

# Appendix 2

## Review of test procedures

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### Contents

<b>1.</b>	<b>Categorisation</b>	<b>2</b>
<b>2.</b>	<b>Brief description of tests</b>	<b>2</b>
2.1	UNLOADED TESTS	2
2.1.1	Unloaded steady states	2
2.1.2	Unloaded transients	3
2.2	LOADED TESTS	5
2.2.1	Loaded steady states	5
2.2.2	Loaded transients	7
2.2.3	Road cycles	11
<b>3.</b>	<b>Equipment requirements</b>	<b>12</b>
3.1	UNLOADED TESTS – BOTH STEADY STATE AND TRANSIENT	12
3.2	LOADED TESTS	12
3.2.1	Review of fundamental laws of motion	12
3.2.2	Review of types of dynamometer	13
3.3	THE COST OF DYNAMOMETERS	15
<b>4.</b>	<b>Factors which influence the prioritisation of the test procedure options</b>	<b>16</b>
4.1	GENERIC	16
4.2	COMMENTS FROM OTHER TEST PROGRAMMES	17

# 1. Categorisation

The type approval regulations for spark ignition (SI) vehicles are for **vehicles** (EU Directive 70/220/EC and its amending directives) with the exception of vehicles powered by heavy-duty gas fuelled engines for which the emissions standards are those for diesel fuelled engines (EU Directive 88/77/EEC and its amending directives). Consequently for this project on in-service testing of SI engine vehicles the test procedures that will be covered are only those for vehicles. Information on engine cycles can be found in Appendix 3 of the Phase 2 report on “Low emission diesels”<sup>1</sup>.

The time/vehicle or engine speed/external load profile of test procedures can be used to categorise them into:

- unloaded or loaded tests – dependent on whether the external load is zero or greater than zero and
- steady-state or transient tests dependent on whether the vehicle or engine speed and/or external load vary with time.

This is the basis used in this report for categorising test procedures. The consequences for the equipment required are considered in Section 3 of this Appendix.

## 2. Brief description of tests

### 2.1 UNLOADED TESTS

#### 2.1.1 Unloaded steady states

##### **Idle:**

##### Engine conditions

engine speed: low idle, e.g. 800 rev/min; external load zero.

##### Use

for checking fuelling levels (initially carburettor settings of pre-catalyst petrol fuelled vehicles; for vehicles with TWCs to check the idle stabilisation system) by monitoring CO.

##### **Fast idle:**

##### Engine conditions

engine speed: constant at typically 2500 - 3000 rev/min; external load zero.

##### Use

in conjunction with the idle test for checking fuelling levels and catalyst performance of modern gasoline fuelled cars fitted with electronic fuel injection and ignition systems, closed

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<sup>1</sup> Low emission diesel research Phase 2 report – CP17/18/770, J.O.W. Norris, AEA Technology, Report no AEAT/ENV/R/0629 Issue 3, June 2001,

loop fuelling, and three way catalysts (parameters monitored are CO, hydrocarbons and lambda).

### 2.1.2 Unloaded transients

#### Blue smoke procedure:

##### Engine conditions

engine speed: variable low idle to 3,500 rev/min; external load zero.

##### Use

for gasoline and diesel fuelled vehicles of all sizes, as a recommended in-service check for blue smoke emissions arising from the burning of lube oil (the parameter measured is smoke using an opacimeter).

Details of procedure, taken directly from report to DETR<sup>2</sup>:

- engine warmed up until oil temperature is 80°C,
- engine maintained for a 60 second period at normal idle, with reading taken during the last 10 seconds,
- engine undergoes a steady acceleration in speed from idle to  $3,500 \pm 100$  rev/min<sup>¶</sup> over a 3 second period with a peak smoke meter reading taken,
- engine speed kept constant at  $3,500 \pm 100$  rev/min<sup>¶</sup> over a 3 second period with a peak smoke meter reading taken,
- deceleration down to idle using engine's own resistance, with a peak reading taken\*.

<sup>¶</sup> for heavy-duty diesels upper engine speed is  $1,200 \pm 100$  rev/min.

\* for gasoline vehicles no reading is taken during this deceleration.

#### INCOLL/AUTONAT

##### Engine conditions

engine speed: variable low idle to 4,500 rev/min in very short (<100 ms) time; external load zero.

##### Use

The INCOLL test was devised by Lars Collin of the University of Technology of Göteborg. Recently a similar technique was also proposed by the French "Centre de Recherche en Machine Thermiques", called AUTONAT (CRMT 1994)<sup>3</sup>. In these tests the vehicle's engine 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 to the load during a normal driving cycle. The accelerator pedal is actuated according to the corresponding "driving schedule" through an electronically controlled mechanism, while either the raw exhaust concentrations are continuously measured or diluted exhaust is collected and analysed after the end of the test.

Both systems have demonstrated reasonably good correlation with emissions in legislated cycles, even in the case of catalyst cars. Whilst the performance of the actual test cycle needs

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<sup>2</sup>Detection of vehicles burning lubricating oil, E Beckman, September 1996, DETR reference 9/33/12, AEA Technology reference RYCA 18681001/M/6.

