International Standard ISO 4008/1

Road vehicles — Fuel injection pump testing —
Part 1 : Dynamic conditions

Véhicules routiers — Essai de pompe d'injection à gazole — Partie 1 : Conditions dynamiques

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 4008/1 was developed by Technical Committee ISO/TC 22, *Road vehicles*, and was circulated to the member bodies in July 1979.

It has been approved by the member bodies of the following countries :

Austria	Japan	South Africa, Rep. of
Belgium	Korea, Dem. P. Rep. of	Spain
Chile	Korea, Rep. of	Sweden
China	Libyan Arab Jamahiriya	Switzerland
Czechoslovakia	Netherlands	United Kingdom
France	New Zealand	USA
Germany, F. R.	Poland	USSR
Italy	Romania	

No member body expressed disapproval of the document.

This second edition cancels and replaces the first edition (i.e. ISO 4008-1977).

Road vehicles — Fuel injection pump testing — Part 1 : Dynamic conditions

Foreword

This International Standard aims to achieve correct setting and adjustment of fuel injection pumps for compression ignition engines by providing standardised conditions for testing.

Part 1 of the International Standard deals with the dynamic behaviour of the rotating components (and certain other components) of the test bench and pump under test. Non-compliance with the dynamic characteristics detailed below can produce large errors in injection pump delivery. Adherence to certain related International Standards listed in clause 3 is essential for the total application of this International Standard.

0 Introduction

The accuracy of readings made on a fuel injection pump test bench depends on the ability of that test bench to fulfil, within acceptable tolerances, all the dynamic demands made by the particular injection pump being tested. In order to establish, in practice, the suitability of any test bench to test any injection pump, this International Standard requires the manufacturers of the test bench and of the injection pump to supply certain data on their products.

Based on this data, together with the injection pump manufacturer's test schedule and certain other typical numerical values common to injection pump operation, this International Standard provides the means to determine whether a particular test bench is capable of satisfying the dynamic demands of a particular injection pump.

1 Scope

1.1 This International Standard defines only the requirements and characteristics of test benches necessary to ensure consistent results when an injection pump is tested to the manufacturer's test specification regardless of the origin of the test bench.

1.2 This International Standard establishes a form in which the test bench manufacturer shall define the capacity of his test benches in terms which enable the user to ensure that he keeps within the requirements and characteristics necessary for any particular injection pump to be tested.

2 Field of application

2.1 This International Standard is primarily applicable to test benches suitable for calibration of fuel injection equipment for compression ignition engines requiring fuel delivery up to 300 mm^3/injection/cylinder at full load.

2.2 No distinction is made between test benches used for different applications, for example laboratories, manufacturers of fuel injection equipment or service stations.

3 References

The following International Standards are essential for the total application of this International Standard :

ISO 4008/2, *Road vehicles — Fuel injection pump testing — Part 2 : Static conditions.*[1]

ISO 4010, *Road vehicles — Calibrating nozzle — Delay pintle type.*

ISO 4020/1, *Road vehicles — Fuel filters for automotive compression ignition engines — Part 1 : Test methods.*

ISO 4020/2, *Road vehicles — Fuel filters for automotive compression ignition engines — Part 2 : Test values and classification.*

ISO 4093, *Road vehicles — Fuel injection pumps — High pressure pipes for testing.*

ISO 4113, *Road vehicles — Fuel injection equipment — Calibration fluid.*

4 Definitions

For the purpose of this International Standard, the following definitions apply :

4.1 Description of terms

4.1.1 angular creep : Limited angular movement which occurs between two interacting members only when under torsional strain.

4.1.2 backlash : Angular clearance between two interacting members.

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1) At present at the stage of draft.

4.1.3 **coupling** : Component connecting the driveshaft to the driven shaft.

4.1.3.1 **coupling mounting face** : The face of the driveshaft for attachment of the coupling.

4.1.3.2 **coupling output driving face** : The face of the termination member of the coupling which engages the driven shaft (or an adaptor on the driven shaft) of the injection pump.

4.1.3.3 **coupling stiffness** : The torsional stiffness between the mounting face and the output driving face of the coupling.

