DIESEL ENGINE SMOKE AND THE UNO-EEC CHECKING REGULATION No. 24

A. MEGGYES and M. A. ABU EL-ENIN*

Department of Heat Engines,
Technical University, H—1521 Budapest

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Abstract

It was studied whether the actual smoke exhaust by Diesel wehicle engines — is it that in steady-state or in unsteady-state operation at free acceleration, or does it differ from either?

Smoke values obtained in steady-state operation are in themselves not typical of those in unsteady-state operation (e. g. urban traffic). No direct relationship can be found between smoke values in either operation. To check real (unsteady-state) smoke exhaust, Diesel engines have to be cycle tested — similar as for Otto engines.

Introduction

Regulation No. 24 of the UNO European Economic Committee [1] specifies gauging of smoke exhaust by Diesel vehicle engines both in steady-state operation at full load, and in unsteady-state operation at free acceleration. Ultimate values are given for steady-state operation. In unsteady-state operation it is sufficient to indicate the maximum value for ulterior checkings. But what as to the actual smoke exhaust by Diesel vehicle engines — is it that in steady-state or in unsteady-state operation, or does it differ from either? Below it will also be considered, — in agreement with other authors [4, 6] — how much, and in what sense they differ if at all.

* Lecturer at the Technical University of Port Said on a study trip at the Technical University of Budapest.

Operating conditions of diesel vehicle engines

Examinations of load cases of Diesel vehicle engines [2] show steady-state operating conditions for more than 3 sec to be exceptional in urban traffic, save in idling. The most frequent load changes are *rpm* range variations for a constant moment. The most frequent moment ranges are those near full load. Angular accelerations of Diesel vehicle engines range from 1 to 25 sec^{-2} [3]. In free acceleration, angular acceleration may be as high as 150 to 200 sec^{-2}.

Unfortunately, there is no run cycle specification for Diesel vehicle engines. But it would be rather realistic to extend the generalized "Europe cycle" — developed for passanger cars in urban traffic — to Diesel-engine trucks.

The starting consideration is the constraint for trucks surrounded by passenger cars in urban traffic to match them. Deviations due to the inability of trucks to achieve the acceleration of passenger cars may be eliminated in later cycle phases (constant speed, etc.).

Testing method and equipment

Tests were performed on a four-cylinder Diesel vehicle engine.

Bore: 100 mm

Stroke: 110 mm

four-stroke, water-cooled, with a Sauer combustion chamber.

Rather than to mount the test engine into a vehicle, it was tested in a test stand, schematically shown in Fig. 1. Temperatures of cylinder head and of exhaust gas were

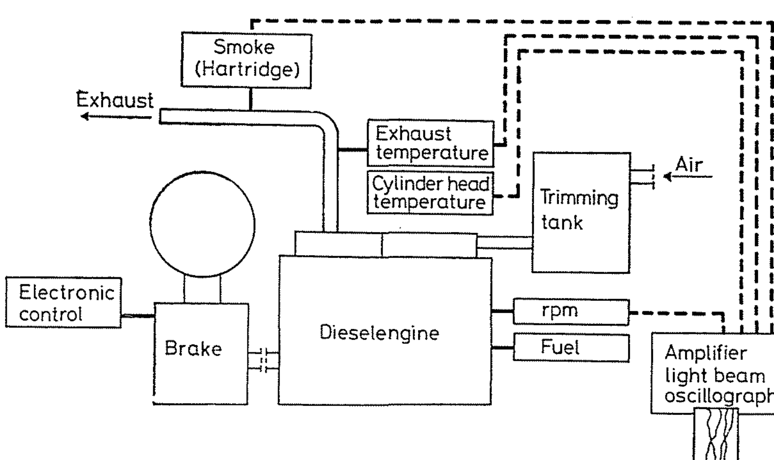

Fig. 1. Scheme of the test stand

taken by thermocouples, and the intake air volume was gauged by an orifice. The fuel quantity was weighed.

Smoke was indicated by a Hartridge apparatus.

Characteristics such as smoke exhaust, temperatures of cylinder head and exhaust, and number of revolutions were recorded by means of a light beam oscillograph.

Electronic control of the eddy-current brake facilitated vehicle-like loading of the Diesel engine.

The performed tests belonged to two categories:

1. Testing smoke exhaust in acceleration under different conditions.
2. Testing smoke exhaust in vehicle operation (run cycle test).

Details of tests according to item 1 are found in ref. [5]. Here only essentials will be quoted.

Diesel vehicle smoke in acceleration

Before accelerating, the engine was driven at a minimum *rpm* to become steady-state. Abruptly "gas was given" to increase the injected fuel quantity up to stop (full load). Thereafter the *rpm* was increased to maximum by electronically controlling the dynamometer.

