *wheel speed sensor* problems are so severe, that the ABS system is not able to regulate the wheel speed without blocking in the snow phase. Furthermore, the failure which leads to the fault memory entry "*plausibility pressure / brake light switch*" leads to a blockage in the snow phase. Natural, the car with the *defect in the ABS control unit* blocks immediately in the snow phase, because the ABS has no function.

3 further problems with *wheel speed sensors* don't seem to be so severe and don't lead to failures on the test bench. At last, the "*Power supply sporadic failure*" has no influence to the ABS functionality which can be measured in the snow or in the ice phase on the test bench.

5.4.7.2. Tests on test bench with failures:

- **12** cars blocking on snow
    - at **8** of it fault memory readable
    - Results of fault memory scan:
        - **5** failure entries before test
        - **5** failure entries after test

        (the same 5 cars)

Fault memory entries:

```
3 x WHEEL SPEED SIGNAL(S)
1 x PLAUSIBILITY PRESSURE/
    BRAKE LIGHT SWITCH
1 x CONTROL UNIT DEFECT
```

At least 3 cars with failed test on test bench, but without fault memory entry!

- **3** blocking on ice
    - at **1** of it fault memory readable
    - Results of fault memory scan:
        - **0** failure entries before test
        - **0** failure entries after test

At least 1 car with failed test on test bench, but without fault memory entry!

Figure 5.18

From the tests with both, fault memory scans and efficiency test, 12 cars didn't pass the snow phase. At 8 of these cars, the fault memory was readable. Only these 8 tests can be analysed in relationship with the results of the fault memory scans.

5 of these cars have one or more fault memory entry before the efficiency test and the same 5 cars have fault memory entries after the test. From these faults, 3 are relating to *speed sensor problems*. The car with the fault entry "plausibility pressure / brake light switch" is part of this 5 car subgroup, too. At last, the car with the defect control unit blocks immediately in the snow phase.

This means, that at least 3 cars failed the efficiency test on test bench in the snow phase without fault memory entry.

In the ice phase, 3 cars show blockage. The fault memory was readable at one of it. This car has neither a fault memory entry before the efficiency test nor after the test.

At least at 1 car with blockage of the wheels in the ice phase, no fault was detected and documented in the fault memory.

6. Conclusion

One aim of this study was to examine the integration of the efficiency test in the normal work for periodic inspection. Therefore, the test bench was extended for an automated test sequence, which can be executed by the normal test centre staff after an instruction of this test. For this, the study comes to following conclusions:

- The ABS-test bench has shown its ability to detect failures with a test procedure that takes only a short time to perform.
- The automated test sequence allows the integration of the test into periodical inspection.
- Fault memory scans would be of advantage at periodic inspection, as more faults are detected than by looking at the warning lamp alone, but there are still some communication difficulties with current equipment.

With the TUEV Rheinland ABS test bench, ABS tests were done and a huge database (more than 250 tested cars) is created. The test procedure simulates a complex and demanding, but realistic task for the ABS (emergency braking on ice and snow). The measurement system and the evaluation possibilities allow a detection of deviations from the normal system behaviour (chapter 5.2.2) and of complete failures (blockage in the snow phase or in the ice phase). For these very strict failures, a statistic analysis is done leading to following conclusions:

- The study points out, that there is a significant failure rate (average value 12,4 %) for ABS.
- The failure rate increases with the distance driven. It starts with 0 % for cars with 0-25.000 km and increases to 21,7 % for cars with 150.000 - 175.000 km.
- The failure rate increases with age of the car. It starts with 0 % for cars from 1998 (age at the time of the test: 3 years) and increases to approx. 20 % for cars built before 1992 (age > 9 years at the time of the test).

From 234 total tests on test bench with valid recorded datasets, a subgroup of 144 tests include both, efficiency test on test bench and scan of the fault memory before and after the efficiency test. From these 144 cars, the fault memory was readable at 95 (66%) and the fault memory was not readable at 49 (34%) because of various reasons.

A significant number of failures are not detected by the self diagnosis routine and are not documented in the fault memory. From 9 cars with readable fault memory and blockage in the snow phase (failed efficiency test), the failure was not detected and documented in the fault memory for 4 cars.

This requires efficiency tests combined with fault memory scans to cover most of the failures of the ABS.

7. Literature

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8. Appendix 1: Main Failures (Blockage)

Plots are included in the printed version.

9. Appendix 2: Further Failures

Plots are included in the printed version.