INTERNATIONAL STANDARD

ISO 13555-3

First edition
2004-07-15

Diesel engines — Procedure for checking the dynamic timing of diesel fuel injection equipment —

Part 3: Validation of timing measurement devices

Moteurs diesels — Procédure pour contrôler le calage dynamique de l'équipement d'injection de combustible diesel —

Partie 3: Validation des dispositifs de mesurage du calage

Reference number
ISO 13555-3:2004(E)

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13555-3 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 7, *Injection equipment and filters for use on road vehicles*.

ISO 13555 consists of the following parts, under the general title *Diesel engines — Procedure for checking the dynamic timing of diesel fuel injection equipment*:

— *Part 1: Preconditioning*

— *Part 2: Test method*

— *Part 3: Validation of timing measurement devices*

Diesel engines — Procedure for checking the dynamic timing of diesel fuel injection equipment —

Part 3: Validation of timing measurement devices

1 Scope

This part of ISO 13555 specifies a test rig and reference method for the validation of timing measurement devices which, by application of the pressure-sensing principle on the high-pressure fuel injection pipe, are used for checking the dynamic setting of fuel injection equipment fitted to diesel engines. (In order to produce a realistic measurement situation, the test rig allows the addition of vibrational excitation of the high-pressure fuel injection pipe — deemed a primary source of signal corruption when used on running diesel engines.) The validation procedure can be used either in the initial approval of a timing measurement device or the verification of its proper functioning when already in use. The aim is to ensure that the devices supplied by different manufacturers provide comparable measurement results.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8535-1, *Compression-ignition engines — Steel tubes for high-pressure fuel injection pipes — Part 1: Requirements for seamless cold-drawn single-wall tubes*

ISO 8535-2, *Compression-ignition engines — Steel tubes for high-pressure fuel injection pipes — Part 2: Requirements for composite tubes*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE All rig angles are given in terms of engine crankshaft angles (crank angles).

3.1
test rig
test device which consists of an operable fuel injection system of conventional type (pump–pipe–injector) and means for the evaluation of sensed signals according to the specified procedure

3.2
clip-on transducer
sensor that can be clamped onto the high-pressure fuel injection pipe to detect dynamic pipe dilations

3.3
top dead centre
TDC
dead centre when the piston is farthest from the crankshaft

[ISO 2710-1:2000, definition 10.1.4.2]

3.4
injection event
time at which the fuel pressure has risen to x % of its peak value, where x % is a defined percentage (e.g. 11 % or 15 %) of the preceding injection

NOTE The peak pressure of the preceding injection is taken as 100 % and the mean pressure between injections is taken as 0 %.

3.5
crankshaft position sensor
sensor producing one or more defined electrical signals, each representing a specified engine crankshaft position

NOTE A plug-in or built-in crankshaft position sensor, e. g. as used for ignition systems testing, is commonly used for diesel engines, too.

3.6
rotational event
reference rotational position of the engine with a known relation to the TDC of the engine reference cylinder, sensed according to the engine manufacturer's recommendation by a pick-up ("TDC-sensor")

3.7
stroboscopic event
reference position of the engine made visible by a stroboscope

3.8
engine speed
mean actual rotational speed of the engine crankshaft, given by the time period between two successive events, which can be either injection events or, preferably, rotational events

NOTE On a 4-stroke engine, one injection period equals two crankshaft revolutions.

3.9
time-to-crank-angle conversion
any event determined on a time base that can be expressed on the engine crank angle base if the relation to the TDC is known

3.10
reference readings
engine speed and crank angle position of the injection event as measured on the test rig

3.11
test readings
engine speed and crank angle position of the injection event as measured by the device under test

4 Test rig

4.1 Apparatus and general components

4.1.1 Main frame with fuel tank and conventional fuel injection system (pump-pipe-injector), the fuel injection pump normally being driven by an electric motor, the injected fuel recirculated into the fuel tank. See, also, 4.2.2, and Figure 1.