4.1.4 **driveshaft** : The member (or integral protrusion from the flywheel) connecting the flywheel to the coupling mounting face.

4.1.5 **driven shaft** : The input shaft for operating the injection pump.

4.1.6 **dynamic characteristics** : The values of those elements of stiffness and inertia which together control the amplitude of cyclic deviation from relative mean angular speed between the driven shaft and the injection pump housing.

4.1.7 **flywheel** : A rotating mass to which the driveshaft is attached.

4.1.8 **full load** : The maximum injection pump power demand.

4.1.9 **injection pump delivery** : The volume of fuel delivered in a single injection at full load.

4.1.10 **delivery period** : The driveshaft angle in degrees represented by the plunger stroke between port closure and port opening at full load.

4.1.11 **mean injection pressure** : The average pressure of the injection, at full load, and measured at the injection pump outlet.

4.1.12 **peak injection pressure** : The highest injection pressure reached during one injection at full load and measured at the injection pump outlet.

4.1.13 **interface** : The whole extent of surface contact between two interacting components.

4.1.14 **maximum delivery setting** : The maximum setting according to the manufacturer's test schedule for the injection pump.

4.1.15 **number of cylinders of an engine** : The number of power strokes in one complete cycle.

4.1.16 **number of cylinders of an injection pump** : The number of pumping actions in one complete engine cycle.

4.1.17 **overall pumping efficiency** : The percentage of mechanical input power represented by hydraulic output power at full load.

4.1.18 **speed droop of a test bench** : The drop in mean speed which occurs as a result of increasing the load at any fixed speed selection setting.

4.1.19 **speed droop of an injection pump governor** : The drop in mean speed necessary to increase pump delivery from minimum to maximum.

4.1.20 **specific speed droop** : The speed droop, expressed as a percentage of initial speed which occurs as a result of increasing the load from one specific value to another.

4.1.21 **test bench** : Device for testing, calibrating and adjusting a fuel injection pump, comprising at least the following :

— coupling mounting face;

— flywheel;

— injection pump mounting arrangement;

— prime mover;

— pump delivery measuring system;

— test injector holder;

— test oil supply system;

— transmission.

4.1.22 **test speed** : The specific speed at which any particular injection pump test is required to be made under conditions in accordance with the requirements of this International Standard.

4.1.23 **mean injection torque** : The average torque acting through 10° of rotation required to deliver one injection at full load.

4.1.24 **peak injection torque** : The highest torque encountered during an injection period at full load.

4.1.25 **transmission of a test bench** : The whole of the mechanism connecting the prime mover to the flywheel.

4.1.26 **transmission of an injection pump** : The combination of the driveshaft and coupling (including any special injection pump drive adaptor mechanism specified by the injection pump manufacturer or provided by the test bench manufacturer).

4.2 Symbols and units

The following symbols and units are used :

4.2.1 injection pump transmission stiffness : S, in newton metres per degree (N·m/°)

4.2.2 coupling stiffness : S_c, in newton metres per degree (N·m/°)

4.2.3 drive shaft stiffness : S_d, in newton metres per degree (N·m/°)

4.2.4 flywheel inertia : I, in kilogram metres squared (kg·m²)

4.2.5 torque : T, in newton metres (N·m)

4.2.5.1 mean injection torque : T_m, in newton metres (N·m)

4.2.5.2 peak injection torque : T_p, in newton metres (N·m)

4.2.6 injection pump delivery : Q_{max}, in cubic millimetres per injection per cylinder (mm³/injection/cylinder)

4.2.7 equivalent injection pump delivery : Q_e, in cubic millimetres per injection per cylinder (mm³/injection/cylinder)

4.2.8 injection period : D, in degrees (°)

4.2.9 injection pressure : p, in bars (bar)[1]

4.2.9.1 mean injection pressure : p_m, in bars (bar)

4.2.9.2 peak injection pressure : p_p, in bars (bar)

4.2.9.3 mean known (actual) injection pressure : p_{ma}, in bars (bar)

4.2.9.4 peak known (actual) injection pressure : p_{pa}, in bars (bar)

4.2.10 number of cylinders : Z

4.2.11 overall pumping efficiency : E, as a percentage %

4.2.12 power : P, in kilowatts (kW)

4.2.13 speed : n, (min⁻¹)

4.2.14 test speed : n_t, (min⁻¹)

4.3 Assumptions

For the purpose of this International Standard, the following

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1) 1 bar = 100 kPa.