The acceleration process is shown in the field of characteristic curves of the cylinder head temperatures in Fig. 2. The engine operated first at points 1, 2, 3, 4 under steady-state conditions, at different cylinder head temperatures to obtain a definite starting condition. Upon abrupt "gas giving", the load rises to point 1′. Acceleration

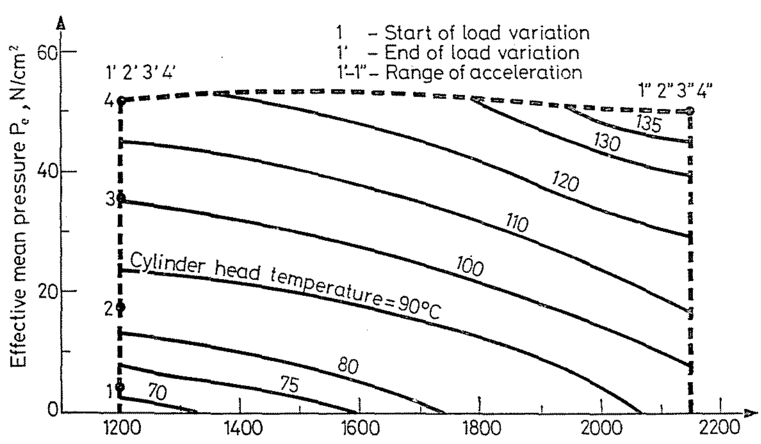

Fig. 2. Acceleration process in the characteristic curve field for mean pressure vs. *rpm*

takes place between points 1′ and 1″. Cylinder head temperature — characteristic of the combustion chamber temperature — lags behind, rather than to match — the variations of load and *rpm*. 90% of the temperature value is achieved in about 55 to 60 sec, while acceleration is complete in 5 to 8 sec, that is, in fact, temperature of the cylinder head (combustion chamber) hardly varies in acceleration.

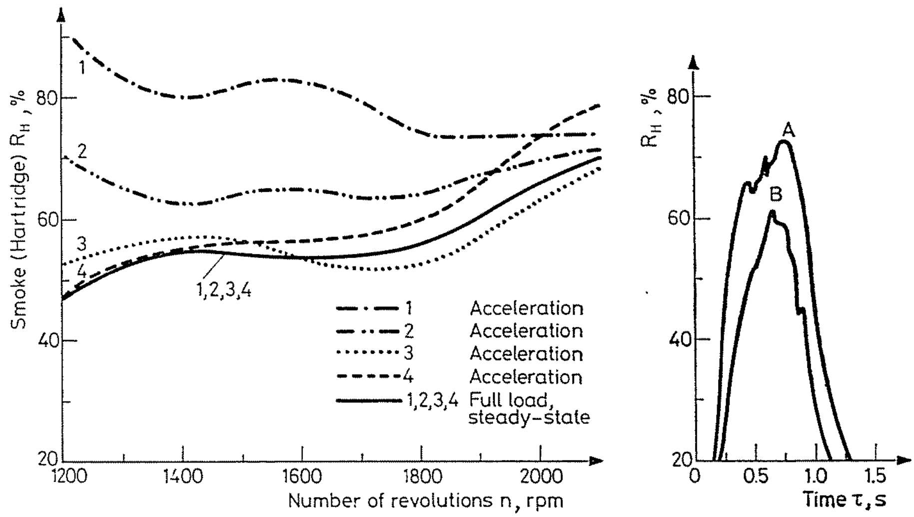

Fig. 3. Unsteady-state and steady-state smoke in full-load acceleration and in free acceleration

Smoke in acceleration at full load according to Fig. 2 is seen in Fig. 3, left side. The acceleration is 15 to 20 sec^{-2}. Also steady-state exhaust measurements have been plotted.

Unsteady-state smoke exhaust is seen to be higher, that is, worse than the steady-state one. The starting condition (1, 2, 3, 4 in Fig. 2) is decisive. A lower temperature of the combustion chamber increases the smoke exhaust, counteracted by the increased air intake of a cooler engine (max. 5%). Though, acceleration reduces the air intake. In the actual case, air intake decreased by about 3 to 6% due to acceleration.

For the sake of unsteady-state tests, the Hartridge apparatus was transformed in a way to produce the 90% value in 0.5 sec. A correction factor was applied for the error due to the lag.

After the outlined tests, the engine was disconnected from the dynamometer, to be accelerated against its own mass alone (free acceleration). Two curves recorded thereof are seen in the right side of Fig. 3. Curve "*A*" has been recorded in acceleration after steady-state operation — according to point 1 in Fig. 2. Curve "*B*" has been recorded after multiple accelerations, at a cylinder head temperature like point 2 in Fig. 2.

Curves "*A*" and "*B*" involve no correction, as free acceleration tests did not, either; acceleration was about 150 sec^{-2}.

Exhaust of Diesel engines in vehicle operation

Vehicle operation was simulated by running the "Europe run cycle". Rather than to fit the engine to a vehicle, acceleration was assumed to be always at full load, and acceleration time to equal that in run cycles.

In conformity with [2], numbers of revolutions range from a minimum to a maximum value (stage 1), and from a mean to a maximum value (stages 2 and 3). Of course, conditions may also be stipulated differently.

Trends of smoke R_H in critical sections of acceleration and of cylinder head temperature t_h along the run cycle have been plotted in Figs 4 and 5. Also steady-state t_h and R_h values under full load have been plotted for the sake of comparison. Smoke has only been plotted during acceleration, involving peak values.