<sup>3</sup> see Section 2.4 of JCS report *Review of Short tests*, LAT Report 9502, Thessaloniki 1995.

only about 2 to 5 minutes, it takes some time (~30 min in the case of AUTONAT) to obtain the relationship between accelerator pedal position and engine speed and load for each car type. This approach is much more complicated than the presently accepted ‘one test for all vehicles’ approach to I/M.

### **Free acceleration smoke (FAS) test:**

#### Engine conditions

engine speed: low idle to max rev/min; external load zero.

#### Use

for assessing the PM emissions performance of diesel fuelled vehicles, of all sizes, by measuring smoke opacity under rapid transient conditions.

Details of procedure: The 72/306/EEC Directive for the free-acceleration smoke test performed as part of the type approval procedure states: *With the engine idling, the accelerator control shall be operated quickly, but not violently, so as to obtain maximum delivery from the injection pump. This position shall be maintained until maximum engine speed is reached and the governor comes into action. As soon as this speed is reached the accelerator shall be released until the engine resumes its idling speed and the opacimeter reverts to the corresponding conditions.*

The corresponding instructions in the MOT testers handbook are:

- d. *When prompted by the smoke meter, depress the accelerator pedal firmly to the maximum fuel delivery position, hold it there until the engine reaches maximum governed speed. As indicated by the smoke meter, release the pedal and allow the engine to return fully to idle.*

### **Air/fuel ratio perturbation test:**

#### Engine conditions

engine speed: constant around “fast idle” typically 2500 - 3000 rev/min; external load zero when emissions stable brake pedal pumped.

#### Use

for checking the active closed loop fuelling feedback system is operating correctly.

This is a test that has been considered, principally in Germany, for testing SI engined vehicles with closed loop fuelling control. The basic principle is to use the brake servo system as a means for injecting additional air into the engine’s inlet manifold after the manifold air flow sensor by briefly depressing the brake pedal. This would change the air/fuel ratio making it leaner. A correctly operating active feedback system would be expected to detect the high  $\lambda$ , increase the fuelling, and restore  $\lambda$  to around 1.00.

The author has found no written description of the test. It is believed to have been used at low idle, and involved a single depression of the brake pedal. If this were the case it is difficult to see how the effects of the resulting transient would persist sufficiently long for the fuelling feedback system to respond.

Practical studies have been undertaken by the author’s team on several vehicles as follows:

- go to high idle condition, e.g. 2,800 rev/min with the exhaust gas analyser running,
- using the left foot repeatedly (e.g. at 1 Hz) stamp on the brake pedal and lift off,
- monitor the values of  $\lambda$  displayed by the exhaust gas analyser.

It was anticipated the ideal output would show briefly a  $\lambda$  increase, followed by it returning to the original value, and a corresponding brief  $\lambda$  decrease on the cessation of the braking as the closed loop fuelling system responds and injects more fuel.

In practice attempts failed to show any systematic change in  $\lambda$ . This was thought to be a result of:

- the volume of air admitted into the inlet manifold being a small proportion of the inlet air volume, and
- practically it was found that the repeated application of the brakes led to small variations in the position of the right foot (on the throttle pedal) which themselves produced variations in  $\lambda$  and engine speed larger than the change due to air from the brake servo.

However, repeating the procedure on a further vehicle using a dead-mans foot to carefully keep the position of the accelerator constant showed a much more positive result. Again changes in  $\lambda$  were constrained to less than 0.005. But this time a clear >250 rpm, increase in engine speed was seen when the brake pedal was depressed. The engine's speed returned to the original value when braking was stopped. In hindsight, this was very probably occurring in the previous tests but the change in engine speed was misinterpreted as variations in the position of the foot on the accelerator.

The explanation for the above is that the engine is detecting the increase in air flow and is increasing fuelling to compensate too rapidly for there to be a clear change in  $\lambda$ . However, the increased air + fuel, under these no load conditions, leads to an increase in engine speed. An attractive feature of the test is that the key measurement parameter, engine speed, is a parameter already measured by garage forecourt analysers.

It must be emphasised that the above practical tests are very preliminary. However, this test does appear to be a potentially viable diagnostic to demonstrate the engine can actively control the air/fuel ratio – a key component in the overall strategies for controlling emissions.

## **2.2 LOADED TESTS**

### **2.2.1 Loaded steady states**

#### **US Federal 3-mode test**

This test involves two different vehicle speed/load points and low idle (unloaded).

This test was developed in the US in the 1970s as a possible short test for vehicle I&M programmes. Whilst its technical performance correlated reasonably well with the Federal Test Procedure (FTP) tests, it was never implemented due to the high capital costs involved for a dynamometer and a NO<sub>x</sub> analyser.

