LAT / AUTh

The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency

Detailed Report 1 - Review of Short Tests

by LAT/AUTh

Thessaloniki, January 1995

Project funded by the European Commission
Directorate Generals for Environment (DGXI), Transport (DG VII) and Energy (XVII)

A R I S T O T L E
U N I V E R S I T Y
THESSALONIKI
FACULTY OF ENGINEERING

LABORATORY OF APPLIED THERMODYNAMICS
ARISTOTLE UNIVERSITY THESSALONIKI - 540 06 THESSALONIKI GREECE

DEPT. OF MECHANICAL ENGINEERING

The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency

Task 1.1: Review of short tests

by Zissis Samaras and Theodoros Zachariadis

LAT Report 9502

THESSALONIKI, JANUARY 1995

The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency

Task 1.1: Review of short tests

Contents

1. Introduction

An Inspection and Maintenance (I/M) programme aims to ensure that motor vehicle emission control systems are functioning properly throughout the lifetime of the vehicle. Hence it is by definition a large-scale project which involves, apart from national and local authorities and inspection stations, all car owners. Therefore it can only be effective if it is technically sound, socially acceptable and not too costly. Among these features the technical aspects (which one can group under the name "test procedure") are crucial and have to be considered carefully before one or more proposals are made. This report summarises the short test procedures that have been developed worldwide for the control of exhaust emissions from passenger cars and attempts to assess them in terms of the emission reductions and the costs associated with each one of them. Under the term "short test procedure" (or briefly "short test") the following technical aspects are included:

- engine operating modes during the test (e.g. idle, constant power output, transient operation)
- type of emission measurements
- pollutants covered
- required pre-conditioning period
- test duration
- necessary test equipment.

Evidently in each inspection a number of visual checks has to be performed before the emission test starts, in order to ensure that specific components of the car exist and/or operate properly. None of the following problems should occur:

- missing air filter
- leaks or damage in the exhaust
- wrong tyre pressure (in case of loaded tests)
- missing fuel inlet restrictor (applies to cars that must operate with unleaded gasoline)
- missing catalyst (where applicable)
- disabled secondary air pump (where applicable)
- disabled exhaust gas recirculation (EGR) system (where applicable)
- disabled positive crankcase ventilation (PCV)
- wrong idle speed setting (compared to manufacturer's specification).

The rest of this report is organised as follows: Sections 2, 3 and 4 summarise and evaluate the no-load, steady-state loaded and transient loaded short tests respectively that have been developed in the United States and Europe according to the available literature. Section 5 briefly describes two short test procedures for the control of evaporative emissions. Section 6 provides an overview of the main features of Inspection and Maintenance programmes adopted around the world. Finally, Section 7 outlines the most important conclusions from this literature search, provides a comparative assessment of the short tests mentioned in the previous sections and gives recommendations concerning the test options that our study has to investigate.

2. No-load tests

This term denotes all tests during which no external load is exerted and the car operates with the transmission in neutral position.

2.1 Idle / fast idle tests

Test sequence

The test involves carbon monoxide (CO), hydrocarbons (HC) and eventually carbon dioxide (CO_2)* concentration measurements in one (or both) of the following engine settings:

– operation of the engine at its idle speed;

– operation at a higher engine speed (2000 ÷ 3000 rpm).

Type of emission measurements

Pollutant concentrations are measured in the raw exhaust gas.

Pre-conditioning

Several pre-conditioning procedures have been proposed and used:

– operation at 2500 ÷ 3000 rpm for 30 seconds (Tierney et al. 1991) or 2-3 minutes (Pucher 1989, Tierney et al. 1991, Laurikko 1994);

– operation at 3000 rpm for 1 minute, which aims primarily at reaching the catalyst light-off temperature (Richter et al. 1993);

– no initial pre-conditioning; if the car fails the initial test then a pre-conditioning period of 3 minutes at fast idle or 30 seconds at steady-state load is foreseen before the car undergoes a "second chance" test (Tierney et al. 1991) or the car is re-tested without second chance pre-conditioning (Laurikko 1994).

Test duration

The test could last from less than one minute (in the case of a one-speed idle test without pre-conditioning) to about 10 minutes (in the case of a two-speed test with "second chance" test including pre-conditioning).

Necessary test equipment

A garage-type non-dispersive infrared (NDIR) analyser capable of measuring CO, HC and CO_2 concentrations is sufficient.

Overall assessment

* Evidently CO_2 is not treated like the toxic pollutants CO, HC and NOx; measurements of CO_2 concentrations in the exhaust gas may be used as an indication of proper engine performance and as a check of exhaust tightness. Therefore in countries where CO_2 measurements are legally enforced in short tests a minimum permissible CO_2 concentration in the exhaust gas is foreseen (e.g. 12%).

Today idle / fast idle tests are still the most widely used tests in I/M programmes because they are the fastest, cheapest and easiest to perform with the minimum possible testing equipment. They could effectively identify malfunctioning mixture preparation systems of carburetted cars by checking the performance of the carburetor's idle mixture orifice in the idle test and the main fuel-metering orifice in the fast idle test. Moreover, the performance of the ignition system could also be detected at idle. Thus a car emitting too much at idle and/or increased idle speed would be a high emitter at almost any operating point of the engine.

However, modern cars equipped with electronic fuel injection and ignition systems and three-way catalysts may have a defect that cannot be detected through their pollutant emissions at idle; even worse, the great bulk of emissions may be generated during transient engine operation, so that even steady-state operation at high load may not be able to identify some serious problems (such as a degraded oxygen sensor - Pidgeon et al. 1991, Richter et al. 1993). Instead of simple maladjustments and misfires, excess emissions are now more related to defective sensors and degraded catalyst efficiency. Moreover, a car's catalyst may be almost destroyed but its emissions at idle may still be acceptable because even a degraded catalyst has relatively high efficiency with the low exhaust flow rate at idle. In addition, the catalyst may "mask" other causes of excess emissions (Austin et al. 1989). The above show that modern catalyst cars which may comply with idle and fast idle CO/HC limit values may emit much more than the corresponding standards when measured in the legislated driving cycles, which better simulate a car's real-world operation, and hence idle tests on their own are not appropriate for characterising the emission behaviour of such cars.

An additional drawback is the negligible amount of emissions of nitrogen oxides (NOx) generated during idle tests (in the order of a few ppm in three-way catalyst cars); NOx emissions are thus impossible or too inaccurate to measure at no-load conditions.

Austin et al. (1989) examined the correlation of the idle and fast idle tests for cars of various model years (including several with three-way catalysts) and came up with coefficients of 0.1 to 0.2 in the idle test and 0.5 to 0.75 in the fast idle test.

2.2 Idle / fast idle tests with lambda test

<u>Test sequence</u>

A lambda (air/fuel ratio) test may be coupled with an idle / fast idle test in order to check the performance of the mixture preparation system. Three types of tests can be performed:

1. The air/fuel ratio is indirectly determined through measurement of CO_2, CO, O_2 and HC concentrations at fast idle (2000 ÷ 3000 rpm) in the raw exhaust, with an acceptable value of $\lambda = 1 \pm 0.3$ or the manufacturer's specification with a similar tolerance in the case of cars that do not operate with the $\lambda = 1$ principle (Pucher 1989, Richter et al. 1993).

2. The air/fuel ratio is artificially modified at idle or fast idle by adding oxygen, propane or recirculated exhaust gas to the intake air, or by tampering with connecting tubes in the area of the mixture preparation system and the engine (according to the German legislation, the air/fuel ratio modification has to be performed according to manufacturers' recommendations). Then the response of the lambda control system is checked, i.e. whether and in how much time the air/fuel ratio is re-adjusted to become equal to its initial value (Richter et al. 1993; see Figure 1). Long response times would imply that the oxygen sensor is degraded, while no response (i.e. no restoration of the initial λ value) would mean that the lambda control system is out of operation. The air/fuel ratio has to change from its initial value within 60 seconds, and it has to be restored to the initial value within another 60 seconds (DEKRA/RWTÜV 1994).
3. One or more of the characteristics of the electronic lambda control circuit are measured and compared with auto manufacturers' specifications (Pucher 1989).

Type of emission measurements

Pollutant concentration measurements in the raw exhaust gas are necessary, like in the simple idle / fast idle test. Note that the lambda test of type 3 is independent of emission measurements (which are however necessary for the exhaust emission determination).

Pre-conditioning

The normal engine/catalyst pre-conditioning period is also sufficient for lambda sensor pre-conditioning.

Test duration

Test type 1 takes no more time than the simple idle / fast idle test. Test type 2 requires 3-5 more minutes (Richter et al. 1993), and so does test type 3.

Necessary test equipment

A garage-type NDIR analyser is required (test type 1) and additional instrumentation for the artificial change towards rich or lean air/fuel ratio (test type 2) As the latter test requires a fully computerised procedure, a personal computer equipped with an A/D card is necessary, too. For test type 3, a NDIR analyser and a voltage meter or corresponding equipment (depending on the electronic control parameter that is measured) are necessary.

Overall assessment

The underlying logic of this test is that a lambda test can identify malfunctioning modern mixture preparation systems, while emission concentration measurements can be used to check the conversion efficiency of the catalyst. Thus it should be possible to investigate separately both parameters that are crucial for the emission performance of a modern car and diagnose which of the two systems is responsible for high emission levels. In this type of test a single pollutant concentration should be able to give a statement regarding catalyst efficiency as an aged or poisoned catalyst will have a significantly lower conversion efficiency of all three major pollutants (CO, HC and NOx). CO would be the most appropriate pollutant as garage-type analysers can display very good accuracy in CO concentrations (which is not always the case with HC) and CO is almost insensitive to modification of internal engine parameters such as the ignition timing (Pucher 1989).

On the other hand, the indirect determination of the λ value at idle or fast idle, which is the simplest of the three mentioned lambda tests, may not be capable of detecting some relevant defects as it involves steady-state operation of the lambda control system. For this reason Germany has adopted since December 1993 a test that involves both test types 1 and 2 (Verkehrsblatt 1993); preliminary investigations have shown that the test performs fairly well with excess emitters (Richter et al. 1993):

- Out of the 106 test vehicles, 67 emitted in the certification test more than their type approval limit; 10 were detected by the short test, with cutpoints of 0.5% CO at idle, 0.3% CO at fast idle and $\lambda \leq 0.98$ or $\lambda \geq 1.02$.
- Out of the 67 “excess emitters”, 7 emitted more than three times the type approval limit for at least one of the three regulated pollutants; 5 of these 7 cars were detected by the short test.
- 5 vehicles were falsely identified as excess emitters in the short test (i.e. they complied with the type approval limit in the certification test); 2 out of these had a fast idle CO concentration slightly over 0.3%, 2 had λ values greater than 1.02 and 1 vehicle had a λ value of 0.98.
- 27 of the 67 vehicles have undergone repairs or adjustments, which has led to average emission reductions of the whole sample of 23% for CO (from 3.01 to 2.33 g/km) and 10% for HC (from 0.299 to 0.267 g/km); NOx emissions were not affected (0.35 g/km).