4.1.2 High-pressure fuel injection pipe, divided into two sections, and with a vibration-generating device (4.1.3) connected to it in its centre. Both the high-pressure fuel injection pipe and the vibration-generating device are specially prepared with mounting locations for the clip-on transducer and the fuel pressure reference sensor(s). The diameters of the pipe sections at the clip-on transducer mounting locations are the minimum and maximum outside, and minimum internal, diameters, according to the tolerances given in the relevant standards (see ISO 8535-1 and ISO 8535-2). The pipe sections and the sensor-mounting device are exchangeable, in order to allow testing of different pipe outside diameters — from 4,5 mm up to 6 mm (nominal values). See, also, 4.2.5.

4.1.3 Vibration-generating device for vibrating the high-pressure fuel injection pipe at the clip-on transducer mounting locations; this device produces vibration in both radial and bending modes. See, also, 4.2.5.

4.1.4 High-precision fuel pressure reference sensor, positioned close to the clip-on transducer mounting locations for detecting fuel pressure in the high-pressure fuel injection pipe.

4.1.5 Two markers on the pump flywheel for a **crankshaft position sensor**, producing a trigger signal twice per pump revolution and thus simulating an engine crankshaft position sensor at a nominal 20° crank angle after the TDC.

4.1.6 Stroboscope light flash detection sensor, used for the detection of the stroboscopic event, where the device under test features a stroboscopic output. See, also, 4.4.

4.1.7 Electric and electronic components commercially available (preamplifiers, electric controls and interfaces).

4.1.8 Data acquisition and evaluation unit, commercially available, allowing for the recording, evaluation, and presentation of the sensor reference signals according to the defined method.

4.2 Mechanical components

4.2.1 General

Figure 1 shows a schematic of the main frame with the fuel tank.

Figure 2 shows a schematic of the fuel injection pump with flywheel and pump drive.

Figure 3 shows a schematic of the vibration-generating device, including the sensor locations.

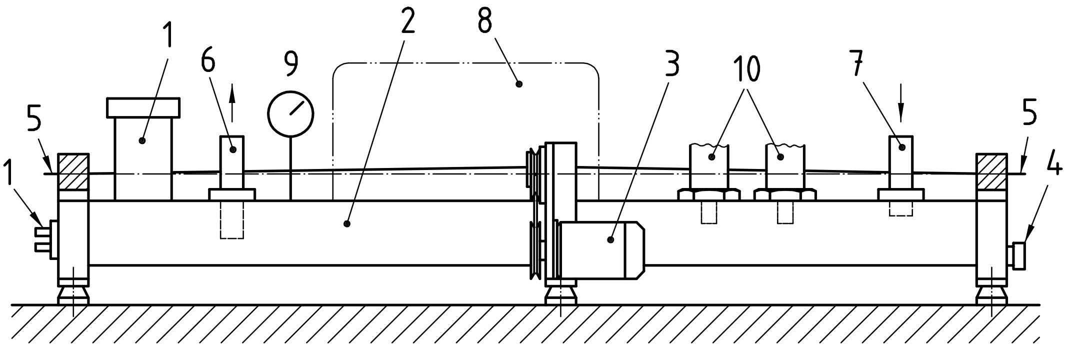
4.2.2 Main frame (see Figure 1)

4.2.2.1 Fuel tank with filler neck, drain plug, fuel temperature gauge and fuel injectors, with the volume of the fuel tank dimensioned so as to ensure almost-constant fuel temperature conditions during operation of the test rig, and a flange adapter being provided on the side of the fuel tank for attaching a fuel temperature conditioning unit, if required.

4.2.2.2 Two sections of the high-pressure fuel injection pipe (4.1.2), with vibration-generating device (4.1.3), mounted on the fuel tank unit, allowing free access to the pipe sections and the clip-on locations.

4.2.2.3 Fuel injection pump with flywheel (see 4.2.4), typically driven by an electric motor, mounted on a separate base and vibrationally decoupled from the fuel tank, having a cover to ensure proper absorption and insulation of the noise generated by the electric motor and the fuel injection equipment. See Figure 2.

4.2.2.4 Cabinet mounted on the main frame (main frame cabinet), provided for the electrical and electronic installation to permit central connection to the power supply, the casing of any electric motor control units, and an easy connection and feed-through of the reference sensor signals to the data acquisition system.