The three modes are, for vehicles of 1136 kg (2500 lbs) and below:

Mode 1	steady 50 mph (80 kph)	at 15 h.p. (11.2 kW) load
Mode 2	steady 30 mph (48 kph)	at 9 h.p. (6.7 kW) load
Mode 3	stationary at low idle	at no load

For vehicles heavier than 1136 kg (2500 lbs) higher loads apply.

### **Clayton Key-mode test and CalVIP test**

These were two further US short vehicular tests developed in the 1970s with three and one mode loaded operation respectively.

### **The Acceleration Simulation Mode (ASM) – e.g. European ASM 4050**

These tests use a constant engine speed, and a constant load that is greater than zero.

The acceleration simulation mode (ASM) principle is that a vehicle is driven on a chassis dynamometer at a constant speed and load that is equal to the actual road load of the car during acceleration. This circumvents the need of flywheels for inertia simulation. At high speeds and loads it was found that engines tended to overheat, thereby restricting the useable speed/power range.

The two ASM tests that were found to correlate best with the FTP cycle were the ASM5015 and ASM2525 tests. In the former the vehicle is driven at a steady 15 mph (24 kph) with a steady state load equal to 50% of the load required for the vehicle to accelerate at  $1.47 \text{ m s}^{-2}$  (the maximum acceleration rate during the FTP cycle), whereas the latter involves the vehicle being driven at 25 mph with a steady state load equal to 25% of that required for the same acceleration. HC, CO and NO<sub>x</sub> were measured at this steady state. An evaluation study concluded these tests can identify over 80% of excess HC and CO emitters with few errors of commission.

### **VdTÜV's steady-state test for diesel cars**

Two different constant engine speed/load points.

In the late 1980s the association of German TÜV also investigated the ASM principle applied to both diesel and gasoline fuelled cars. In this variant the car is driven at a nominal speed and full load, and then 45% of the nominal speed and full load. Two smoke measurements were taken at each condition.

This test procedure was examined in a study conducted by VdTÜV. 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 (by a study whose report was published in 1993) to be satisfactory.

## 2.2.2 Loaded transients

### NEDC

The New European Drive Cycle (NEDC) is specified in directive 98/69/EC (an amending directive to 70/220/EEC). It has a key role in the type approval process, being the Type 1 test specified in the directive. It has, to a large extent, evolved to take account of changes in gasoline technology. The test comprises two distinct sections: the urban cycle (a series of accelerations, steady speeds, decelerations and idling) and the extra urban cycle which is run immediately following the urban cycle. The latter comprises roughly half steady speed driving (at 75 to 120 kph) and half accelerations/decelerations and a little idling. The test is undertaken on a vehicle which has been left to soak at between 20°C and 30°C for at least 6 hours, and until the engine oil and coolant temperatures are within  $\pm 2^\circ\text{C}$  of the temperature of the room.

The duration of the cycle is 19m 40s (1180 seconds) for Euro III and later certification, with the two phases being 13m and 6m 40s long, respectively. The Euro III test differs from the Euro II and earlier certification procedure (specified in directive 98/69/EC) in that the earlier test started with a 40 second idling period that preceded the start of gaseous emissions sampling. Consequently the earlier test:

- was 40 seconds longer, i.e. 20m 20s, although emissions were only collected for the last 19m 40s and
- vehicles were idling for 51 seconds, rather than 11 seconds, before the start of the first acceleration.

These changes were implemented to quantify, and control, the high level of emissions (especially carbon monoxide) that occurs during the first part of a journey before the three way catalyst of a gasoline fuelled car is fully operational and reduces polluting emissions to a very low level.

**For passenger cars and light-duty vehicles it is the emissions of CO, NO<sub>x</sub>, HC and NO<sub>x</sub> (and PM for compression ignition engine vehicles) from this drive cycle that defines the EU emission standards for new cars.**

However, key aspects of this cycle which make it unattractive for I&M testing are:

- it is a cold start test, requiring at least a 6 hour pre-run soak,
- its duration (now 19 minutes and 40 seconds),
- its requirement of a dynamometer that has full inertia simulation capability,
- the specification of a full flow dilution tunnel emissions measurement system and
- the high specification of the analysers required.

Even if raw exhaust measurements were used, the first three of these aspects render this cycle impractical for I&M programmes.

### The MODEM “actual” driving cycle

As part of a part EC funded programme on “modelling of emissions and consumption in urban areas” (known by the acronym MODEM) a real world “actual cycle” was developed by INRETS on the basis of a large scale study into the driving behaviour in three countries (France, Germany and the UK). This work was in the framework of the EC DRIVE

“Dedicated road infrastructure for vehicle safety in Europe – DRIVE” project. The drive cycle comprises four portions:

1. slow urban (speeds hardly exceeding 30 kph)
2. road (with speeds up to 100 kph)
3. free flow urban (with speeds up to 60 kph)
4. motorway (with speeds exceeding 120 kph).