A combined idle / fast idle / lambda test (involving lambda test types 1 and 2) is also in force in Austria, where it has also demonstrated satisfactory effectiveness (Pucher et al. 1990). A similar test (but with lambda test type 1 only) is also foreseen for three-way catalyst cars in all EU countries with Directive 92/55/EC, which will come into force from 1997 onwards.

2.3 Free acceleration test (diesel cars)

Test sequence

The (diesel) engine is accelerated with the transmission in neutral position until its maximum speed and is then decelerated to its idle speed. The amount of soot emissions is sampled during most of the whole acceleration and deceleration period.

Type of emission measurements

A part of the raw exhaust gas flows through either a filter or an opacimeter, where soot emissions are determined with the Bacharach method or with opacity measurement respectively.

Pre-conditioning

No pre-conditioning period is necessary as this method applies to diesel cars.

Test duration

The procedure takes less than one minute.

Necessary test equipment

A Bacharach device or an opacimeter is required.

Overall assessment

The free acceleration method is very fast, cheap and easy to perform, and can give indications about the condition of the engine and the fuel injection system. It has been criticised, however, because it bears no correlation with full load emission measurements (operation at full load represents a high fraction of total operation in diesel engines) and it can lead to wrong conclusions regarding the emission behaviour of a diesel car (Voss et al. 1987a). Moreover, it cannot give an indication for a car's NOx emission levels, which however become increasingly significant for photochemical air pollution.

2.4 INCOLL/AUTONAT

Test sequence

This test type was devised by Professor Lars Th. Collin of the University of Technology of Göteborg, called INCOLL (Collin 1985); recently a similar technique was also proposed by the French "Centre de Recherche en Machine Thérmiques" (CRMT), called AUTONAT (CRMT 1994a). The car engine operates with the transmission in neutral position and is accelerated and decelerated rapidly so that the load that the engine has to overcome in order to accelerate its rotating and reciprocating parts (including flywheel and gearbox) approximates its load during a normal driving cycle. Thus it should be possible to have a transient loaded test without external load. An acceleration - constant load - deceleration - idling cycle (at least in AUTONAT) typically takes about 10 milliseconds and is repeated continuously several times (see Figure 2). The above apply to gasoline cars; there is a separate 10 millisecond AUTONAT "cycle" for diesel cars consisting of a rapid acceleration, constant full rack engine speed, a rapid deceleration and an idling period (Figure 3). The accelerator pedal is actuated according to the corresponding "driving schedule" through an electronically controlled mechanism.

Type of emission measurements

As the engine is not operated at steady-state conditions, exhaust emissions will vary with time. Hence there are two options: either to measure concentrations in the raw exhaust (where modal analysis has to be applied) or to collect diluted exhaust and analyse pollutant emissions after the end of the test.

In the case of the AUTONAT test for diesel cars, smoke opacity is measured continuously with a “full-flow” opacimeter (CRMT 1994b).

Pre-conditioning

According to Collin (1985), a 3-minute pre-conditioning period is required.

Test duration

AUTONAT takes about 30 minutes in total; the actual AUTONAT cycle takes about 2 minutes, but it takes some time to obtain the relationship between accelerator pedal position and engine speed and load (CRMT 1994b) - evidently there will be a different relationship for each car type. INCOLL takes apparently about 5 minutes in total, but it is not clear whether additional time is necessary in order to adjust the system to each particular car type.

Necessary test equipment

The INCOLL/AUTONAT devices are quite simple and do not require high-quality analysers (although one would need a chemiluminescence NOx analyser, but the initial AUTONAT configuration does not include NOx measurements probably in order to keep costs low). An additional burden is the electronically controlled actuator, which should not be too costly. On the other hand, an exhaust gas sampling system is necessary unless continuous measurements are conducted and modal analysis is applied. Finally the AUTONAT test for diesel cars requires an opacimeter for continuous opacity measurements.

Overall assessment

Both systems have demonstrated reasonably good correlation with emissions in legislated cycles, even in the case of catalyst cars. However, the purely dynamic engine operation during these tests does not allow for identification of defects in the λ sensor; moreover, the driving sequence has to be adjusted to the characteristics of each car type in order to achieve equally good correlation with legislated cycles for all car types; in this respect the finding of an old U.S. Environmental Protection Agency (EPA) study that “...the INCOLL system as tested requires a unique inertial cycle for each engine/transmission combination. This approach is much more complicated than the presently accepted ‘one test for all vehicles’ approach to I/M.” (Smuda 1980) is still valid.

2.5 Other proposed methods

Several automobile manufacturers have suggested other no-load short tests (see Pucher 1989) such as:

– inspection of the catalyst oxygen storage capacity, which requires electronic equipment for the modification of the lambda control system’s time constant (proposal of Daimler-Benz);

- continuous measurements of raw exhaust gas concentrations upstream and downstream the catalyst during an INCOLL-like driving sequence and direct computation of the catalyst efficiency (proposal of Volkswagen);
- inspection of various engine control components (throttle valve sensor, battery voltage, ignition timing, lambda sensor, cooling water sensor etc.) with a so called Opel-tester (proposal of Opel).

The above methods have two common characteristics: they have a great capability of identifying malfunctioning systems in a car and would therefore be excellent test procedures for Inspection and Maintenance programmes; on the other hand, they all require too sophisticated equipment that is not possible for an average garage to obtain (moreover, Volkswagen’s proposal cannot be realised in many car models, which do not have an insertion probe before the catalyst). Due to the latter fact these tests are not realistic alternatives for a large-scale project such as a nationwide I/M programme.

It is also worth mentioning that another approach has been examined, based on statistical processing of test samples and taking into account internal emission-relevant engine parameters such as engine displacement, ignition timing and dwell angle (Pattas et al. 1987). It was thus possible to derive relationships between legislated mass emissions and idle / fast idle test results. For both CO and HC emissions, functions of the following type were obtained:

(Mass emission at legislated cycle) = A + B · (pollutant concentration at idle) +
+ C · (pollutant concentration at fast idle) + D · (engine displacement)

where A,B,C,D are coefficients derived through multiple regression analysis.

The above method was experimentally applied for carburetted non-catalyst cars and demonstrated reasonable correlation with legislated (ECE 15) emissions. Correlation coefficients were 0.87 for CO and 0.78 for HC - well above those of idle / fast idle tests that do not consider other engine parameters (see Section 7). Such a phenomenological approach shows that a simple test may be an effective procedure if coupled with measurements of additional engine parameters, and it might therefore be useful to attempt such correlations even for modern electronically controlled catalyst cars.

3. Steady-state loaded tests

NOx emissions at no-load conditions are negligible; a loaded test is therefore necessary in order to measure NOx emission levels, which constitute a critical issue for urban air pollution and cannot be directly determined from CO or HC measurements. The simplest loaded tests are the steady-state loaded tests. These involve a dynamometer with steady-state power absorption. A simulation of the car's inertia weight is not required because there is no transient phase in the emission test: the car is driven at constant speed and load, and pollutant concentrations (CO, HC, NOx and CO_2) are measured during the load phase.

3.1. U.S. Federal 3-Mode Test

<u>Test sequence</u>

The test consists of a high speed phase, a low speed phase and an idle phase. During the first two phases the car is operated at top gear (or in position "D" for cars with automatic transmission). The load varies according to the car's inertia weight (Berg 1982):

	High speed phase		Low speed phase	
Inertia weight	Speed [mph]	Load [HP]	Speed [mph]	Load [HP]
≤ 2500 lbs	50	21	30	9
2501 - 3500 lbs	50	26	30	12
3501 - 4500 lbs	50	31	30	15
≥ 4500 lbs	50	36	30	18

<u>Type of emission measurements</u>

Pollutant concentrations (CO, HC, NOx) are measured in the raw exhaust.

<u>Pre-conditioning</u>

A 15 to 30 s pre-conditioning period at 2500 rpm is foreseen.

<u>Test duration</u>

About 10 minutes (2 minutes maximum in each operating phase, where the recorded concentration of each pollutant was the highest of the concentrations measured in the last 30 seconds).

<u>Necessary test equipment</u>

NDIR analysers for CO, HC and chemiluminescence analyser for NOx; dynamometer without flywheels.

<u>Overall assessment</u>

The Federal 3-Mode Test was developed in the seventies and was one of various short test procedures that the U.S. EPA considered for I/M programmes. Although it demonstrated reasonably good correlation with Federal Test Procedure (FTP) tests (correlation coefficients varied between 0.63 and 0.85 for cars up to model year 1976* - see Berg 1982), it was never implemented due to the high cost of the dynamometer and the NOx analyser. Besides, tests had a bad repeatability even though they were carried out in test stations well above the level of an average garage.

3.2. Clayton Key-Mode Test

Test sequence

Like the Federal 3-Mode test, it consists of a high speed phase, a low speed phase and an idle phase. During the first two phases the car is operated at top gear (or in position "D" for cars with automatic transmission). The load varies according to the car's inertia weight (Berg 1982, Austin et al. 1989):

	High speed phase		Low speed phase	
Inertia weight	Speed [mph]	Load [HP]	Speed [mph]	Load [HP]
≤ 2800 lbs	36 - 38	14	22 - 35	5
2801 - 3800 lbs	44 -46	22.5	29 - 32	9
> 3800 lbs	48 - 50	28.5	32 - 35	11

Type of emission measurements

Pollutant concentrations (CO, HC, NOx) are measured in the raw exhaust.

Pre-conditioning

A 15 to 30 s pre-conditioning period at 2500 rpm was foreseen.

Test duration

About 10 minutes (2 minutes maximum in each operating phase, where the recorded concentration of each pollutant was the highest of the concentrations measured in the last 30 seconds).

Necessary test equipment

NDIR analysers for CO, HC and chemiluminescence analyser for NOx; dynamometer without flywheels.