Key

1 filler neck
2 fuel tank
3 asynchronous electric motor with vibration-generating device
4 drain plug
5 connection for high-pressure fuel injection pipe assemblies: one to the fuel injection pump; the other to the fuel injector
6 supply to fuel injection pump
7 fuel return from fuel injection pump
8 cabinet for the electrical and electronic installation (main frame cabinet)
9 fuel temperature gauge
10 fuel injector
11 flange adapter

Figure 1 — Schematic of main frame with fuel tank

4.2.3 Fuel injection equipment

4.2.3.1 Fuel injection pump, typically a two-cylinder in-line pump, with one cylinder in operation, e.g. Bosch, Type A, No. E 040 089 500 [1)]. See Figure 2.

4.2.3.2 Fuel injectors, e.g. Bosch, Type S, No. 9 430 032 256 [1)], fitted with hole-type nozzles.

4.2.3.3 Accessories (e.g. feed pump, filter, overflow valve, etc.) as required.

4.2.4 Pump drive and flywheel (see Figure 2)

Typically, an electric motor of 1,5 kW with a speed control is used to drive the fuel injection pump and an attached flywheel.

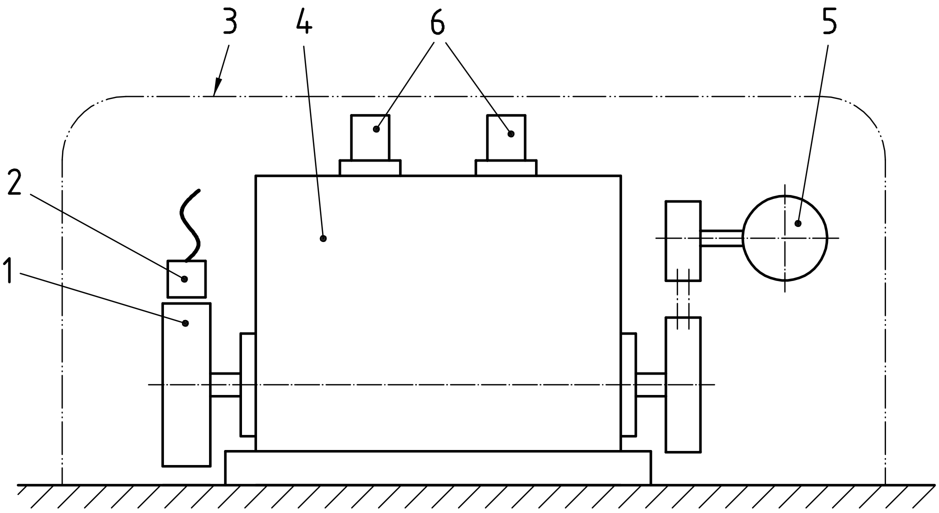
These components are mounted on a separate base plate and decoupled from the vibrations of the main frame.

In addition to the requirement for an adequate moment of inertia, the flywheel shall have a diameter sufficiently large to give the required accuracy for the two reference position sensors. The repeatability shall be 0,1° crank angle and the minimum diameter for the flywheel 300 mm. One sensor shall be positioned at – 20° crank angle (20° after TDC) and the other 180° from that position.

The flywheel position on the pump shaft shall be set to achieve an injection event at approximately 12° crank angle before TDC. This results in a difference between the injection event and the TDC of 12° crank angle and a simulated reference crankshaft position of 32° crank angle, in accordance with Table 1.

---

1) These are examples of suitable products available commercially. This information is given for the convenience of users of this part of ISO 13555 and does not constitute an endorsement by ISO of these products.



Key

1 flywheel with crank angle markers
2 crankshaft position sensor
3 cover for absorption and insulation of noise
4 fuel injection pump (2-cylinder in-line pump) with accessories
5 electric motor
6 fuel injection pump outlets

Figure 2 — Schematic of fuel injection pump with flywheel and pump drive

Table 1 — Crankshaft and pump shaft positions (crank angles) for timing events

Timing event	Crankshaft position	2 sensor positions (on flywheel)	
Injection event (1 per 720° crank angle)	+ 12° (12° before TDC)	0°	—
TDC of reference cylinder	0°	−6°	+174°
Rotational events (reference positions)	−20° (20° after TDC)	−16°	+164°
The pump shaft 0° position shall be adjusted precisely to the injection event at 12° crank angle before TDC.			