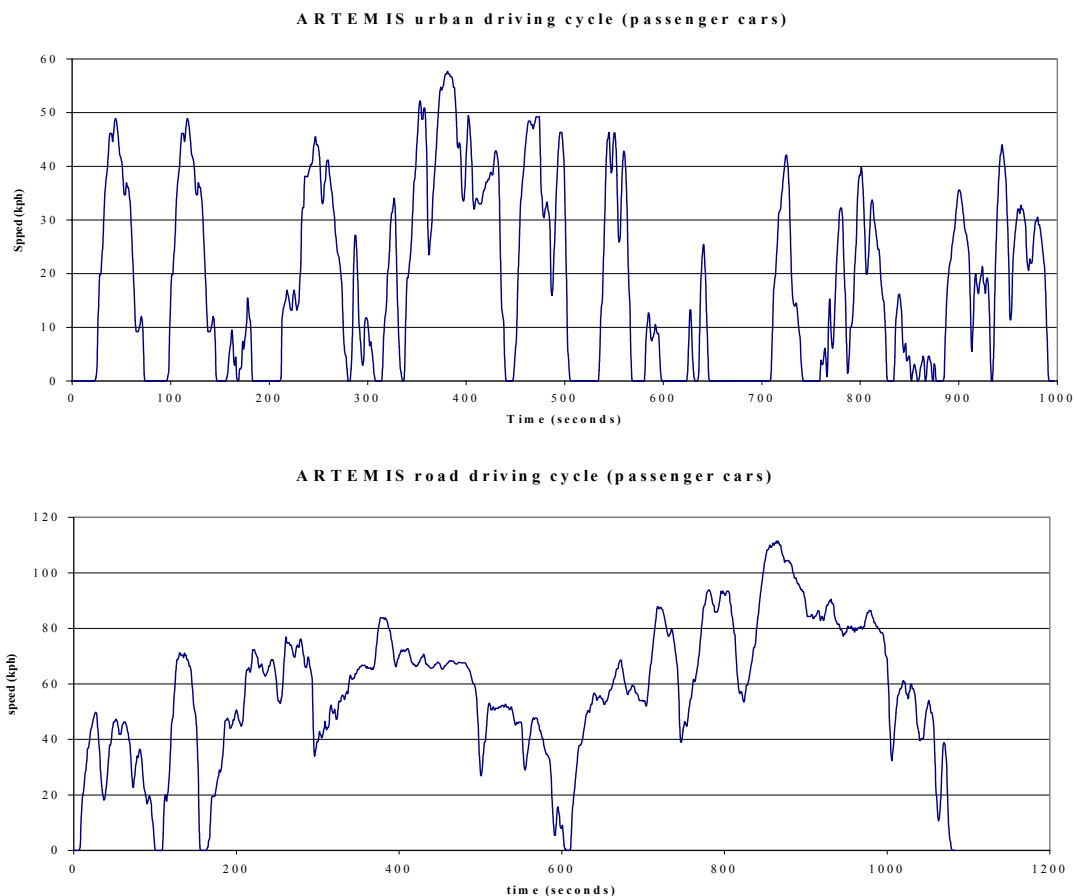
In total it is around 32 minutes long, and like the NEDC requires a transient chassis dynamometer with full inertia simulation.

### ARTEMIS cycles

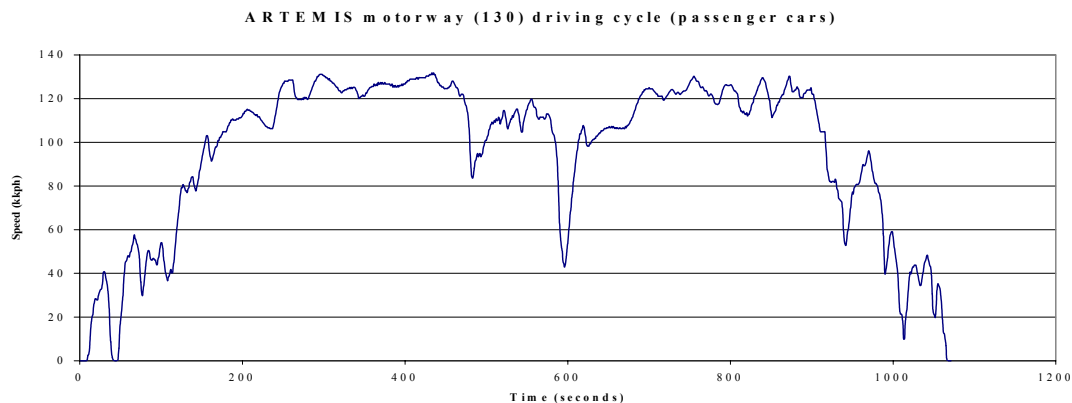
Within the EU 5<sup>th</sup> Framework programme there is a project entitled “Assessment and reliability of transport emission models and inventory systems” (ARTEMIS). INRETS has built a set of reference driving cycles which are being used within the framework of national and European projects aiming to access emission factors from light-duty vehicles. These cycles have been called the Common ARTEMIS Driving Cycles (CADC).