Overall assessment

Like the Federal 3-Mode Test, the Clayton Key-Mode Test was developed in the seventies and was one of various short test procedures that the U.S. EPA considered

*About 80% of 1975 and 1976 model year cars in the U.S. were equipped with oxidation catalysts and about 90% with EGR; three-way catalysts were not in the market yet (U.S. EPA 1991).

for I/M programmes; it was actually tested in California and Arizona. Its correlation with FTP tests (correlation coefficients were 0.65 to 0.85 for cars up to model year 1976 - see Berg 1982) was equally good with that of Federal 3-Mode Test, but it was not implemented for the same reasons: the high cost of the dynamometer and the NOx analyser as well as the bad repeatability of the test results.

3.3. CalVIP

Test sequence

The car is driven on a dynamometer with the following inertia weight - dependent settings (Austin et al. 1989):

	Speed [mph]	Load [HP]
≤ 4 cylinders	40	10
5 - 6 cylinders	40	15
≥ 7 cylinders, ≤ 3250 lbs	40	17.5
≥ 7 cylinders, > 3250 lbs	40	20.5

Type of emission measurements

Pollutant concentrations (CO, HC, NOx) are measured in the raw exhaust.

Pre-conditioning

Although it was not possible to find more details about CalVIP in the available literature, it is reasonable to assume that either a brief operation at 2500 rpm (like in the Federal 3-Mode Test and the Clayton Key Mode Test) or a 3-minute steady-state loaded operation on the roller bench (like in transient loaded tests) was used for pre-conditioning purposes.

Test duration

The test would last in total less than 10 minutes.

Necessary test equipment

NDIR analysers for CO, HC and chemiluminescence analyser for NOx; dynamometer without flywheels.

Overall assessment

CalVIP was developed by the California Air Resources Board and was used in the centralised I/M programmes that ran in Los Angeles from 1979 to 1984. It showed slightly higher correlation with FTP emissions of catalyst cars than the Clayton Key-Mode Test; however, correlation with NOx emissions was still modest (of the order of 0.6 - see Austin et al. 1989).

3.4. Acceleration Simulation Mode Tests

Test sequence

The car is driven on a chassis dynamometer without flywheels for inertia weight simulation at a constant speed and steady-state power absorption that is equal to the actual road load of the car during an acceleration. The acceleration could be either the maximum acceleration of the FTP or a fraction of it. By setting the dynamometer to absorb power equivalent to the total load that the car experiences during an acceleration (except the rolling resistance, i.e. the sum of wind resistance and the load required to accelerate the inertial masses) one can achieve a realistic simulation of the car’s load at a specific driving mode without the need of flywheels for inertia simulation. However, at high speed / high acceleration combinations the required power absorption is too high to be achieved without engine overheating problems (Austin et al. 1989).

Type of emission measurements

Pollutant concentrations (CO, HC, NOx) are measured in the raw exhaust. Mass emission measurements were also considered as these improved the tests’ correlation with the FTP.

Pre-conditioning

As the study of Austin et al. (1989) did not aim at proposing a complete short test procedure but only at examining the performance and cost-effectiveness of ASM tests, it did not foresee a specific pre-conditioning period.

Test duration

Each steady-state test mode would require about 10 minutes for preparation, pre-conditioning, actual testing and documentation.

Necessary test equipment

NDIR analysers for CO and HC and chemiluminescence analyser for NOx. Besides, higher accuracy CO and HC analysers as well as a Constant Volume Sampler (CVS) would be required if measurements were to be carried out on a mass basis. A multiple-curve dynamometer is necessary as the load varies with the inertia weight of each car.

Overall assessment

Austin et al. (1989) compared several speed / load combinations with idle tests and already developed steady-state loaded tests as well as with the transient loaded CDH 226 test (see 4.2); special attention was given to the correlation of ASM and FTP NOx emissions, which constitutes the main drawback of no load tests. Cars of model years 1976 to 1986 (equipped with various emission control systems) were tested, each one with several configurations (one “normal” and one or more with implanted defects in an emission control component such as: EGR disconnection, rich idle setting, catalyst removal, oxygen sensor disconnection, air injection system disconnection, spark plug misfire). Most of the ASM tests performed better (in terms of NOx correlation with the FTP) than the idle / fast idle tests and the steady-state Clayton Key-Mode test and the CalVIP test (see 3.2 and 3.3 respectively). The best correlation was obtained from the ASM 5015 test, which had a constant speed of *15* mph (24 km/h) and a steady-state load equal to *50*% of the load required to accelerate at 1.47 m/s^2 (the maximum acceleration rate on the Federal Test Procedure) at the speed of 15 mph. ASM 5015 demonstrated a NOx correlation coefficient of 0.83 with the FTP versus 0.16 of idle tests and 0.45 to 0.60 of the other steady-state loaded tests. A further conclusion, however, was that "...no loaded mode testing program should be implemented until the next generation of Test Analyzer Systems is available" because for an ASM test "it is necessary to use a relatively complicated set of emission standards and dynamometer load settings."

Further examination of the two most promising ASM tests, namely ASM 5015 and ASM 2525, was conducted by the EPA, the California Air Resources Board (CARB) and the California Bureau of Automotive Repair (BAR). A Radian Corp. study that evaluated those test results concluded that both ASM tests can identify over 80% of the excess HC and CO emissions without using extremely low cutpoints that would result in too high errors of commission. ASM 2525 was not as good as ASM 5015 in identifying excess NOx emissions. In any case, the performance of both ASM tests in excess emissions identification and FTP correlation (with coefficients ranging from 0.47 to 0.77) was not as good as that of transient loaded tests (see 4.3, 4.4). Finally, a recent EPA finding states that "even in a maximum annual program covering all weight classes, ... the ASM test yields insufficient benefits to meet the performance standard for HC, CO and NOx." (Pidgeon et al. 1993).

3.5. VdTÜV's steady-state test for gasoline cars

Test sequence

The car is driven at 50 km/h and at 7 kW dynamometer power absorption in the third gear (position "D" for cars with automatic transmission) and then idles; pollutant concentrations are measured at the end of both the loaded phase and the idling phase (Voss et al. 1987a, 1987b). The sequence is shown in Figure 4.

Type of emission measurements

Pollutant concentrations (CO, HC, NOx) are measured in the raw exhaust.

Pre-conditioning

The car is driven on the roller bench at 50 km/h and 7 kW until pollutant concentrations have been stabilised (or for 5 minutes at the maximum); the emission measurements are performed immediately after this phase.

Test duration

Vehicle preparation, pre-conditioning, test phase and documentation take on the average about 10 minutes.

Necessary test equipment

NDIR analysers for CO, HC and chemiluminescence analyser for NOx; single-curve dynamometer without flywheels.

Overall assessment

The practical implications of adopting this combined steady-state loaded / idle test procedure were investigated in a study that was carried out by the Association of the German Technical Inspection Unions (VdTÜV - Voss et al. 1987a, 1987b). The study concluded that the test is much more appropriate for the inspection of catalyst cars than a simple idle / fast idle test, although some false failures and false passes (i.e. errors of commission and omission respectively) were observed. The authors point out that, in order to improve the performance of the test, type-specific reference values (and not fixed values) have to be used as cutpoints that determine whether a car passes or fails the short test.

3.6. VdTÜV's steady-state test for diesel cars

Test sequence

The test involves 2 successive measurements at nominal speed and full load and then 2 measurements at 45% of the nominal speed and full load (60% for cars with automatic transmission). Smoke emissions are collected at each one of the 4 steady-state points. The sequence is shown in Figure 5.

Type of emission measurements

Smoke measurements with the Bosch method.

Pre-conditioning

No pre-conditioning period is necessary as this method applies to diesel cars.

Test duration

Average test duration is 10 to 15 minutes.

Necessary test equipment

A single-curve dynamometer without flywheels and a Bosch smoke meter are required.

Overall assessment

This test procedure was examined in a study conducted by VdTÜV (Voss et al. 1987a, 1987b). The study concluded that the test is more appropriate than a no-load test for the characterisation of the emission behaviour of diesel passenger cars. However, it was not legally enforced in Germany because the EC-wide adopted (with Directive 92/55/EC) free acceleration test was considered to be satisfactory (Verkehrsblatt 1993).

4. Transient loaded tests

In transient tests cars are driven on the dynamometer according to a specific driving schedule; thus their main difference from type approval tests is the duration of the driving cycle. Since exhaust gas samples are collected continuously over the test duration, they have to be expressed in mass units and therefore a CVS system is in principle necessary. Laboratory-quality analysers are also required in order to detect low pollutant concentrations in the diluted exhaust sample. A multiple-curve dynamometer with flywheels is required in order to simulate the instantaneous road load and the necessary power to accelerate the inertia masses of each car.

4.1. Proposed transient tests in the 70s in the United States

Test sequences

A number of transient loaded short tests were developed in the 70s in the United States and were examined as to their correlation with the FTP 75. These were (Berg 1982):

- The "Modal Exhaust Emission Test Procedure", which consists of two phases. The first modal test is a sequence of 7 steady-state phases (idle, 5, 10, 15, 30, 45 and 60 mph). Emissions are measured in each one of these phases separately: after concentrations have been stabilised for 30 seconds, the exhaust gas probe is connected to a CVS bag for 3 minutes while the car remains at the same mode. Pollutant emissions are then derived on a mass basis, and the next operating mode follows. After all seven modes are conducted, the car is driven at 50 mph for 3 minutes and then runs at idle for 1 minute (idle concentrations are also measured). The second modal test is shown in Figure 6; inertia weight dynamometer settings and gear changes are those of the FTP.
- The U.S. "Federal Short Cycle" (see Figure 7); inertia weight dynamometer settings and gear changes are those of the FTP.
- The "New Jersey ACID Test" (Figure 8) with dynamometer settings of 3000 lbs and 3.5 HP at 30 mph for all cars.
- The "New Jersey / New York Composite Cycle" (Figure 9), where the dynamometer settings are 3000 lbs and 3.5 HP at 30 mph for all cars. Gear changes are those of the FTP.
- The "New York City Cycle" (Figure 10), where the whole test procedure is identical with the type approval tests.

Type of emission measurements

All the above tests required mass emission measurements with a CVS. Smoke opacity measurements were additionally performed in the New Jersey ACID Test.

Pre-conditioning

Pre-conditioning periods varied from 15 to 30 seconds at 2500 rpm (Federal Short Cycle and New Jersey / New York Composite Cycle) to 3 minutes at 50 mph driving (Modal Exhaust Emission Test Procedure).