4.2.5 High-pressure fuel injection pipe and vibration-generating device (see Figure 3)

The high-pressure fuel injection pipe with clip-on transducer mounting locations shall be exchangeable, in order to allow for testing of different pipe outside diameters: from 4,5 mm up to 6 mm (nominal values).

The high-pressure fuel injection pipe shall be divided into two sections of equal length (each approximately 300 mm), one leading to, and the other from, the vibration-generating device, which shall have an integrated fuel pressure reference sensor. Each section of the high-pressure fuel injection pipe shall have a clip-on transducer mounting location close to the fuel pressure reference sensor (max. distance 30 mm).

The diameters of the high-pressure fuel injection pipe at the mounting locations shall be precisely defined at + 0,06 mm and – 0,06 mm, relative to the nominal value.

The vibration-generating device between the two sections of the high-pressure fuel injection pipe shall have an eccentric drive of eccentricity 2 mm and shall be driven by a “vee”-belt drive of 3:5 step-up ratio from an asynchronous electric motor with two selectable speeds.

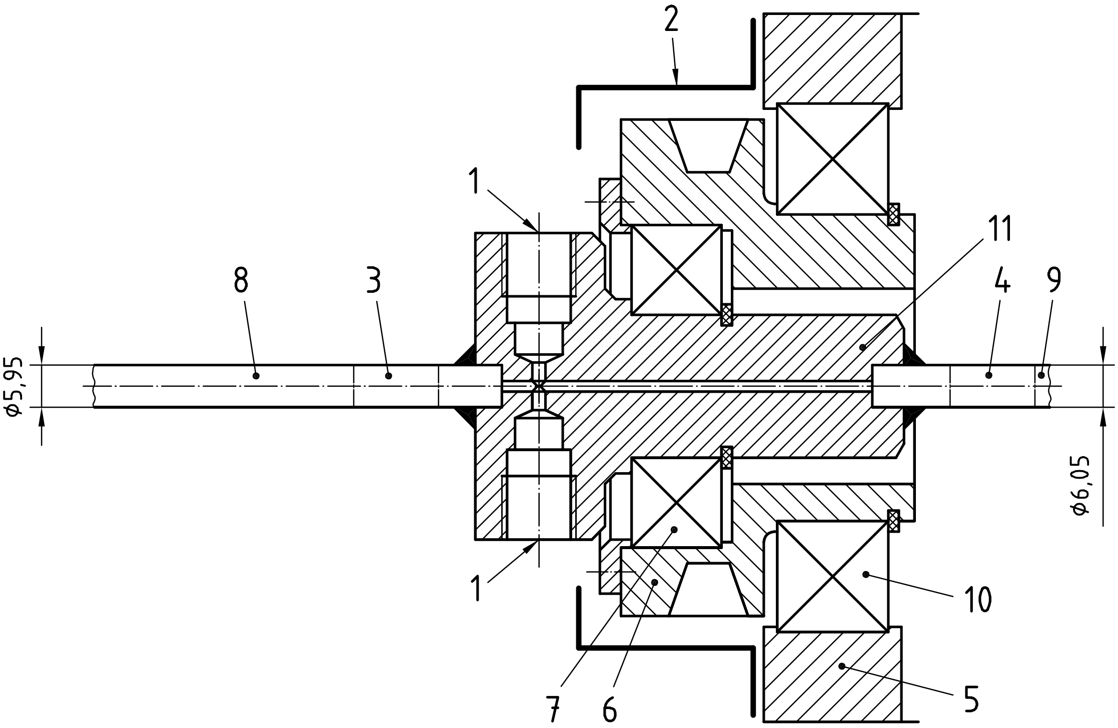
For a supply frequency of 50 Hz, the values shall be according to Table 2. The use of a different type of electric motor and electronic speed controller is permitted, provided the same results are obtained.