The analysis of >100,000 km of driven miles in >80 passenger cars in 6 European countries has culminated in three driving cycles representing urban, subsidiary/main roads and motorway driving behaviours. There are two variants of the motorway driving cycle with top speeds of 130 and 151 kph.

The three ARTEMIS cycles are shown in Figure A2.1.







**Figure A2.1 ARTEMIS driving cycles**

Using similar principles INRETS have also developed specific cycles for light-duty commercial vehicles, from commercial cars to 2.5 tonne vans.

### **TÜV short and MODEM short**

A short driving cycle of 200 seconds duration was developed by TÜV Rheinland. It was designed to mimic the kinematic characteristics of the NEDC, whilst being of much shorter duration and of potential use as an I&M test.

As part of the Joint Commission Services (JCS) study<sup>4</sup>, INRETS developed a short (255 second) MODEM test simulating the long MODEM “actual” driving cycle, described above.

These two cycles were the “short” transient drive cycles selected and assessed in the JCS study (see Detailed Report 3: Test protocol and average results of long and short emission tests for passenger cars).

### **FTP 75**

The US equivalent of Europe’s NEDC type approval cycle is the Federal Test Procedure 75 (FTP-75). (Here 75 is derived from a date, not the cycle’s duration in seconds!) This cycle has three-phases as follows.

1. Phase 1 – cold start transient phase , 505 seconds duration with maximum speed of 57 mph (91.2 kph)
2. Phase 2 – cold stabilised transient phase, 864 seconds, maximum speed around 30 mph (50 kph)
3. Phase 3 – hot transient phase, repeat of Phase 1 but from a hot start.

The total distance travelled is 11.04 miles (17.77 km) in 31 minutes 14 seconds. Also, there is a 10 minute “engine-off” pause between phases 2 and 3, making the duration of the whole cycle just over 41 minutes.

<sup>4</sup> The inspection of in-use cars in order to attain minimum emissions of pollutants and optimum energy efficiency – Main Report, EC DGs for Environment (DG XI) Transport (DG VII) and Energy (DG XVII), LAT AUTH INRETS TNO TÜV Rheinland and TRL, May 1998

Supplementary Federal Test Procedures (SFTPs) have been designed to address shortcomings of the FTP-75 and are being phased in between 2000 and 2004. These are:

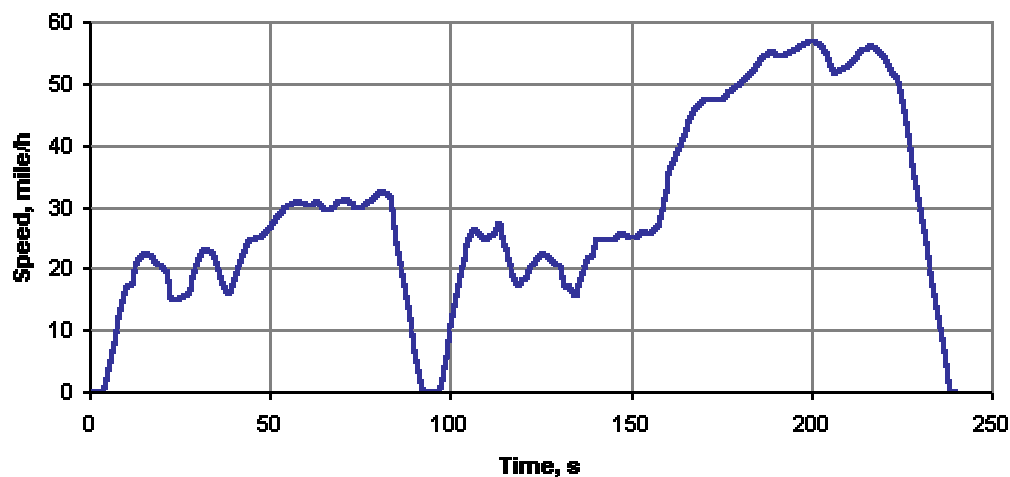
US06 cycle – a high speed high load cycle that measures emissions during aggressive motorway driving (maximum speed 80.3 mph, duration 10 minutes) and

SC03 cycle – an air conditioning cycle designed to measure emissions for urban driving whilst the vehicle's air conditioning system is operating (maximum speed 54.8 mph, duration 9 minutes and 54 seconds).

As for the NEDC, no serious consideration appears to have been of using the FTP-75 cycle as an in-service test in the US.

### IM240

The title of this test is an abbreviation of its full title: the Inspection and Maintenance 240 second duration test. It was developed by the EPA, in the US, as a condensed version of the FTP-75 test. This transient test involved idle, accelerations, cruise and decelerations. Its time/road speed characteristics are shown in Figure A2.2 below.



**Figure A2.2 Inspection & Maintenance Driving Cycle IM240**

The IM240 test is a chassis dynamometer schedule used for emission testing of in-use light duty vehicles in I&M programmes implemented in a number of states. It is a short (240 second) test representing a 1.96 mile (3.1 km) route with an average speed of 29.4 mile/h (47.3 km/h) and a maximum speed of 56.7 mile/h (91.2 km/h).