Test duration

Test duration varied from about 20 minutes (New Jersey ACID Test, Federal Short Cycle and New Jersey / New York Composite Cycle) to about one hour (Modal Exhaust Emission Test Procedure).

Necessary test equipment

NDIR analysers were used for CO and HC (although FID HC measurements were also conducted at least on the New York City Cycle and on the New Jersey ACID Test) and chemiluminescence analyser for NOx measurements. The New Jersey ACID Test required an opacimeter as well. The New Jersey ACID Test and the New Jersey / New York Composite Cycle had a standard inertia weight simulation and dynamometer load (a single-curve dynamometer was sufficient), while all other tests required flywheels and dynamometer loading like in the type approval tests.

Overall assessment

The correlation of the Federal Short Cycle, the New Jersey / New York Composite Cycle and the New York City Cycle with the FTP was better than that of the Federal 3-Mode Test, the Clayton Key Mode Test and the idle / fast idle test, their correlation coefficients ranging from 0.82 to 0.95 even in the case of NOx emissions (Berg 1982). The New Jersey ACID Test did not correlate well with the FTP as it was constructed in order to correlate with the previous type approval 7-mode test. However, the cost of the implementation of such tests for generalised I/M programmes was prohibitive, and test repeatability was not satisfactory. For these reasons the idea of adopting one or more of these tests for official I/M schemes was abandoned. The fact that cars equipped with three-way catalysts were just starting to enter the U.S. market in the late 70s and the performance of these tests with such cars had not been examined yet must have played a role in that decision too.

4.2. CDH 226

Test sequence

The test sequence of CDH 226 is shown in Figure 11 (Ragazzi et al. 1985). Its average driving characteristics are:

Total idle time [s]	% idle time of total test time	Average speed [km/h]	Avg. running speed [km/h]	Maximum speed [km/h]
45	19.9	36	45	82

Type of emission measurements

Mass emission measurements (CO, HC and NOx) are performed with a CVS.

Pre-conditioning

Cars are driven on the roller bench at 50 mph for 3 minutes.

Test duration

The driving cycle lasts 226 seconds, and total test duration is about 10 minutes.

Necessary test equipment

A dynamometer with type approval inertia weight and load simulation and a CVS are required.

Overall assessment

The CDH 226 test was developed by the Colorado Department of Health (CDH) and aimed at achieving high correlation with the FTP, especially for three-way catalyst cars. Numerous studies have demonstrated correlation coefficients of 0.79 to 0.96 for all three pollutants - either with the whole cycle or with its hot start portion (Ragazzi et al. 1985, Austin et al. 1989, Klausmeier 1994). Excess emission identification rates were about 90% for all three pollutants at 5% errors of commission (Ragazzi et al. 1985). However, the U.S. EPA wished to develop a more transient alternative to the CDH 226 in order to better simulate transient driving modes of the FTP (Pidgeon et al. 1991) and therefore came up with the IM 240.

4.3. IM240

Test sequence

The driving schedule of the IM 240 is illustrated in Figure 12 (Pidgeon et al. 1991). Its average driving characteristics are:

Total idle time [s]	% idle time of total test time	Average speed [km/h]	Avg. running speed [km/h]	Maximum speed [km/h]
9	3.8	48	49	91

Type of emission measurements

Emissions in the diluted exhaust gas are normally derived on a mass basis with a CVS, but in some preliminary investigations second-by-second raw exhaust concentrations were also measured in order to examine the possibility of correlating raw exhaust concentrations with mass emissions.

Pre-conditioning

At the I/M programme administrator’s discretion vehicles may be pre-conditioned using any of the following methods (CONCAWE 1994):

- no-load operation at approx. 2500 rpm for up to 4 minutes
- steady-state operation at 30 mph on the dynamometer for up to 4 minutes

– driving of a preliminary transient cycle on the dynamometer.

Test duration

The test takes in total about 10 minutes to perform.

Necessary test equipment

A multiple-curve dynamometer with flywheels, a CVS and laboratory-quality analysers are necessary, although in a generalised I/M programme simpler dynamometer settings can be considered (e.g. with two inertia masses only: 2500 lbs and 3500 lbs).

Overall assessment

The IM 240 showed correlation coefficients with the FTP hot start portion of 0.89 to 0.97 for all three pollutants; another test sample had coefficients of 0.54 to 0.82 with the full FTP. This was better than both CDH 226 and BAR 120 (see 4.4 - Klausmeier et al. 1994). Compared to a four-mode steady-state test with two ASM phases, the IM 240 demonstrated better ability to:

- correctly identify vehicles needing repair;
- distinguish sufficiently repaired vehicles from insufficiently repaired ones;
- distinguish between functioning and malfunctioning evaporative canister purge systems (Pidgeon et al. 1993).

The EPA proposes that states or regions which will have to implement so called “Enhanced I/M Schemes” in order to comply with the 1990 Clean Air Act Amendments enforce the IM240 at least for the cars of the newest model years. Studies evaluating alternative loaded test procedures are under way as well (Walsh 1994, Klausmeier 1994).

A transient loaded test for *diesel* cars has not been considered so far as there are almost no diesel cars in the United States.

4.4. BAR 120

Test sequence

The BAR 120 follows a simplified transient driving schedule (Klausmeier 1994); it was not possible to find more information in the available literature.

Type of emission measurements

Emissions in the diluted exhaust gas are derived on a mass basis with a CVS.

Pre-conditioning

No indication is given in the available literature.

Test duration

The cycle lasts 120 seconds; therefore the whole test procedure should take less than 10 minutes.

<u>Necessary test equipment</u>

A multiple-curve dynamometer with flywheels, a CVS and laboratory-quality analysers are necessary, although simpler dynamometers may be used if the test is to be implemented in I/M programmes.

<u>Overall assessment</u>

An evaluation of test results on various short tests has indicated that the BAR 120, which is quicker and easier to conduct, performs almost equally well with the IM 240; it was therefore proposed as a promising alternative to the latter (Klausmeier 1994).

5. Short tests for the control of evaporative emissions: EPA's purge/pressure test and ESP's helium test

Aim of a short test for the control of evaporative emissions of gasoline cars equipped with a carbon canister is to make sure that the canister retains fuel vapour coming from the fuel tank and purges it to the engine so that it is burnt together with the injected fuel. What follows is an excerpt from a study conducted by Radian Corp. that briefly describes and reviews two relevant short test procedures developed in the U.S. (Klausmeier 1994):

"EPA's proposed evaporative system involves disconnecting two vapor lines that are located under the hood of the vehicle. The line from the fuel tank is disconnected and nitrogen gas is injected to assure that the system can hold pressure and therefore retain evaporative emissions. The line from the canister to the engine is disconnected and a flowmeter is installed to determine if the canister is being purged of evaporative emissions. There are obvious problems with these approaches. Disconnecting lines in a high volume inspection environment has potential to introduce problems in the vehicles. Furthermore, on many of the vehicles, lines cannot be easily disconnected. Radian conducted a study in-house where we performed purge and pressure tests on 151 employee vehicles. We found that 15% of the vehicles could not be tested because the canisters were inaccessible. Many of the vehicles that we considered testable were difficult to inspect. New Jersey has been conducting a pilot Enhanced I/M program which includes performing EPA's purge pressure test. New Jersey estimates that 35% of their vehicles cannot be tested.

Environmental Systems Products (ESP) has developed an alternative test whereby helium is injected in the fuel tank to confirm that the evaporative system is collecting vapors and routing them to the engine. The helium test avoids the problems associated with disconnecting the fuel tank and canister purge vapor lines. Including a functional gas cap check along with the helium test would help assure that many high emitting vehicles are identified."

6. Summary of existing Inspection and Maintenance programmes worldwide

Tables 1 and 2 summarise the existing Inspection and Maintenance programmes for gasoline and diesel cars around the world in terms of the implemented test modes, the cars subject to inspection and the emission limit values in the corresponding test modes.

7. Conclusions and recommendations

It is evident that a great variety of test procedures has been conceived, developed and tested over the last twenty years. Based on the experience gained so far, one can identify among the tests those ones that are the most promising in terms of both effectiveness and practicability. A thorough evaluation of all the above tests, however, is not straightforward. Almost all sophisticated procedures (i.e. loaded tests) were considered in the United States and were designed in such a way that they would correlate well with the American certification test (FTP 75); as correlation between the FTP and the new European certification cycle (NEDC) is fair, reasonable correlation between a U.S. short test and the NEDC would be very difficult to achieve. Nevertheless, American tests can provide important indications as to how promising specific test types could be. Table 3 is an overall assessment matrix of the tests mentioned in Sections 2 to 4. Cost estimates are also included where they were available or they could be simply derived.

As far as loaded mode testing is concerned, some additional conclusions of an American study concentrating on the ASM tests are worth noting (Austin et al. 1989):

– “In addition to confirming the ability of loaded mode testing to identify excess NOx emissions... [it] ...would also contribute to the identification of excess hydrocarbon emissions” which may be equally or even more important for photochemical smog formation.

– “Since the major benefit of loaded mode testing is the identification of excess NOx emissions, there is less benefit associated with using loaded mode testing on vehicles that were not equipped with NOx emission control systems...The greatest benefits of loaded mode testing are projected for the 1981 and later models [in the U.S. market] that are subject to the most stringent control level.”

– “If a loaded mode test program is implemented, it is important to maintain an underhood inspection...(For example, one of the test vehicles passed the loaded mode test with a disconnected EGR system.) More importantly, loaded mode testing cannot detect problems with positive crankcase ventilation (PCV) and evaporative emissions control systems. Visual inspection of these systems is critical to maximizing the emission reductions from the Smog Check program.”

It is therefore important to investigate the performance of alternative loaded tests that are adjusted to the European conditions. Special attention should be given to transient engine operating modes because extensive field testing in the Netherlands and Germany has shown that “the long-term stability of a number of emission-relevant ignition, mixture and Lambda control loop components proved to be poorer than anticipated” (Becker et al. 1993). As already mentioned, the condition of these components is quite decisive for a car’s emissions, and defects such as a degraded oxygen sensor or a disabled λ control system may be impossible to detect at idle or even steady-state loaded tests.

In light of the above, the following tests have to be further examined in order to evaluate the most promising procedures for Inspection and Maintenance purposes:

- the combined idle / fast idle / lambda test (including at least variants 1 and 2 of the λ test) for gasoline cars;
- the free acceleration test for diesel cars;
- one or more steady-state loaded tests for gasoline and diesel cars, such as the ones developed by VdTÜV;
- one or more new transient loaded tests for gasoline and diesel cars that will be selected for their acceptable correlation with the NEDC.