Table 2 — Radial acceleration for specified speeds of asynchronous electric motor — Supply frequency: 50 Hz

Number of poles	Speed of motor	Speed of eccentric	Radial acceleration
4	1 500 min^{-1}	2 500 min^{-1}	approx. 100 ms^{-2} eff.
2	3 000 min^{-1}	5 000 min^{-1}	approx. 400 ms^{-2} eff.

The two sections of the high-pressure fuel injection pipe shall be welded to a central piece of the eccentric drive (sensor mounting device), thus enabling the eccentric drive to vibrate each section of the high-pressure fuel injection pipe at the clamp locations in both modes: radial and bending. The other ends of the two sections of the high-pressure fuel injection pipe shall be tightly fixed to the main frame and connected via the high-pressure fuel injection pipe assemblies to the fuel injection pump and the fuel injector.

NOTE The vibrations will not have a constant phase relationship with the injection events, because of the load dependent slip of the asynchronous electric motors used.



Key

1 port for fuel pressure reference sensor (180° displaced on the circumference, if two are present)
2 guard
3 measurement (mounting) location, with min. outside diameter (e.g. ∅ 5,94 mm) [a]
4 measurement (mounting) location, with max. outside diameter (e.g. ∅ 6,06 mm) [a]
5 mounting plate
6 “vee”-belt pulley
7 bearing
8 pipe section
9 pipe section
10 bearing
11 sensor mounting device

[a] The measurement locations are interchangeable.

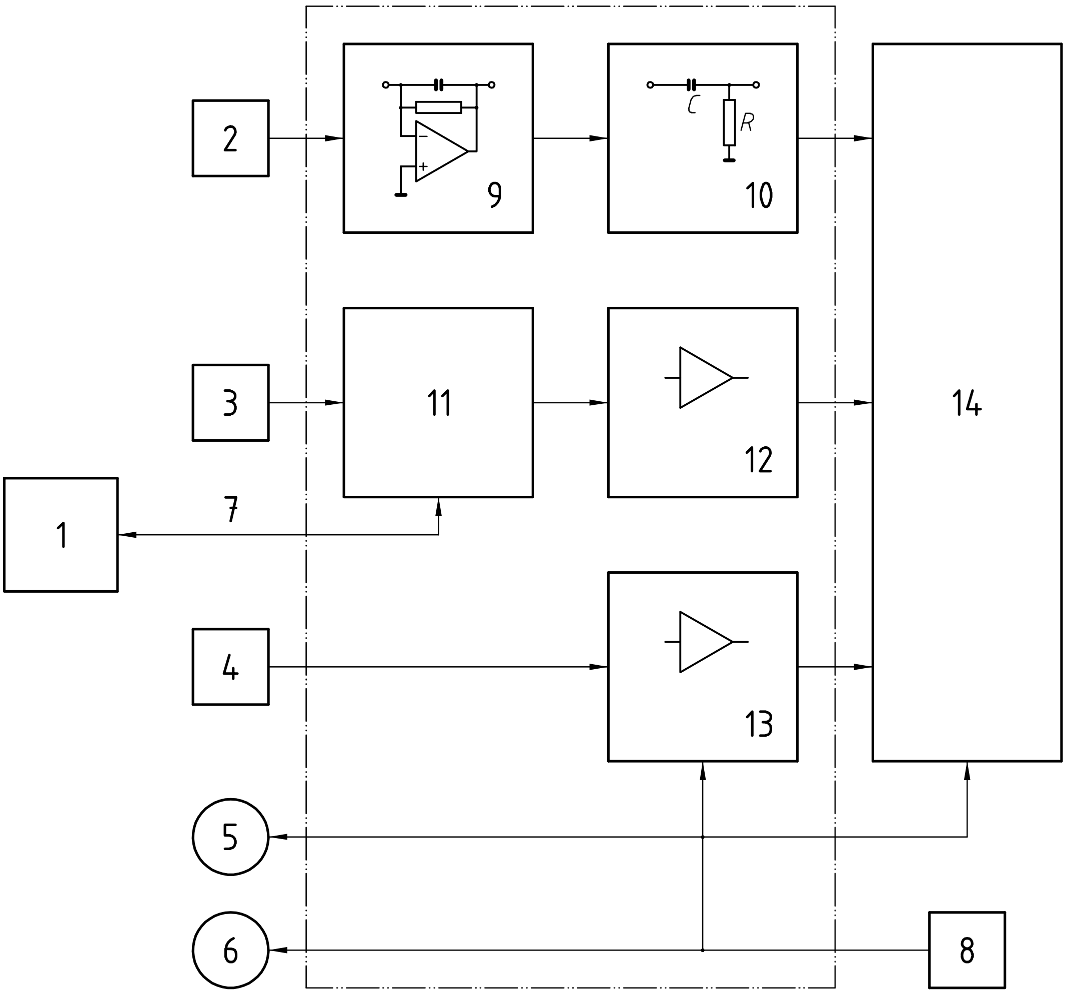
Figure 3 — Schematic of vibration-generating device with sensor locations for pipe of 6 mm outside diameter (nom.)