Further comments regarding some feedback of strengths and weaknesses of the IM240 test are given in section 4.2 of this appendix.

### Hong Kong test

The Environmental Protection Department of Hong Kong has recently introduced an “advanced smoke test” to control emissions from all diesel vehicles. This puts Hong Kong at the vanguard of in-service diesel testing. The testing of heavy-duty vehicles, which in Hong Kong are defined as those weighing more than 5.5 tonnes, started on 28/12/00, four months after it had been introduced for light duty vehicles.

The test itself comprises three components:

1. a free acceleration smoke test,
2. a smoke test at the steady speed of 70 kph at full power and
3. a smoke test during a full power lug-down procedure.

The last two of these require a simple chassis dynamometer.

An important aspect of Component 2 is to select a gear so that the vehicle's speed **under no load conditions and maximum accelerator travel**, is close to the target 70 kph, i.e. the engine's speed is close to its governed upper limit. For Component 3 the controlling computer applies an increasing load to the vehicle until, whilst still at maximum accelerator travel, its speed has been reduced to 90% of the target speed (i.e. around 63 kph). This speed is held for 10 seconds during which time the vehicle's power, road speed, engine speed and the smoke level are recorded. Then the load is further increased to reduce the vehicle's road speed to 80% of the target speed (i.e. around 56 kph). Again this is held for 10 seconds whilst data is recorded.

Therefore the test is, in essence, a steady state test run with the vehicle on maximum fuelling, somewhat similar to the 100% load point at the highest engine speed from the R49 or ESC engine tests.

### 2.2.3 Road cycles

Road cycles can be as varied as the journeys people undertake day by day. The chassis dynamometer drive cycles are laboratory simulations of "on-the-road" driving. Therefore these cycles (the NEDC, MODEM, ARTEMIS, FTP-75, IM240 etc.) could all be driven as true road cycles. However, some challenges of achieving this relative to using a chassis dynamometer are:

- finding suitable empty road or a test track where the test can be driven safely, and without interference from other vehicles,
- giving the driver speed/time information because, unlike a vehicle on a chassis dynamometer which is stationary relative to its surroundings and can use an externally mounted driver's aid, an alternative display is required,
- variations in climatic conditions (e.g. ambient temperature, humidity, wind speed and direction, rain or ice on the test track),
- the need for mobile analysers or sampling equipment.

Generally the emphasis has been on testing reproducibly, i.e. with as little uncontrolled variability as possible. This, plus the general convenience of laboratory testing once the initial investment and setting up costs have been made, has meant that road testing for emissions measurement is not commonly used.

## 3. Equipment requirements

In this section a very brief description of the equipment implications of the various test procure options is given. This does not include the pollutant measurement instruments which are considered in Appendix 1.

### 3.1 UNLOADED TESTS – BOTH STEADY STATE AND TRANSIENT

These are the tests used by the current I&M programme. The only additional test equipment that would be required to perform any of the test procedures described in these sections beyond what is currently used is **a testers' prompt**. This is software indicating what engine speed the test requires as a function of time, and some feedback on what the current engine speed is.

### 3.2 LOADED TESTS

This type of test requires either a chassis dynamometer or on the road driving.

Dynamometers can be classified into four functional types:

1. simplest absorption only
2. variable absorption only
3. variable absorption plus inertia simulation for acceleration
4. variable absorption plus full inertia simulation.

#### 3.2.1 Review of fundamental laws of motion

In order to understand some of the issues involved a brief review of the fundamental laws of motion is helpful.

Generally it is found that the road load force required to sustain a vehicle at a V kph can be expressed:

$$RLF = A + B V + C V^2 \quad \text{Equation 1}$$

In the European regulations (Annex III, Appendix 2 of 70/220/EEC)

A is described as the rolling resistance (a speed independent constant, in N)

B is zero and

C is the coefficient of air resistance (in N/kph<sup>2</sup>).

Section 3.2.1 of the directive gives values for the coefficients A and C as a function of the vehicles weight from <480 kg to >2610 kg in 21 steps. It also gives the value of F at 80 kph (calculated from equation 1 above) and the power absorbed by the dynamometer at this speed from the familiar formula:

$$\text{power} = \text{force (N)} \times \text{distance travelled (W)} \quad \text{Equation 2}$$

i.e. power = force  $\times$  22.22 W for 80 kph.

The other important equation of motion gives the rate of acceleration for a system:

$$F = M A + \text{RLF} \quad \text{Equation 3}$$

where F is the total force supplied by the vehicle

RLF is the road load force required to sustain its current speed of V ( $\text{m s}^{-1}$ ), see eqn. 1

M is the vehicles mass and

A is the resulting acceleration (in  $\text{m s}^{-2}$ ).

### 3.2.2 Review of types of dynamometer

#### Simplest absorption only dynamometer

This type of dynamometer absorbs power delivered through the vehicle's wheels, with the amount of power being absorbed being an operator-controlled constant. It is the simplest, and consequently the cheapest, form of dynamometer.