An additional consideration will be the emissions on non-legislated driving cycles which reflect real-world driving. An extensive database with on-road recordings of driving behaviour in France, Germany and the United Kingdom has been formed in the framework of the DRIVE *modem* project. On the basis of these data a set of “actual driving” cycles has been proposed (André et al. 1991), out of which one will be used in the test sequence. Recently a short “actual driving” cycle was also developed (André 1994), which will also be examined as an alternative short test procedure.

Evidently all test cars will have to be measured on the NEDC as well in order to investigate the correlation of each short test with the legislated cycle. In this way the NEDC will also serve as a pre-conditioning cycle. Moreover, the test cars have to be measured both in their “as received” condition and after they have undergone maintenance in order to realise the average condition and emission behaviour of in-use cars and quantify the potential benefit (expressed as emission and fuel consumption reductions) from the adoption of each one of these test procedures for an I/M programme.

For all tests where a dynamometer and/or a CVS system are necessary, CVS configuration and dynamometer weight classifications will be determined upon completion of the evaluations conducted by TÜV Rheinland under Task 1.2 of the project.

The above recommendations are summarised in the Appendix, which contains a schematic diagramme of the proposed test sequence. It has to be noted that this proposal contains the *minimum* tests and measurements to be performed on each car; additional tests (or measurements of additional parameters) may be conducted by each Institute. Such additional measurements may be of particular interest for deriving statistical correlations between short tests and the certification test. Moreover, this sequence mainly concerns gasoline cars (both non-catalyst and catalyst ones); a separate (though similar) test schedule has to be followed for diesel cars, too.

This report has dealt exclusively with the technical aspects of an Inspection and Maintenance scheme. However, it is important to keep in mind that even the best short test can prove to be ineffective if the pertinent social, administrative and financial parameters are overlooked. An illustrative example of what (and how much) can go wrong in the real-world application of an I/M programme is given by Lawson (1993):

"In spite of annual Smog Check program costs of about $450 million, random roadside survey data collected over several years in California show little effect of the program on the motor vehicle fleet's in-use operating conditions and emissions characteristics. These real-world findings are at odds with emission reductions reported by the California I/M Review Committee. ... It appears that motorists do not perceive the Smog Check program as beneficial to air quality, and that they are avoiding the costs associated with vehicle repairs. This implies that design of I/M programs should confront the obvious human behavior problems associated with failing vehicles and not just the technological problems. All current I/M programs in the U.S. and Canada consider only technological issues."

8. References

1. André M., Joumard R., Hickman A.J. and Hassel D., Modelling of Emissions and Consumption in Urban Areas: Realistic Driving Cycles for Passenger Cars. INRETS Report LEN 9105, 1991
2. André M., The Inspection of In-Use Cars in Order to Attain Minimum Emissions of Pollutants and Optimum Energy Efficiency: Short Driving Cycle Based on the European Real Driving. INRETS Report LEN 9436, 1994.
3. Austin T.C. and Sherwood L., Development of Improved Loaded-Mode Test Procedures for Inspection and Maintenance Programs. SAE Paper 891120, 1989.
4. Barlow T.J., Inspection and Maintenance Programmes for Exhaust Emissions from Light Duty Petrol Engined Vehicles. Transport Research Laboratory Project Report 20, ISSN 0968-4093, 1993.
5. Becker K., Baarbé H.L., Rijkeboer R.C. and Richter A., Emission Behaviour of Low-Pollution Petrol-Engine Motor-Vehicles in Use. SAE Paper 930776, 1993.
6. Berg W., Aufwand und Probleme für Gesetzgeber und Automobilindustrie bei der Kontrolle der Schadstoffemissionen von Personenkraftwagen mit Otto- und Diesel-Motoren. Dissertation, TU Braunschweig, 1982.
7. Centre de Recherche en Machine Thérmiques, “AUTONAT”: A Short Test System for Vehicle Power and Emissions Control, 1994a.
8. Centre de Recherche en Machine Thérmiques, Private communication with Dr. Robert Joumard of INRETS, December 1994b.
9. Collin L.T., INertiaCOLLection - A Simplified Dynamic Engine Test Method. SAE Paper 850132, 1985.
10. CONCAWE, Motor Vehicle Emission Regulations and Fuel Specifications - 1994 Update. CONCAWE Report 4/94, Brussels, 1994.
11. DEKRA/RWTÜV, Leitfaden zur Begutachtung der Bedienerführung von AU Meßgeräten. Verabschiedete Fassung vom 6. AU-Arbeitskreis am 23.06.1994.
12. Klausmeier R., Analysis of I/M Test Alternatives. Paper presented at the International Conference ‘Ozone Control Strategies for the Next Decade (Century)’, San Francisco, April 1994.
13. Laurikko J., In-Use Vehicle Emissions Control in Finland: Introduction and Practical Experience. SAE Paper 940930, 1994.
14. Lawson D.R., “Passing the Test” - Human Behavior and California’s Smog Check Program. *J. Air Waste Manage. Assoc.* **43**:1567 (1993).
15. National Institute on Environmental Research of Korea (NIER), Motor Vehicle Emission Control in Korea. Report of the Motor Vehicle Emission Research Laboratory, 1993.
16. Pattas K.N. and Hassiotis P.G., Short Test for Gasoline Powered Vehicle Emission Control. SAE Paper 871989, 1987.

17. Pidgeon W.M. and Dobbie N., The IM240 Transient I/M Dynamometer Driving Schedule and The Composite I/M Test Procedure. U.S. EPA Technical Report EPA-AA-TSS-91-1, 1991.

18. Pidgeon W.M., Sampson D.J., Burbage IV P.H., Landman L.C., Clemmens W.B., Herzog E., Brzezinski D.J. and Sosnowski D., Evaluation of a Four-Mode Steady-State Test With Acceleration Simulation Modes As An Alternative Inspection and Maintenance Test for Enhanced I/M Programs. U.S. EPA Technical Report EPA-AA-AQAB-93-01, 1993.

19. Pucher E., Überprüfung von im Verkehr befindlichen Katalysatorfahrzeugen auf Basis einer Luftverhältnisbestimmung aus dem Motorabgas. Fortschr.-Ber. VDI Reihe 12 Nr. 121, Düsseldorf: VDI-Verlag, 1989.

20. Pucher E. and Lenz H.P., First Results in Testing In-Use Catalyst Cars Using Air-Fuel Ratio Measurement from the Exhaust Gas. XXIII FISITA Congress, Paper ATA 905114, 1990.

21. Ragazzi R.A., J.T. Stokes and G.L. Gallagher, An Evaluation of A Colorado Short Vehicle Emission Test (CDH-226) in Predicting Federal Test Procedure (FTP) Failures. SAE Paper 852111, 1985.

22. Richter A., Michelmann G. and Albus C., Weiterentwicklung der Abgassonder-untersuchung. Berichte der Bundesanstalt für Straßenwesen, Unterreihe ‘Fahrzeugtechnik’, Heft F4, 1993.

23. Smuda B., Evaluation of Applicability of the INCOLL Procedure as an I/M Strategy. U.S. EPA Technical Report EPA-AA-IMS/81-5, 1980.

24. Tierney E.J., E.W. Herzog and L.M. Snapp, Recommended I/M Short Test Procedures for the 1990's: Six Alternatives. U.S. EPA Technical Report EPA-AA-TSS-I/M-90-, 1991.

25. U.S. EPA, Supplement A to Compilation of Air Pollutant Emission Factors (AP-42), Volume II: Mobile Sources. U.S. Environmental Protection Agency, 1991.

26. Verkehrsblatt (Amtsblatt des Bundesministers für Verkehr der Bundesrepublik Deutschland), Verordnung Nr. 48 zur Änderung straßenverkehrsrechtlicher Vorschriften und der Eichordnung, Heft 5, pp. 187-199, 1993.

27. Voss H.-J, Neppel H.-P., Heckötter N., Hassel D. and Richter A., Praxiserprobung eines Prüfverfahrens zur Periodischen Überwachung der Abgasemission von Schadstoffarmen Otto-PKW und Dieselfahrzeugen - Textband. Vereinigung der Technischen Überwachungsvereine e.V., Bonn, 1987a.

28. Voss H.-J, Hassel D., Neppel H.-P., Richter A., Heckötter N. and Friedrich A., Periodic Inspection of Exhaust Emissions from Low Pollutive Otto Engine Vehicles and Diesel Engine Vehicles. SAE Paper 871084, 1987b.

29. Walsh M.P., Car Lines, Issue 94-6, pp. 6-8, November 1994.

9. Tables and Figures

Table 1: Summary of existing Inspection and Maintenance programmes for gasoline cars*

Country	Test Mode	Vehicle	Limits
AUSTRALIA	IDLE	All Vehicles:	CO 4.5%
AUSTRIA	IDLE FAST IDLE	No Cat: 3-Way Catalysts:	CO 3.5% CO 0.3% λ 1 ± 0.03 + lambda circuit check
BELGIUM	IDLE	All Vehicles:	CO 4.5%
BRITAIN	IDLE	From August 1983: From August 1975: Pre August 1975:	CO 4.5% HC 1200 ppm CO 6.0% HC 1200 ppm Exempt
CANADA (British Colombia)	IDLE + LOADED	All Vehicles:	To be decided
CZECHOSLOVAKIA	IDLE	From 1986: From 1973: Pre 1973:	CO 3.5% HC 800 ppm CO 4.5% HC 1200 ppm CO 6.0% HC 2000 ppm
DENMARK	 IDLE	From Oct 1990: From April 1984: From Jan 1971: Pre Jan 1971:	CO 0.5% CO 4.5% CO 5.5% CO 7.0%
FINLAND	IDLE + FAST IDLE IDLE	Low Emission Vehicles: From Jan 1986: From Jan 1978: Pre Jan 1978:	CO 0.3% HC 100 ppm λ 1 ± 0.03 CO 3.5% HC 600 ppm CO 4.5% HC 1000 ppm Exempt
GERMANY**	IDLE FAST IDLE	No Cat: 3-Way Cat: 3-Way Cat:	CO 3.5% CO 0.5% CO 0.3% λ MS ± 2% *or* 1 ± 0.03 + lambda circuit check