4.3 Sensors and electronic component

The electronic system shall consist of three measurement chains of a standard data acquisition and evaluation system. Additional input/output channels may be used for the control and monitoring of the test rig operation.

See Figure 4.

An example in detail of the electronic system is given in Annex A.



Key

1 device under test
2 fuel pressure reference sensor
3 pump timing sensor
4 stroboscope light flash detection sensor
5 pump drive electric motor
6 eccentric drive asynchronous electric motor
7 TDC sensor connection
8 mains: 50 Hz
9 charge amplifier
10 high-pass filter
11 selector and connection network
12 preamplifier (if required)
13 preamplifier (if required)
14 data acquisition and evaluation unit

Figure 4 — Schematic of electronic system with three measurement chains

4.4 Provisions for stroboscopic operation of device under test

A stroboscope light flash detection sensor shall be used to test the device under test with a stroboscope as an alternative to the operation with the crankshaft position sensor.

On performing the test, set the stroboscope and, respectively, the device under test, in a first run to a crank angle of 0° (which means flashing at the injection event) and, if possible, in a second run to 12° — which means flashing at TDC, i.e. 12° later than the injection event. Then, the reference readings shall give 0° and 12° respectively.

Direct the stroboscope towards the light flash detector. Record the light flash signal and set in relation to the other reference signals.

NOTE 1 The use of the light flash detection sensor has the following advantages:

- a possible operator error in the operation of the stroboscope is eliminated;
- no stroboscope markers on the flywheel are required.

NOTE 2 The use of either stroboscope type — crank angle fixed to zero degree or adjustable crank angle — is possible.

5 Validation procedure

Perform the following procedure in the sequence given.

a) Precondition the device under test and the test rig according to the manufacturer's specifications; check to ensure that the fuel temperature is between 18 °C and 30 °C.

b) Connect the device under test to the test rig and mount the clip-on transducer at one of the defined measurement locations. Perform measurements sequentially at both locations.

c) Start the fuel injection pump to perform measurements.