#### Variable absorption only dynamometer

The mechanical essence of this type of dynamometer is as for the simplest absorption dynamometer described above. Its sophistication derives from the use of a feedback loop, changing the RLF absorbed by the dynamometer according to the vehicles' speed. Such a system enables the power absorbed at steady speeds to follow the RLF given by equation 1.

Depression of the accelerator would cause the vehicle's speed to increase to a new speed where the new higher RLF is balanced by the increased power being absorbed by the dynamometer. However, the rate of acceleration for such a system would be higher than for a vehicle on the road because of the lack of vehicle inertia.

#### Dynamometer with variable absorption plus inertia simulation for acceleration

The next level of electronic sophistication, again only requiring the simplest mechanical dynamometer, is to have the dynamometer's control system measure the rate of acceleration and to vary the RLF applied by the dynamometer by an additional amount (relative to that appropriate for the vehicle's speed) determined by the vehicle's mass and the rate of acceleration, i.e. reproducing equation 3. Such a dynamometer would give rates of acceleration equal to those of the vehicle on the road.

However, its rate of deceleration would be greater because this system neither has, nor can emulate, the vehicle's inertia pushing against the engine.

#### Dynamometer with variable absorption plus full inertia simulation

The more usual method of emulating inertia during accelerations is for the dynamometer to have a number of flywheels that are mechanically coupled into the system in a combination depending on the vehicle's weight. For steady speed running their effect is negligible. However, during acceleration the vehicle not only has to provide additional power to meet the

increased RLF of the dynamometer at the new increasing speeds, but also further power to accelerate these flywheels.

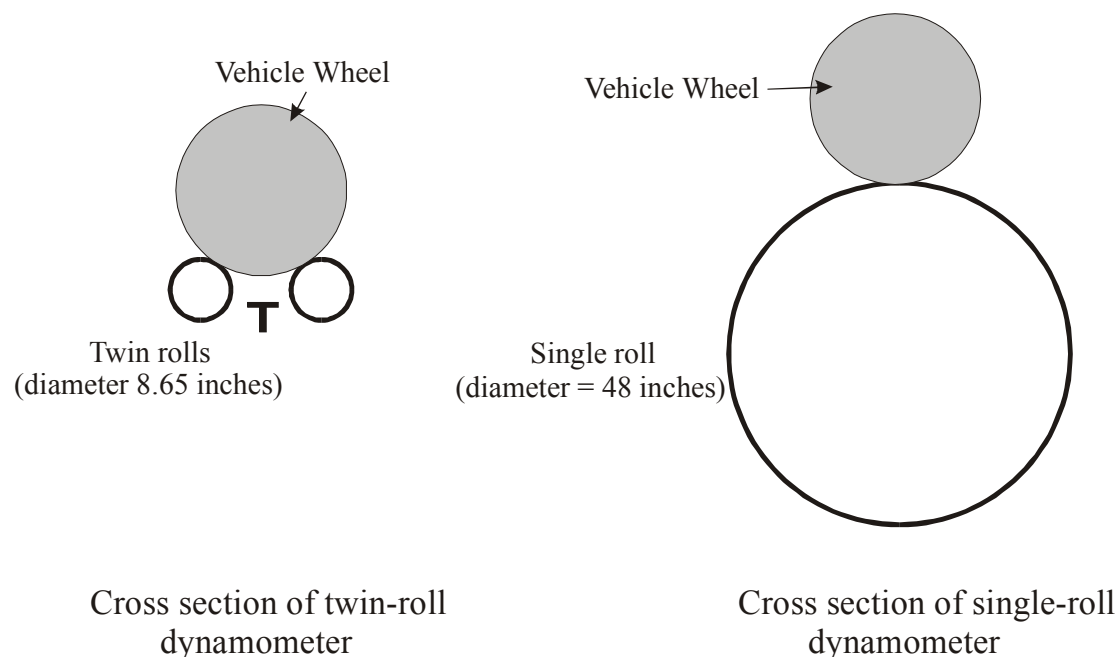
This type of dynamometer has full inertia simulation because on deceleration the flywheels' stored rotational kinetic energy pushes against the vehicle's engine in the way that the mass of a moving vehicle keeps the engine revolving. Whilst full inertia simulation is seen as important for type approval emissions measurements, for example because of the effect of some braking strategies fitted to heavy-duty vehicles, it is regarded by the author as an unnecessary over elaboration for an in-service test. It also involves additional costs.

### Other dynamometer characteristics

In addition to the dynamometer retarding force/vehicle road speed and acceleration characteristics already discussed, other dynamometer variables are:

- number of rolls per axles, and
- number of driven axles it can accommodate.

Dynamometers can have either one or two rolls per driven wheel. In cross section the options look like:



The two roll option was the most common, but within the US there is a preference for using a single roll dynamometer for regulatory testing, although the IM240 regulations specify a twin-roll configuration. The dynamometers being supplied by Clayton Industries for the HGV I&M testing in Hong Kong and Thailand are of the twin roll type.