Country	Test Mode	Vehicle	Limits
GREECE	IDLE	Pre 1.10.86:	CO 4.5%
			HC 800 ppm
		From 1.10.86:	CO 3.5%
			HC 500 ppm
		3-Way Cat:	CO 0.5%
			HC 120 ppm
		Other Cat:	CO 1.2%
			HC 220 ppm
	FAST IDLE	Pre 1.10.86:	CO 4%
			HC 700 ppm
		From 1.10.86:	CO 3%
			HC 400 ppm
		3-Way Cat:	CO 0.3%
			HC 100 ppm
			λ 1 ± 0.03
		Other Cat:	CO 1%
			HC 200 ppm
HUNGARY	IDLE	No Cats:	CO 2.5% to 4.5%
	IDLE + FAST IDLE	4-Strokes only:	HC 1000 ppm
		3-Way Cat:	CO 0.4%
			HC 250 ppm
	IDLE + FAST IDLE	Other Cat, 4-Stroke:	CO 1.0%
			HC 400 ppm
		Other Cat, 2-Stroke:	CO 2.5%
			HC 2000 ppm
ITALY	IDLE	No Cat, pre 1986:	CO 4.5%
		No Cat, after 1986:	CO 3.5%
		Cat:	CO MS
JAPAN	IDLE	All:	CO 4.5%
		4-Stroke:	HC 1200 ppm
		2-Stroke:	HC 7800 ppm
		Rotary:	HC 3300 ppm
NETHERLANDS	IDLE	Cat, From Jan 1986:	CO 0.5%
		Cat, Pre Jan 1986:	CO 4.5%
		Pre Jan 1980:	CO 4.5%
		Pre Jan 1974:	Exempt
		LPG:	CO 4.5%
NORWAY	IDLE	Group 1 Vehicles - from July 1991:	CO 0.5%
			HC 100 ppm
		Group 2 Vehicles - from Oct 1991:	CO 1.0%
			HC 200 ppm
		From Oct 1979:	CO 3.5%
		Pre Oct 1979:	CO 4.5%

Country	Test Mode	Vehicle	Limits
SOUTH KOREA***	IDLE	1979 - July 1984: July 1984 - July 1987: From July 1987: Old model cars: New model gasoline cars: New model LPG cars:	CO 4.5% CO 4.5% HC 1200 ppm CO 4.5% HC 1200 ppm CO 1.2% HC 220 ppm CO 1.2% HC 400 ppm
SWEDEN	IDLE	Group 1 Vehicles - from 1989: Group 2 Vehicles - from 1989: From 1985: From 1976: Pre 1976:	CO 0.5% HC 100 ppm CO 1.0% HC 200 ppm CO 3.5% CO 4.5% CO 5.5%
SWITZERLAND	IDLE + FAST IDLE IDLE	3-Way Catalyst: Group 2 Vehicles - from Oct 1988: Group 1 Vehicles - from Oct 1987: From Oct 1986: From Oct 1982: From Oct 1980: From Jan 1974: From Jan 1971: All above:	CO 0.1% HC 50 ppm CO 1.0% HC 200 ppm CO 0.5% HC 100 ppm CO 1.0% HC 200 ppm CO 2.5% HC 300 ppm CO 3.0% HC 400 ppm CO 3.5% HC 500 ppm CO 4.5% HC 800 ppm CO_2 12% (min)
USA Current	IDLE OR IDLE + FAST IDLE Arizona: LOADED + IDLE	Generally - From 1981: From 1981:	CO 1.2% HC 220 ppm CO 1.2% HC 220 ppm CO_2 4% (min)

Country	Test Mode	Vehicle	Limits	
USA Proposed for Enhanced I/M Programmes	TRANSIENT (IM240)	Pre 1984:	CO HC NO_X	25 - 30 g/mile 1.2 - 2.0 g/mile 3.0 - 3.5 g/mile
		1984 - 1995:	CO HC NO_X	15 g/mile 0.8 g/mile 2.0 g/mile
	STEADY-STATE LOADED	1968 - 1986:	CO HC CO_2	1.2% 220 ppm 6% (min)
European Union (Directive 92/55/EEC)	IDLE	Uncontrolled:	CO	TA + 0.5% *or*
		From Oct 1986:	CO	3.5%
		Pre Oct 1986:	CO	4.5%
		Pre Jan 1970:	Exempt	
	IDLE		CO	TA *or*
		Controlled:	CO	0.5%
	FAST IDLE		CO λ	0.3% 1 ± 0.03

*Most of the contents of this table are a reproduction of Table 3 of TRL report PR 20 (Barlow 1993) with additional information from CONCAWE Report 4/94 (CONCAWE 1994).

**See Richter et al. 1993.

***See NIER 1993.

TA: Type approval limits.

MS: Manufacturer's specification

Group 1 Vehicles: Vehicles with a gross weight of less than 3500 kg and a loading capacity of less than about 700 kg.

Group 2 Vehicles: Vehicles with a gross weight of less than 3500 kg and a loading capacity of greater than about 700 kg.

Table 2: Summary of existing Inspection and Maintenance programmes for diesel cars (see CONCAWE 1994)

Country	**Test Mode**	**Limits**
AUSTRIA	Free acceleration	4.5 Bacharach
GERMANY	Free acceleration	Opacity: TA
GREECE	Free acceleration	5 Bacharach
ITALY	Free acceleration	70% opacity
SOUTH KOREA (see NIER 1993)	Free acceleration	50% opacity (1979-1990 cars) 40% opacity (post-1990 cars)
SWITZERLAND	Free acceleration	Opacity: TA
Directive 92/55/EEC	Free acceleration	Opacity: TA + 0.5 m^{-1} *or* 2.5 m^{-1} (naturally aspirated engines) 3.0 m^{-1} (turbocharged engines)

TA: Type approval limits.

Table 3: Assessment Matrix of Short Tests

Test Mode	*Test Type*	*Correlation with certification cycles*	*Identification Rates*	*Equipment*	*Duration*	*Approx. Cost*
Idle	No-load	0.21 for CO, 0.13 for HC, 0.16 for NOx (with FTP)		NDIR	1 - 10 min	7000 ECU
Fast Idle	No-load	0.75 for CO, 0.49 for HC, 0.56 for NOx (with FTP)		NDIR	1 - 10 min	7000 ECU
Fast Idle + lambda	No-load		10/67 of cars emitting more than the limit, 5/7 of cars emitting over 3 times the limit, 5% errors of commission	NDIR + equipment for tampering with λ (+ PC + A/D card)	1 - 15 min	10 000 ECU
Free acceleration	No-load			Bacharach or Opacimeter	1 min	Bacharach: 1000 ECU
INCOLL/AUTONAT	No-load	INCOLL: 0.66 for CO, 0.76 for HC, 0.62 for NOx (with FTP)		NDIR (+ NOx), CVS or modal analysis + excitation equipment	30 min	AUTONAT: 25000 ECU + CVS (+ 6500 ECU for opacimeter)

Test Mode	*Test Type*	*Correlation with certification cycles*	*Identification Rates*	*Equipment*	*Duration*	*Approx. Cost*
U.S. Federal 3-Mode	Steady-state loaded	0.64-0.69 for CO, 0.83-0.85 for HC, 0.65-0.68 for NOx (with FTP)		NDIR + NOx analysers, dynamometer w/o flywheels	10 min	
Clayton Key-Mode	Steady-state loaded	0.67-0.69 for CO, 0.80-0.85 for HC, 0.65-0.74 for NOx (with FTP)		NDIR + NOx analysers, dynamometer w/o flywheels	10 min	
CalVIP	Steady-state loaded	0.60 for NOx (with FTP)		NDIR + NOx analysers, dynamometer w/o flywheels	10 min	
ASM 5015	Steady-state loaded	0.60 for CO, 0.47 for HC, 0.60-0.83 for NOx (with FTP), 0.52 for CO, 0.49 for HC, 0.65 for NOx (with hot start FTP)	80% of excess emissions for all three pollutants at 10-15% errors of commission	NDIR + NOx analysers, multiple-curve dynamometer w/o flywheels	10 min	
ASM 2525	Steady-state loaded	0.77 for CO, 0.70 for HC, 0.69-0.77 for NOx (with FTP), 0.22 for CO, 0.48 for HC, 0.58 for NOx (with hot start FTP)	80% of excess emissions for all three pollutants at approx. 10% errors of commission	NDIR + NOx analysers, multiple-curve dynamometer w/o flywheels	10 min	

Test Mode	*Test Type*	*Correlation with certification cycles*	*Identification Rates*	*Equipment*	*Duration*	*Approx. Cost*
TÜV 50 km/h, 7 kW	Steady-state loaded			NDIR + NOx analysers, dynamometer w/o flywheels	10 min	
TÜV full load diesel	Steady-state loaded			Bosch smoke meter, dynamometer w/o flywheels	10 - 15 min	
Modal Exhaust Emission Test	Transient loaded			Laboratory analysers + CVS, multiple-curve dunamometer	1 h	
U.S. Federal Short Cycle	Transient loaded	0.93 for CO, 0.95 for HC, 0.92 for NOx (with FTP)		Laboratory analysers + CVS, multiple-curve dunamometer	20 min	
New Jersey ACID	Transient loaded			Laboratory analysers + CVS, single-curve dynamometer with one inertia weight, opacimeter	20 min	
New Jersey / New York Composite Cycle	Transient loaded	0.86 for CO, 0.91 for HC, 0.82 for NOx (with FTP)		Laboratory analysers + CVS, single-curve dynamometer with one inertia weight	20 min	

Test Mode	*Test Type*	*Correlation with certification cycles*	*Identification Rates*	*Equipment*	*Duration*	*Approx. Cost*
New York City Cycle	Transient loaded	0.86 for CO, 0.90 for HC, 0.90 for NOx (with FTP)		Laboratory analysers + CVS, multiple-curve dunamometer	30 min	
CDH 226	Transient loaded	0.92 for CO, 0.89 for HC, 0.88 for NOx (with full FTP); 0.79 for CO and HC, 0.96 for NOx (with hot start FTP)	89% of excess emissions for CO and NOx, 95% for HC at 5% errors of commission and 15% errors of omission	Laboratory analysers + CVS, multiple-curve dunamometer	10 min	
IM 240	Transient loaded	0.54 for CO, 0.82 for HC, 0.70 for NOx (with full FTP); 0.92 for CO, 0.89 for HC, 0.97 for NOx (with hot start FTP)	80% of excess emissions for all three pollutants at approx. 10% errors of commission	Laboratory analysers + CVS, multiple-curve dunamometer	10 min	
BAR 120	Transient loaded	0.80 for CO, 0.64 for HC, 0.92 for NOx (with hot start FTP)	Similar with IM 240	Laboratory analysers + CVS, multiple-curve dunamometer	10 min	