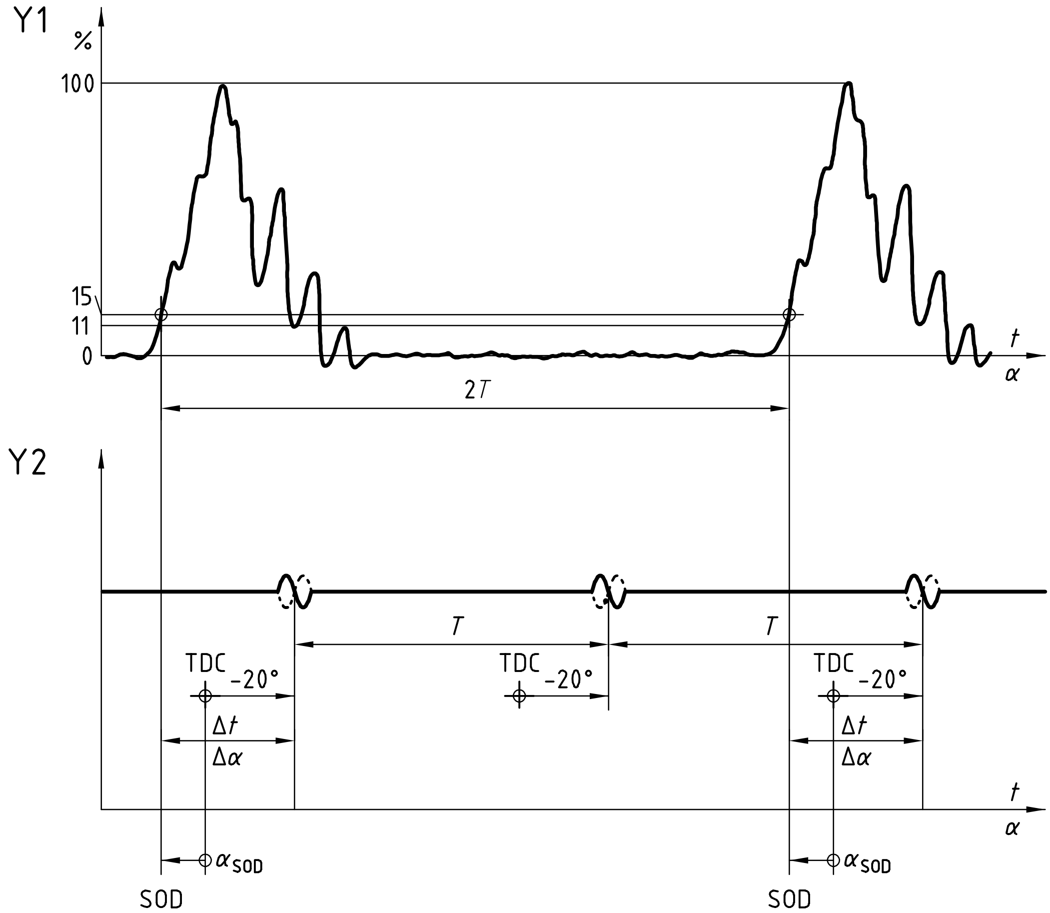
d) Perform measurements with and without induced vibrations generated by the eccentric drive at the defined two speeds.

e) Where the stroboscopic operation of a device under test has adjustable crank angle, perform measurements

   1) at the crank angle set to 0°, then

   2) at the crank angle set to 12°.

f) Record the test readings and respective camshaft position sensor signals over at least 5 consecutive injection cycles; see Figure 5 for the principal relationship between test readings and sensor signals. Each cycle shall be presentable on screen and shall be evaluated in accordance with Clause 6.



Key

Y1	line pressure
Y2	camshaft position sensor signal
T	engine revolution period, in seconds
t	time, in seconds
α	angular rotation, in degrees, crankshaft
α_{SOD}	start of delivery angle, in degrees
Δt	time interval from start of delivery to crankshaft to position sensor signal, in seconds
$\Delta\alpha$	angular rotation interval from start of delivery to crankshaft position sensor signal, in degrees
SOD	start of delivery
TDC	top dead centre

Figure 5 — Evaluation of test readings and related camshaft position sensor signals

6 Recording and evaluation of test results

Using the data acquisition and evaluation system, make a fully transparent presentation of the reference signals and determination of the reference readings, as follows.

a) Present the preamplified reference fuel pressure AC-coupled signal as a trace on an arbitrary (voltage) scale over time, the time window being triggered by the pump timing sensor signal and having a width to include the fuel pressure pulses of the evaluated 5 consecutive injections.

b) Indicate the actual 0 %-value position given by the zero voltage of the a.c.-coupled or high-pass filtered fuel pressure reference signal.

c) Indicate the actual 100 %-value position given by the fuel pressure a.c.-coupled reference signal peak value of the preceding injection event.

d) Indicate the actual x %-value position — x % being selectable as one of the pre-defined values, e. g. 11 % or 15 % — with reference to the 0 %- to 100 %-value span, as defined above.

e) Indicate the time of the injection event by means of a cursor of the x %-value line crossing the fuel pressure reference signal for the last time before the signal rises to its peak fuel pressure.