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typical numerical values and relationships shall be assumed :

a) $D = 10°$

b) $p_m = 400$ bar

c) $E = 75 \%$

The pressure diagram of the injection shall be represented by a semi-sinusoidal form.

Hence :

$$p_p = p_m \times \frac{\pi}{2}, \text{ thus } p_p - 628 \text{ bar}$$

$$T_p = T_m \times \frac{\pi}{2}$$

5 Dynamic requirements

5.1 Required dynamic characteristics and limiting values

5.1.1 Speed variation at constant load

The mean speed of the driveshaft under any steady admissible load and stabilised power supply conditions, shall remain constant within ± 0,25 % at speeds above 800 min⁻¹ and within ± 2 min⁻¹ below 800 min⁻¹ for a period of not less than 1 min.

5.1.2 Flywheel

The test bench shall contain a flywheel which shall be capable of fulfilling the requirements of 5.1.3 when supplying from its stored energy the whole of the energy of injection without aid from the transmission.

5.1.3 Speed variation at cyclic load

The cyclic variation of instantaneous speed of the coupling mounting face of the driveshaft, due to the cyclic torque demand of the pump to be tested, shall not exceed 1 % from peak to peak at any design test condition. (See annex A; A.1).

5.1.4 Stiffness of the driveshaft

When subjected to the peak injection torque demand, the driveshaft shall not deflect angularly by more than 0,02°.

5.1.5 Stiffness of the coupling

When subjected to the peak injection torque demand, the coupling shall not deflect angularly by more than 0,1°.

5.1.6 Stability of the injection pump mounting

The mounting platform together with any adaptor provided by

the test bench manufacturer to mount the injection pump to be tested shall not permit angular deflection of the mounting face of the pump body, induced by the full load reaction of the torque pulse of an injection and about an axis parallel to the pump driven shaft, in excess of 0,02° with respect to earth.

5.1.7 Torsional resonance of the transmission of the test bench

Means shall be provided to prevent any other mass in the transmission from falling into torsional resonance with the flywheel when excited by the cyclic torque demand of an injection pump having the maximum number of cylinders provided for and when running at any speed within the test bench overall speed range.

5.1.8 Backlash

There shall be no backlash in the transmission of the injection pump between the flywheel and the coupling output driving interface.

5.1.9 Misalignment

The injection pump mounting platform together with any adaptor provided by the test bench manufacturer to locate the injection pump to be tested shall be so constructed that misalignment at the coupling between the axis of the driveshaft and the axis of the driven shaft does not exceed :

radially : 0,13 mm;

angularly : 0,25 mm over a length of 300 mm.

5.1.10 Angular creep

There shall be no angular movement between any two interacting members, between the flywheel and the coupling output interface, when subject to torque reversals equal to twice the peak injection torque.

5.2 Methods of test

5.2.1 The **speed variation at constant load** (see 5.1.1) shall be assessed by measured observation when running the test bench through a matrix of three speeds and three loads (covering 70 % of the available speed range and load range using a suitable dynamometer to absorb the load). Power supply voltage shall be checked using an on-line voltmeter across all lines. During the test, the power supply shall remain stable to within the following limits :

voltage : ± 0,5 %

frequency : ± 0,1 %.

5.2.2 Because of the large number of physical tests which would be represented by all the combinations of test bench type, injection pump type and test speed, **formulae** have been developed, based on the typical values and relationships shown in 4.3, so that the values for the flywheel inertia, driveshaft

stiffness and coupling stiffness necessary to achieve the required dynamic characteristics of 5.1.2 to 5.1.5 can be established by reference to the following two parameters at full load :

injection pump delivery : Q_{max};

test speed : n_t.