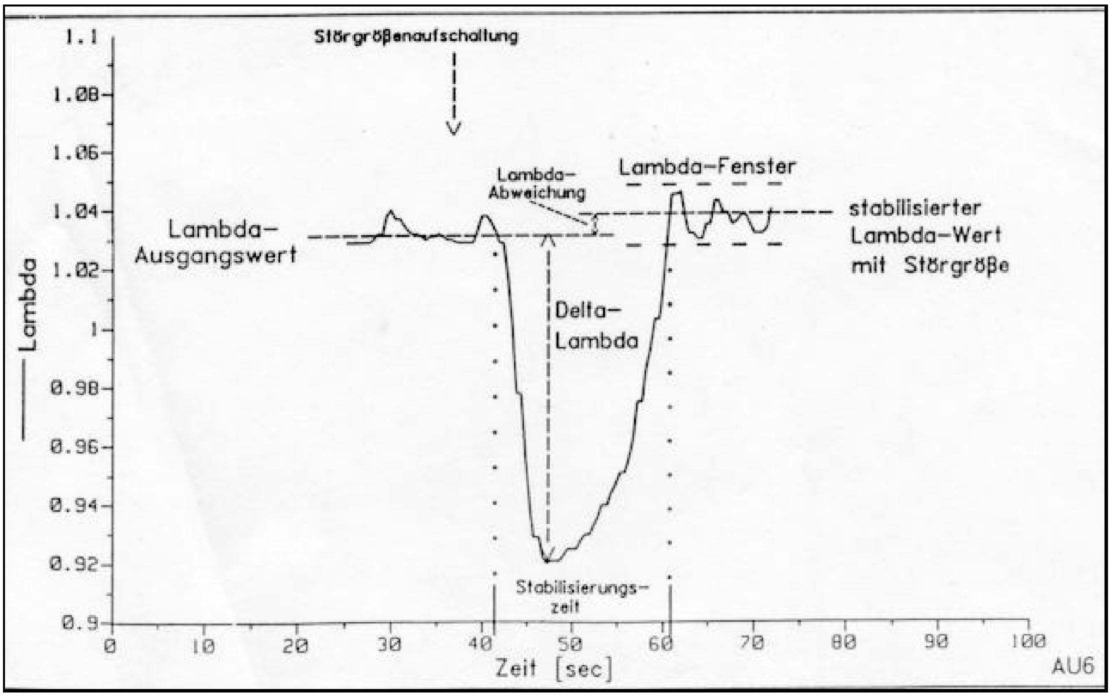
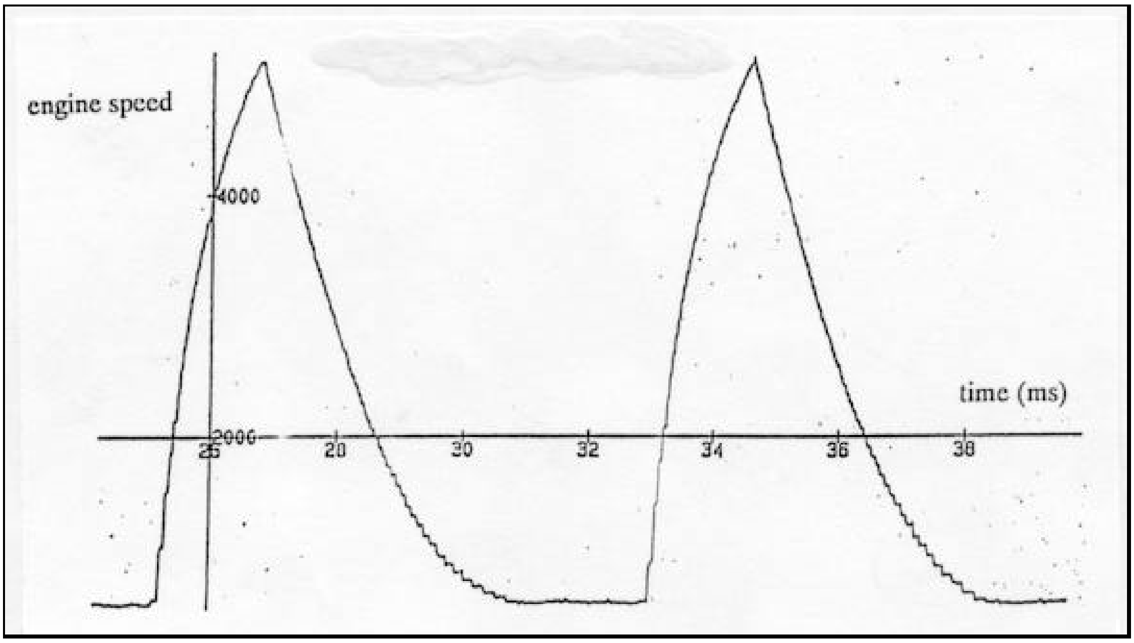
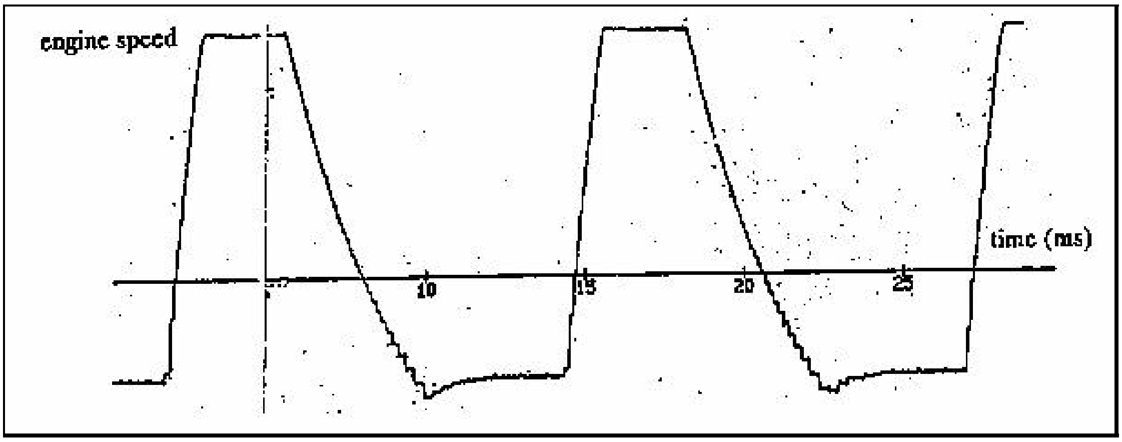


Figure 1: Example of artificial air/fuel ratio modification (Richter et al. 1993). When propane gas is added to the engine at t = 36 s ("Störgrößenaufschaltung"), the engine switches to rich operation until the lambda control system restores a stabilised λ value ("stabilisierter Lambda-Wert mit Störgröße") that slightly deviates from the initial one ("Lambda-Ausgangswert"); stabilisation time in this case is about 20 s.



<u>Figure 2</u>: The AUTONAT sequence for gasoline cars.



<u>Figure 3</u>: The AUTONAT sequence for diesel cars.