Figures 4 and 5 indicate also velocity values (in dash-and-dot lines).

In course of acceleration, the cylinder head temperature but slowly increases, and it lags far behind the steady-state values. A lower temperature entrains increased

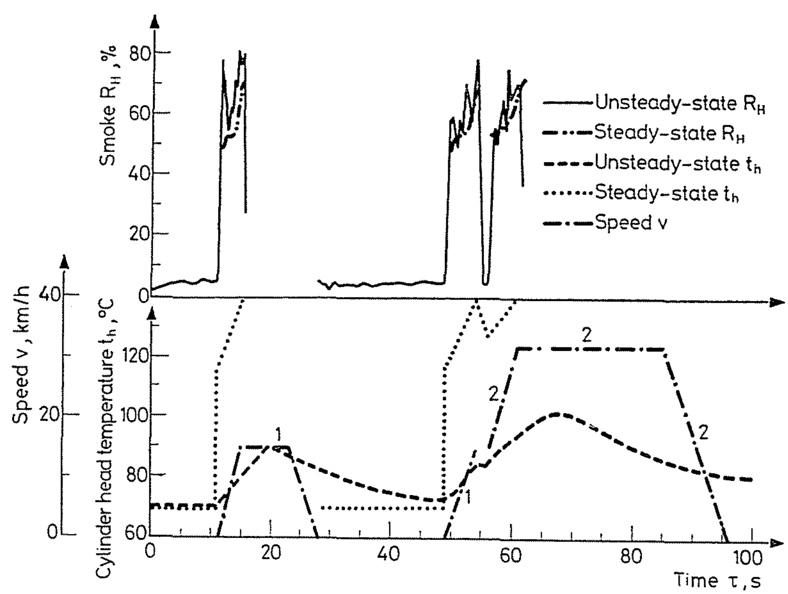

Fig. 4. Variations of smoke and of cylinder head temperature along the cycle

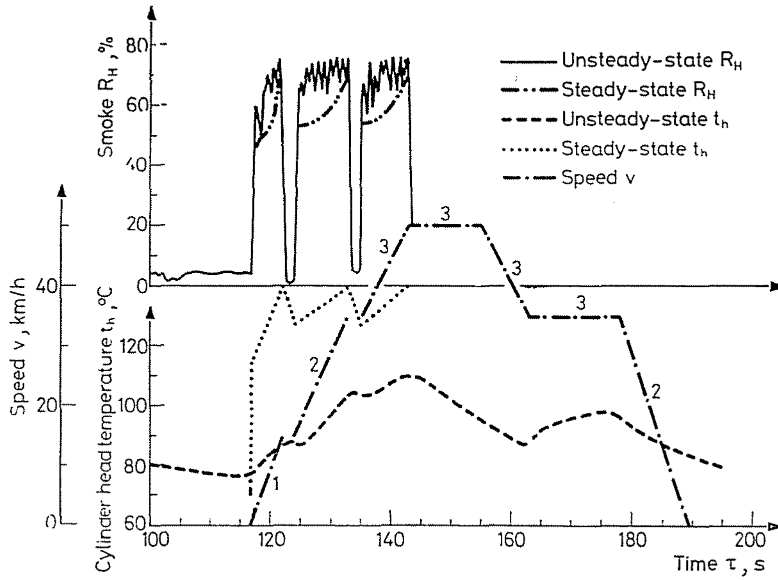

Fig. 5. Variations of smoke and of cylinder head temperature along the cycle

smoke exhaust — like that in Fig. 3. For any acceleration in stage 1, the engine cools almost to the starting temperature, worsening the exhaust.

In conformity with Figs 4 and 5, in vehicle (unsteady-state) operation, smoke values exceed those in steady-state operation. The tested engine showed significant differences. Though, another engine, with a MAN-M combustion chamber, exhibited a steady-state smoke exhaust of 18%, that increased to as high as $R_H = 63\%$ in unsteady-state operation!

Analysis of results, conclusions

Test results showed the smoke exhaust in unsteady-state operation to exceed that in steady-state operation.

Smoke values in free acceleration (see Fig. 3). are not typical of the vehicle operation, since the angular acceleration much differs from that under real conditions. Besides of that, the Hartridge apparatus records the process with a lag, simply defying correction of errors.

Free-jet exhaust meters of different brands, practically synchronous with the process, are more expedient.

Smoke values obtained in steady-state operation are in themselves not typical of those in unsteady-state operation (e.g. urban traffic). No direct relationship can be found between smoke values in either operation, they being dependent on several circumstances: engine type, engine-vehicle interaction, accelerational conditions, load conditions, etc.

The regulation for steady-state smoke exhaust provides for respecting a smoke level only close to reality. To check real (unsteady-state) smoke exhaust, Diesel engines have to be cycle tested — similar as for Otto engines.

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Dr. Attila MEGGYES H—1521 Budapest
Dr. Mohamed Abu EL-ENIN University of Port-Said Egypt.