

3 Driving Cycles

3.1 Introduction

To propel an automobile one needs energy. This need for energy is in most cases covered by the conversion of chemical energy from fossil fuels to mechanical energy. For this, one uses often the internal combustion engine (ICE). The efficiency of this machine is low and the combustion causes hazardous emissions. These two issues have been neglected for a long time. However, due to the increasing use of automobiles and herewith increasing environmental damage, these points are placed in the picture. In the seventies and the eighties the state California has given an impulse to the automobile industry to develop engines with higher efficiency and lower emissions, by the establishment of emission laws. Connected with this there arise the need for test procedures to compare several engines with each other. These test procedures are called driving cycles.

3.2 The use of driving cycles

A driving cycle is a standardised driving pattern. This pattern is described by means of a velocity-time table. The track that is to be covered is divided in time-steps, mostly seconds. The acceleration during a time step is assumed to be constant. As a result the velocity during a time step is a linear function of time. Because velocity and acceleration are known for each point of time, the required mechanical power as a function of time can be determined with formulas, which will be discussed later. This function integrated over the duration of the driving cycle produces the mechanical energy needed for that driving cycle. Off the road a vehicle can execute a driving cycle on a dynamometer. In the case of ICE driven vehicles, the fuel consumption and emissions are directly measured. The same holds for the fuel conversion system of hybrid electric driven vehicles. The primary energy can be calculated from the fuel consumption. For electric vehicles (EV) or hybrid electric vehicles (HEV) which make use of an external electric source (such as the public grid), the electric energy withdrawn from that source will be separately accounted for. The electric energy is turned into the required primary energy by dividing it by the efficiency of power generation. The emissions are determined by using emission values handed up by power companies. In all driving systems the efficiency of the driving system is determined by dividing the calculated mechanical energy by the primary energy.

3.3 Description of several driving cycles

The world-wide used driving cycles can be divided into three groups:

- European driving cycles
- US driving cycles
- Japanese driving cycles

3.3.1 European driving cycles [1]

These driving cycles belong to the modal cycles. This means there are parts in these cycles where the speed is constant. Because modal cycles don't represent real driving patterns an additional group of driving cycles has been developed: the HYZEM cycles. These cycles

will be discussed later in this paragraph. For the European driving cycles the following subdivision can be made.

3.3.1.1 ECE 15

This driving cycle represents urban driving. It is characterised by low vehicle speed (max. 50 km/h), low engine load and low exhaust gas temperature.

3.3.1.2 EUDC

This cycle describes a suburban route. At the end of the cycle the vehicle accelerates to highway-speed. Both speed and acceleration are higher than the ECE 15 but it still is a modal cycle.

3.3.1.3 EUDCL

The EUDCL is a suburban cycle for low-powered vehicles. It is similar to the EUDC but the maximum speed is 90 km/h.

3.3.1.4 NEDC

This is a combined cycle consisting of four ECE 15 cycles followed by an EUDC or EUDCL cycle. The NEDC is also called the ECE cycle..

3.3.1.5 HYZEM [2]

The cycles mentioned above are stylistic cycles. These cycles can not represent real driving patterns. The HYZEM cycles are transient cycles. The parts at which the speed is constant are much smaller than in modal cycles. The HYZEM cycles are derived from real driving patterns throughout Europe. Therefore, they are a better representation for driving conditions than the standard European cycles. The HYZEM cycles are often used but they are not official. The HYZEM cycles consist of an urban cycle, an extra-urban cycle and a highway cycle.

3.3.2 US driving cycles [1]

These driving cycles belong to the transient cycles. Like the HYZEM cycles they give a better representation of real driving patterns than the modal cycles. The following subdivision can be made.

3.3.2.1 FTP 72

In the early seventies this cycle has been developed to describe an urban route. The cycle consist of a cold start phase. This phase is followed by a transient phase with many speed peaks which start from rest. The emissions are measured. In the United States weight factors are used for both phases to norm the emissions. The FTP 72 is often called FUDS, UDDS or LA-4.

3.3.2.2 SFUDS [4]

The SFUDS has been developed to simulate battery discharge and charge during a trip with an EV. The SFUDS was derived for a specific vehicle, the improved dual shaft electric propulsion. The velocity profile is adapted to this vehicle, to obtain a battery discharge- and charge profile that consists of constant power phases.

3.3.2.3 FTP 75

The FTP 75 is the FTP 72 with an extra third phase. This phase is identical to the first phase of the FTP 72 but is executed with a hot engine.

3.3.2.4 HFEDS

This cycle represents extra urban and highway driving.

3.3.2.5 IM 240

This is a cycle is used for inspection purposes. With this cycle, the emissions are determined during the periodic maintenance test.

3.3.2.6 LA-92

The LA-92 represents like the FTP 72 an urban route. The LA-92 has been developed in 1992, because the existing FTP 72 turned out to be a non-realistic representation of urban driving patterns. For example the LA-92 has an higher average speed.

3.3.2.7 NYCC

This cycle represents an urban route through New York. A characteristic of this cycle is the low average speed.

3.3.2.8 US 06

This is the so called aggressive driving cycle. It is developed to describe a driving pattern with high engine loads.

3.3.3 Japanese driving cycles [1]

The Japanese driving cycles belong to the modal cycles. The following cycles can be subdivided.

3.3.3.1 10 Mode

This cycle represents an urban route.

3.3.3.2 15 Mode

This is a combination of an urban and an extra-urban route. The maximum speed is 70 km/h.

3.3.3.3 10-15 Mode

This is a combination of five cycles. First the 15-Mode, then three times 10-Mode and at last again the 15 Mode.

3.4 Comparison of driving cycles

Section 3.3 gives a short description of the most used driving cycles. In this section those cycles are separated which are representative for real driving patterns. From paragraph 3.3.1 it can be concluded that of the European driving cycles only the HYZEM cycles are representative. The US cycles will be considered by comparing the average speed, $\langle v \rangle$ (km/h), the maximum acceleration rate a_{\max} (m/s^2) and the maximum specific power K_{\max} (m^2/s^3). K is defined as $2 \cdot \text{velocity} \cdot \text{acceleration rate}$ and is a measure of the change rate of a vehicle kinetic energy. These parameters can be seen for five driving cycles in table 3.1. Among these cycles, the HFEDS is very close to freeway driving, with the lowest K_{\max} value and highest average speed. The FTP 72 is the most moderate cycle with low $\langle v \rangle$, a_{\max} , and K_{\max} values. The LA 92 cycle is a much more powerful cycle than the HFEDS and FTP 72 cycles, with much higher values of a_{\max} and K_{\max} . The NYCC is the most representative of urban driving that includes signals and congestion, with an average speed of only 11.4 km/h. The US 06 cycle is the most powerful cycle, with an average speed of 77.2 km/h, a maximum acceleration of 3.8 m/s^2 and a maximum specific power of $97 \text{ m}^2/\text{s}^3$, which is about 2.5 times of the corresponding FTP value.

Table 3.1 Characteristics of five driving cycles [3]

	$\langle v \rangle$ (km/h)	a_{\max} (m/s^2)	K_{\max} (m^2/s^3)
HFEDS	77.6	1.5	31.4
FTP 72	31.4	1.5	38.4
LA 92	39.7	4.0	74.3
NYCC	11.4	2.7	38.8
US 06	77.2	3.8	97.3

The described Japanese cycles are all modal cycles so they are not considered as representative cycles.

Concluding, it can be said that the following driving cycles are considered as representative for real driving patterns:

- All HYZEM cycles
- HFEDS
- LA 92
- NYCC
- US 06