5.2.3 The values for flywheel **moment of inertia,** driveshaft torsional stiffness and torsional stiffness of couplings shall be established by physical measurement (for coupling stiffness, see annex C).

5.2.4 The **stability of the injection pump mounting** (see 5.1.6) shall be established by dynamic measurement using the special injection pump simulating apparatus and test procedure specified in annex B. At least five equispaced test speeds n_t within the overall speed range of the test bench shall be chosen and the equipment shall be operated to measure, relative to each chosen test speed, the value of the injection pump delivery Q at which the pump mounting face (including any pump locating adaptor) deflects angularly by 0,02° (See annex B; B.4.1).

5.2.5 The test bench **output power** and **speed droop** shall be checked by physical measurement using a suitable dynamometer connected to the test bench driveshaft. Five measurements of power P shall be made (at equispaced intervals of test speed n_t between the extremes of the stated range) to verify that the test bench can deliver its stated maximum permissible power. Four equispaced measurements shall be made through the speed range to obtain the speed droop values.

5.2.6 Absence of **backlash** and **angular creep** shall be checked by measurement by applying a reversal of torque between the flywheel and the coupling output driving face. The value of the torque to be applied shall be calculated according to the formula in A.4 (see annex A).

To apply the test, the flywheel shall be locked to the test bench main frame by any convenient means and the coupling shall be connected to a fuel injection pump or other suitable fixture. The torque shall be applied to the driven shaft first in a clockwise direction. (The fixture described in annex C may also be used).

It shall then be slowly reversed in an anti-clockwise direction. The applied torque shall then be relaxed and any resulting angular displacement at the interface of any two interacting components shall be measured with a resolution better than 0,02°. Special attention should be taken with respect to tapered and cylindrical interfaces and bolted flanges. The test shall be repeated five times in both directions of torque reversal.

NOTE — "Backlash" includes clearance of positive engagement clutches, torque limiting devices, or gears in a gear box.

5.2.7 Misalignment shall be checked by any suitable conventional apparatus with adequate resolution and stiffness. (Extension bars more than 200 mm long shall be not less than 30 mm diameter).

6 Product classification

6.1 Classification parameters

Test benches shall be classified in terms of the following two sets of parameters :

a) output power, speed range and speed droop[1];

b) the maximum injection pump delivery Q_{max} and test speed n_t which the test bench can accept within the tolerances stated in 5.1.3, 5.1.4 and 5.1.6.