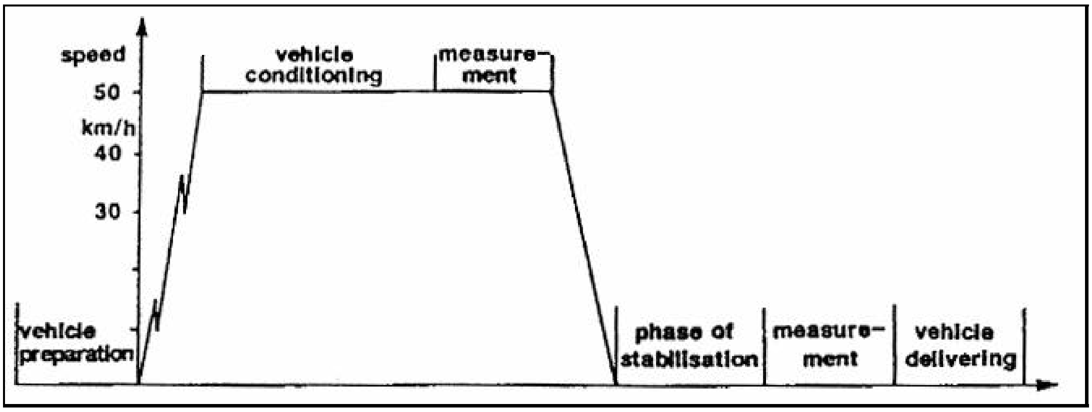


Figure 4: VdTÜV's short test for gasoline cars

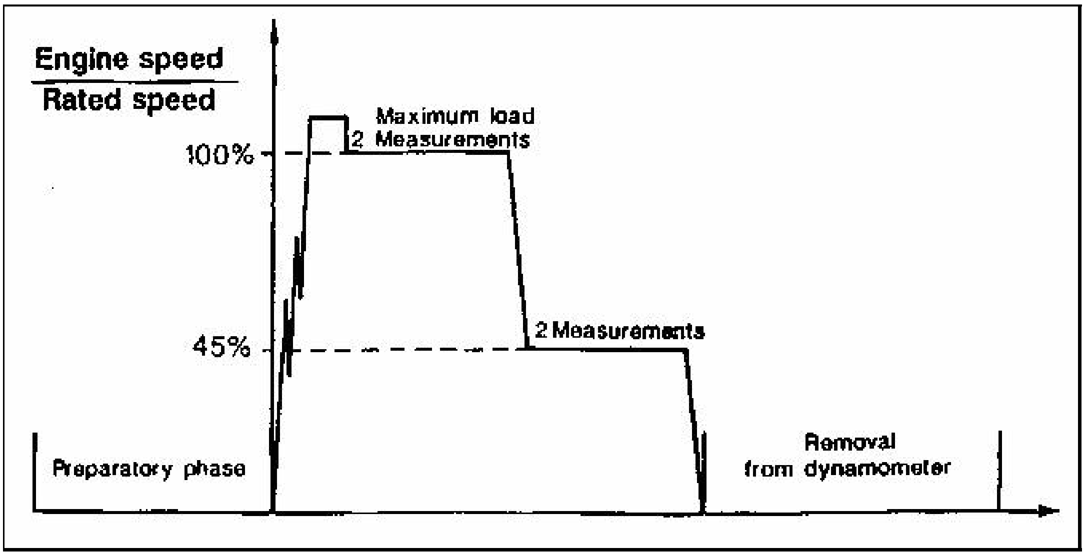


Figure 5: VdTÜV's short test for diesel cars

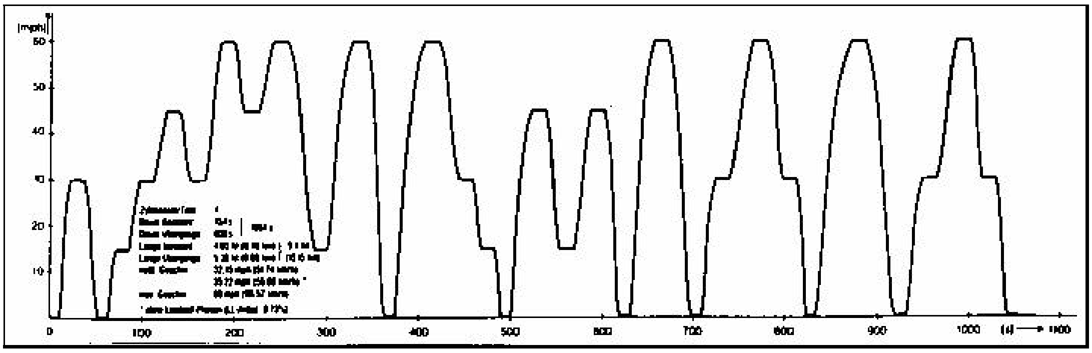


Figure 6: Second modal test of the Modal Exhaust Emission Test Procedure

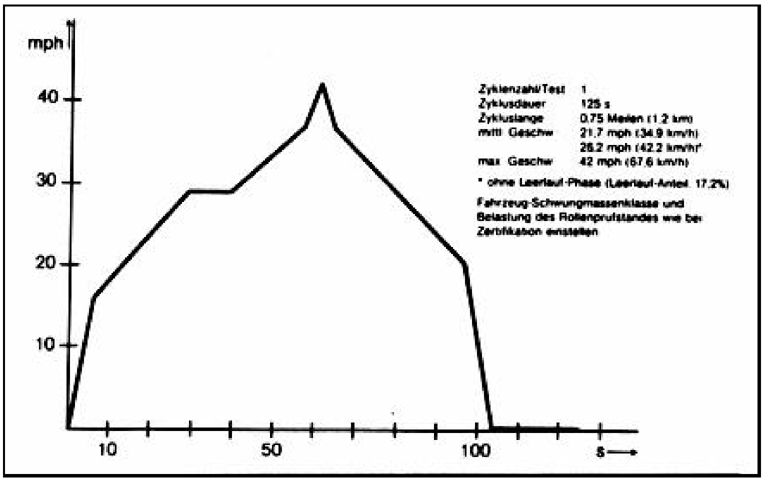


Figure 7: The U.S. Federal Short Cycle

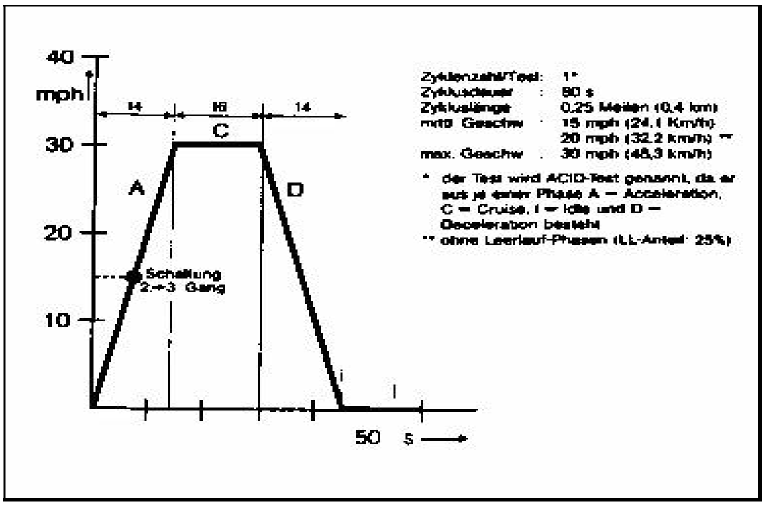


Figure 8: The New Jersey ACID Test

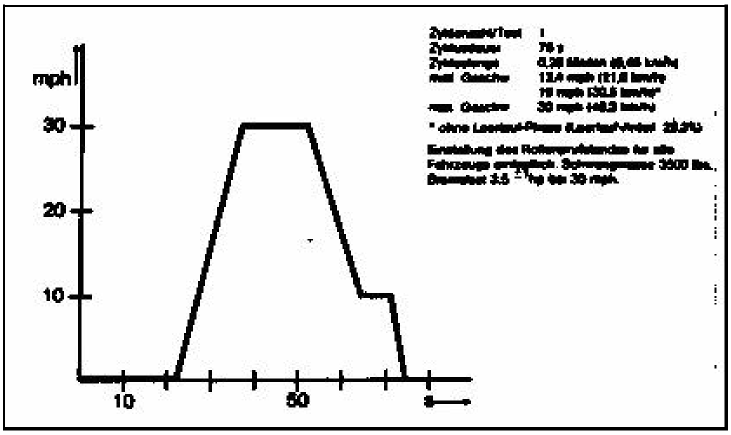


Figure 9: The New Jersey / New York Composite Cycle

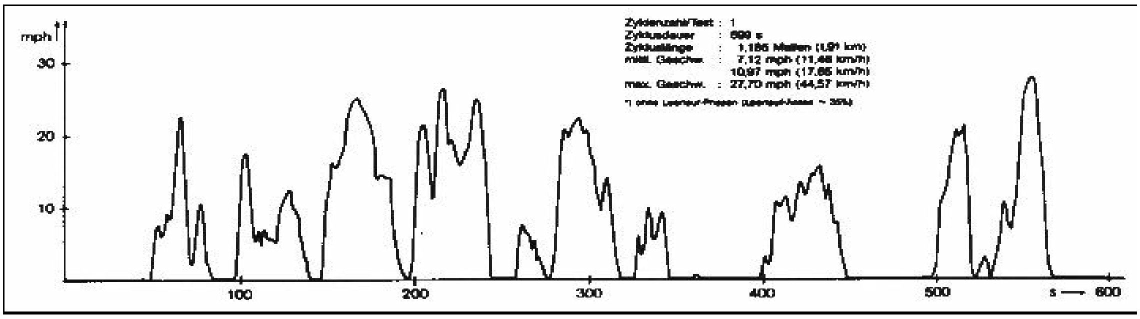


Figure 10: The New York City Cycle

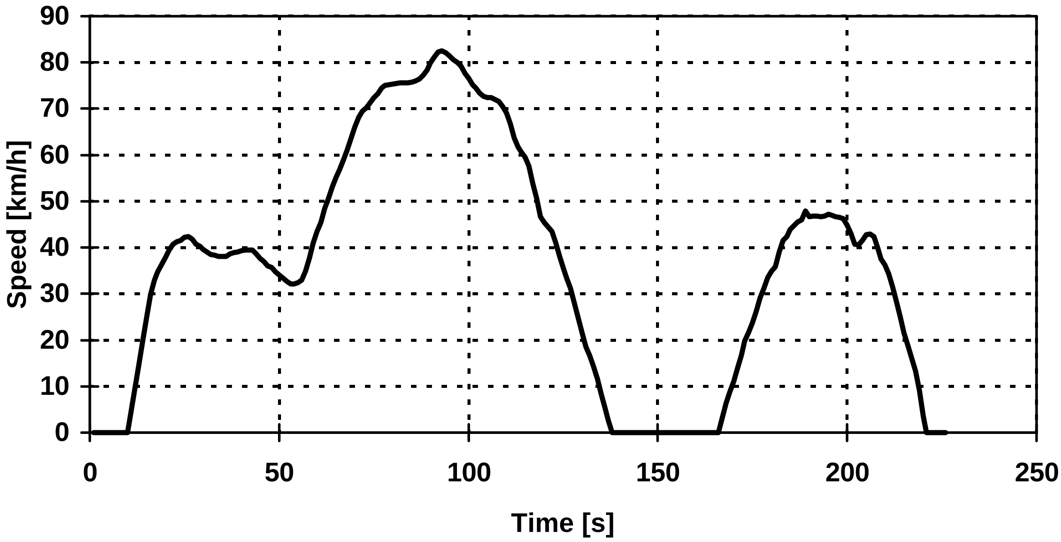


Figure 11: The CDH 226 Test

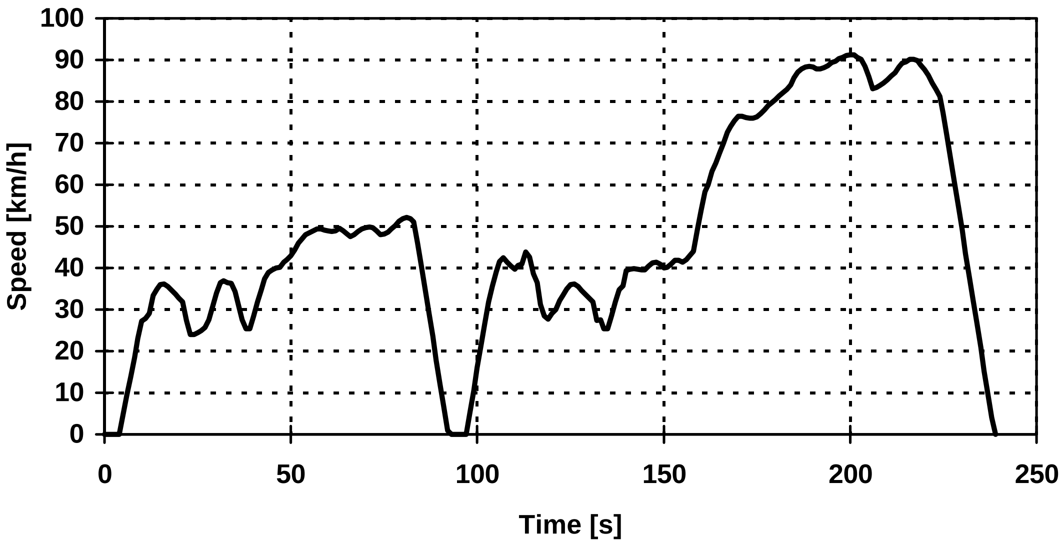


Figure 12: The IM 240 Test