f) Present the preamplified pump timing trigger signal used to trigger the presentation time window.

g) Indicate the reference time position given by the pump timing trigger signal and indicate a nominal 20° crank angle before TDC position.

h) Evaluate and indicate the engine speed as a result of the time interval between two consecutive rotational events.

i) Evaluate and indicate the result of the injection event crank angle position calculated in relation to the reference time position.

j) Present the stroboscope light flash signal used to correlate the stroboscopic measurement to the rotational event.

k) Indicate the crank angle offset between the rotational event and the stroboscope flash.

l) Calculate and indicate the reference readings given by the mean of 8 consecutive values of engine speed and the injection event crank angle.

7 Allowed deviation of the device signal

The deviation of the signal of the device under test to the reference signal given by the test rig shall not exceed ± 0,5°.

Annex A
(informative)

Description of the electronic system (typical)

A.1 System specifications

The typical system's specifications are as follows:

- system accuracy of 12 bit (min.);
- high impedance voltage inputs (1 mΩ min.) of data acquisition and evaluation unit;
- data sampling rate of 100 kHz (min.), synchronously at three input channels (min.);
- anti-aliasing filters for all channels;
- buffer type data recording of the three input channels (min.) continuously during at least 5 injection periods (800 ms at a pump speed of 375/min);
- signal evaluation off-line, with representation of the measured signals on a screen, and indication of the deduced trigger levels, and resulting trigger time positions and time intervals, respectively;
- continuous synchronisation of test readings and reference readings;
- manual start to record the reference data.

A.2 Basic system components

A.2.1 High-precision fuel pressure reference sensor connected to a precision amplifier contained in the main frame cabinet. The amplifier intrinsic high-pass filter cut-off frequency shall meet both the requirements of

- long-range operation over several injection periods, and
- signal base drift elimination.

If two fuel pressure sensors are used, both shall meet all of the above requirements.

As a compromise, the cut-off frequency shall be set below 0,16 Hz (corresponding to a time constant of higher than 1 s).

A.2.2 Passive first-order high-pass filter, consisting of a coupling capacitor C (2,2 µF) and a resistor R (100 kΩ) which gives a time constant (RC) of 220 ms and a cut-off frequency of 0,72 Hz. This is used to eliminate any d.c.-offset of the preamplifier output voltage and to produce an a.c.-coupled output voltage to the data acquisition and evaluation unit. In order to prevent unacceptable loading, the minimum acceptable input impedance of the data acquisition and evaluation unit is 1 MΩ.

A.2.3 Pump timing sensor of an inductive current-fed type without permanent magnet (see Note to 3.5) connected to an interface circuit contained in the main frame cabinet. This interface provides for the splitting of the signal and supply currents which may be required for the connection, in parallel, of the test rig data acquisition and evaluation unit and the device under test.

A.2.4 If the stroboscope light flash detection sensor is used, connect the sensor to a **preamplifier**. The signal is passed to the data acquisition and evaluation unit and correlated to the injection event to give the reference readings.

A.2.5 **Data acquisition and evaluation units** which are functionally defined and which may consist of a digital storage oscilloscope or a PC with plug-in data acquisition boards and a related software package. Preferably, the unit will be based on commercially available products.

A.3 Automatic data recording

Software may be used to facilitate the operation of the test rig by automatic data recording and evaluation.

The system should allow a free-running, continuous indication of the reference readings, and be able to manually store the recorded data and the reference readings obtained from the last injections. Comparison can then be made with the test readings taken from the device under test at the same instant.

Bibliography

[1] ISO 2710-1:2000, *Reciprocating internal combustion engines — Vocabulary — Part 1: Terms for engine design and operation*

[2] ISO 4093, *Diesel engines — Fuel injection pumps — High-pressure pipes for testing*

[3] ISO 13296:1997, *Diesel engines — High-pressure fuel injection pipe assemblies — General requirements and dimensions*

[4] ISO 13296:1997/Cor 1:2000, *Diesel engines — High-pressure fuel injection pipe assemblies — General requirements and dimensions — Technical Corrigendum 1*

ICS 43.060.40

Price based on 13 pages