6.2 Graphical form of presentation of characteristics

These characteristics shall be given by the test bench manufacturer in two graphical forms as shown in figures 1 and 2.
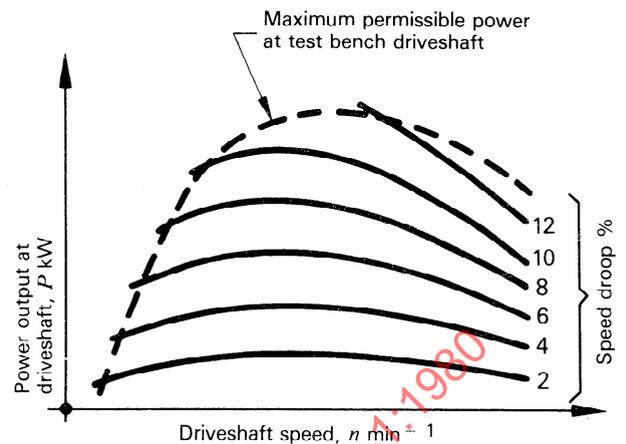
Figure 1 — Test bench power and speed droop characteristics — Graph 1
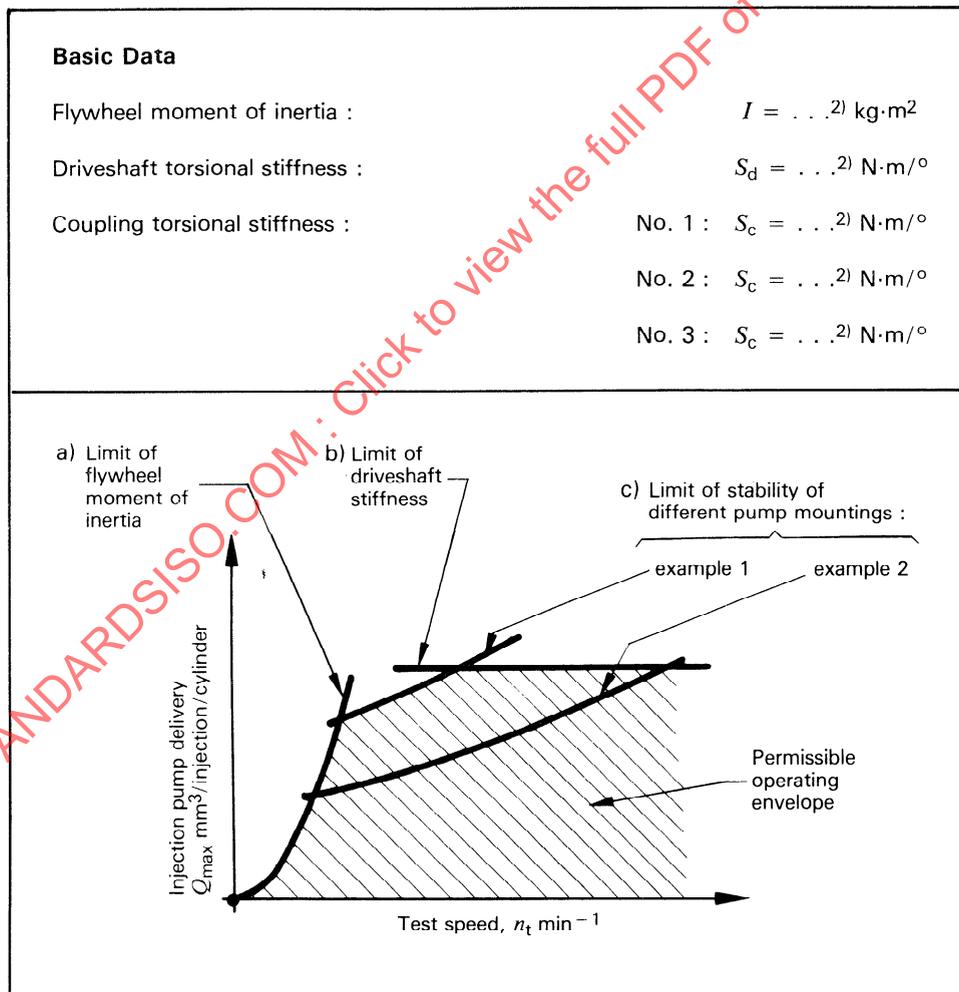
Figure 2 — Test bench permissible operating envelope and basic data — Graph 2

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1) Output power and speed droop may be measured by a dynamometer as shown in annex D.

2) Insert the appropriate value.

6.3 Construction of graph 2

Graph 2 shall be constructed using the formulae given in annex A (A.1 and A.2) and the testing apparatus specified in annex B. The basic operating envelope shall first be defined by the lines a) and b). Lines c), one for each type of injection pump mounting adaptor, shall then be superimposed. That portion of the basic operating envelope not cut off by the highest of the lines c)[1] shall be shaded and entitled "permissible operating envelope". The wording shown at a), b) and c) is for explanatory purposes only. The wording at a) and b) may be omitted entirely or altered to the customer's choice (for example "ISO limit"). But suitable wording shall be included relating to lines c) which clearly identify the injection pump mounting adaptors to which they refer.

6.4 Basic data

In addition to the graphs shown in figures 1 and 2, the test bench manufacturer shall give with graph 2 :

a) the moment of inertia of the flywheel in kilogram metres squared (kg·m²);

b) the torsional stiffness of the driveshaft in newton metres per degree (N·m/°);

c) the torsional stiffness of each coupling type supplied in newton metres per degree (N·m/°).

6.5 Variants

Where test benches have a combination, duplication or choice of driveshaft, flywheel, transmission or prime mover arrangements, each one shall conform in all respects with the requirements of this International Standard and additional graphs 1 and/or 2 shall be supplied as applicable.