There exists in the vehicle parc a number of vehicles whose power is permanently transmitted to more than one axle. These range from 4-wheel drive passenger cars to twin drive axle rigid and articulated HGVs. Such vehicles can not be tested on a single axle dynamometer without

first disconnecting the drive-shaft to the second axle. This is not an option for an in-service test where a fundamental premise is that testing occurs without interfering with the mechanical integrity of the vehicle. It is estimated that the numbers of vehicles in these categories are:

- up to 5% for passenger cars and light-duty vehicles and
- 5 – 10% for HGVs.

For HGVs it is noted that the geographical distribution of such vehicles is uneven with some test stations having >10% of vehicles with more than one driven axle and others rarely ever seeing such a vehicle. Therefore one option within the scenario of an in-service testing programme that requires dynamometers would be to have one lane of some, not all, stations able to test twin drive-axle vehicles<sup>5</sup>. An alternative approach would be to test vehicles using different procedures. The way this approach is used in Oregon, US, is described in Section 4.2 of this Appendix.

### 3.3 THE COST OF DYNAMOMETERS

A number of enquiries were made to the providers of power test equipment to garages and enthusiast clubs. Similarly, enquiries were made to the companies who supply the test houses with their high specification, very versatile, VCA certifiable equipment. This enabled price ranges for the various levels of dynamometer sophistication to be found for both light-duty and heavy-duty vehicles. The price ranges are:

Dynamometers for regulatory testing

Light-duty    £150k - £200k

Heavy-duty    £200k - £300k.

Dynamometers for in-service testing

Light-duty    £24k - £28k

Heavy-duty    £44k - £55k.

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<sup>5</sup> Vehicles with a single drive axle can be tested on a twin-axle dynamometer (while in single axle mode, the other roll set would be idle).

## 4. Factors which influence the prioritisation of the test procedure options

### 4.1 GENERIC

The choice of a preferred procedure comes down to prioritising the possibilities. One technique for achieving this is to weight the various factors which influence the “usefulness” of prospective test procedures, to assign a value to each factor for each possible test, and to combine the marks to give an overall score. The various factors can be grouped onto those involved with the application of the test, and more fundamentally, the relevance of possible procedures to the test’s objective. This is because it would be possible to devise a cheap, convenient test that, when scrutinised, was found to be virtually irrelevant to the fundamental objective of the requirement.

The factors to be considered include:

Factors related to the convenience of the test:

- the applicability of test to different vehicle types
- the investment in equipment, training and infrastructure required to undertake the test
- the time taken to undertake each individual test
- the level of difficulty of test procedure for the tester
- the intrinsic friendliness of the measuring instrument
- the durability of the measuring instrument.

Factors related to the relevance of the test:

- the applicability of test to different vehicle types
- the correlation of the test to “real world” driving
- the correlation of the test to type approval standard
- the ease with which a vehicle might beat the system
- the intrinsic repeatability of test
- the variability of results due to testers equipment
- the variability of results due to differences introduced (unintentionally) by the testers
- the accuracy of measuring instrument.

Ultimately one can generate both cost effectiveness and convenience/relevance semi-quantitative or quantitative “scores” for the various possibilities.



## 4.2 COMMENTS FROM OTHER TEST PROGRAMMES

Reports published by the EPA, and discussions with a member of the office of Transportation and Air Quality have been very useful in learning from the US's experience of the loaded in-service testing. Overall the following correlations have been found:

Lab-IM240 – FTP 75 for CO and HC	Poor
Lab-IM240 – FTP 75 for CO <sub>2</sub> and NO <sub>x</sub>	Good.

The principal reason for the above is that the IM240 is a hot start cycle whereas the FTP75 is a cold start cycle, and the importance of the cold start contribution to the total CO and HC emissions is large, whereas the cold start contribution to the total CO<sub>2</sub> and NO<sub>x</sub> emissions is much smaller. Also:

Lab-IM240 – Lane-IM240 for all species	Moderate.
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Lab-IM240 and Lane-IM240 are where the IM240 test are undertaken either in a vehicle emissions laboratory or on an in-service test lane. The EPA ascribe the only moderate correlation between the emissions results from the same test on the same vehicle but undertaken in different circumstances as being primarily caused by variations in the operating temperature of the vehicle.

Discussions with staff in the Vehicle Inspection Programme for Oregon (US) has found that they use different test procedures for different vehicles. This is in recognition that the different tests have different strengths and weaknesses. Since 1<sup>st</sup> January 2001 their testing programme for petrol fuelled vehicles is:

Age	Test
1975 – 1980	Two speed idle test
1981 – 1995 vehicles with single drive axle	BAR-31 loaded (dynamometer) test
1981 – 1995 vehicles which can not operate on a 2 wheel drive dynamometer (e.g. 4WD, active traction control)	Two speed idle test
1996 -	OBD system check

The stark message the author receives from these discussions is that, on balance, neither of the currently used in-service loaded tests is now recommended as the basis for an in-service I&M test programme.