6.6 Identification of couplings

Individual couplings shall be clearly marked in the following manner based on the stiffness formula in A.3 (see annex A) :

"MAX. . . .[2] mm³/stroke, S_c = ...[2] N·m/°".

6.7 Conformity of test benches to declared characteristics

The values of the characteristics declared by the test bench manufacturer shall be achieved as a minimum for all test benches to which this International Standard is claimed to apply.

6.8 Mean injection pressure

In cases where injection pressure, using test injectors and pipes, exceeds the assumed typical value, stated in 4.3, by a known amount, proportional adjustment should be made to the value of Q_{max} used when referring to the permissible operating envelope in graph 2.

Example :

An injection pump delivers 200 mm³/injection/cylinder at full load and the actual peak injection pressure is known to be 900 bar when using test injectors and pipes :

$$p_{pa} = 900 \text{ bar},$$

thus

$$p_{ma} = \frac{2}{\pi}\,900 \text{ bar} = 573 \text{ bar [see 4.3 d)]}.$$

By proportion :

$$Q_e = \frac{Q p_{ma}}{400} \text{ [see 4.3 b)]},$$

thus

$$Q_e = 200 \times 573/400 = 286 \text{ mm}^3/\text{injection/cylinder}.$$

The equivalent delivery Q_e of 286 mm³/injection/cylinder should now be compared with graph 2 to determine whether this particular injection pump falls within the permissible operating envelope of the test bench.

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1) If the highest line c) does not cut off any of the area of the operating envelope, it may be omitted. Alternatively, if it cuts off the whole of line b), line b) may be omitted.

2) Insert the appropriate value.

Annex A

Formulae to be used for constructing graph 2

A.1 Flywheel

The relationship between maximum permissible injection pump delivery Q_{max}, required test speed n_t and flywheel moment of inertia I, to ensure that the flywheel can liberate, from its stored energy, the whole of the energy of injection without the cyclic speed variation exceeding 1 %, shall be given by :

$$Q_{max} \cong In_t^2/480.$$

The above formula also requires that only mass(es) connected to the driving side of the coupling mounting face of the test bench by means having a torsional stiffness equal to or greater than that specified for the driveshaft (see A.2) shall be included in the flywheel inertia.

A.2 Torsional stiffness of the driveshaft

The relationship between driveshaft stiffness and maximum injection pump delivery Q_{max} to ensure that torsional deflection under peak injection torque does not exceed the maximum permissible value of 0,02°, shall be given by :

$$Q_{max} \cong S_d/28.$$

A.3 Torsional stiffness of coupling (see annex C)

The relationship between coupling stiffness and maximum injection pump delivery Q_{max} to ensure that torsional deflection under peak injection torque does not exceed the maximum permissible value of 0,1°, shall be given by :

$$Q_{max} \cong S_c/5.$$

A.4 Torque to be applied for measurement of coupling stiffness and detection of backlash and angular creep

The value of torque T to be applied in alternating directions for the purpose of measuring coupling stiffness and detection of backlash and angular creep in the injection pump transmission shall be twice the peak injection torque according to the formula :

$$T \geqslant Q_{max} \text{ (numerically)}$$

Annex B

Specification for the simulator which shall be used for measuring injection pump mounting stability

B.1 Operating principle

B.1.1 A flywheel receives initial kinetic energy from a first energizing spring (see figure 3).

B.1.2 Pads on a side face of the flywheel then contact two second stiff buffer springs, the other ends of which are connected to a mounting flange (see figure 4).

B.1.3 The mounting flange is located at the injection pump mounting face to be tested thereby transferring the torsional shock pulse, produced at the buffer springs, to the mounting face (see figures 8, 9, 10, 11 and 12).

B.1.4 The buffer springs are variable in effective torsional rate. The required test speed n_t to be simulated is achieved by selecting the appropriate value of torsional rate so that the time interval during which the pads are in contact with the buffer springs equals the time for 10° of rotation at the desired test speed n_t (see figures 4 and 5).

B.1.5 The amplitude of the torque pulse is equivalent to the simulated injection pump delivery Q and is controlled by the value of the initial strain in the energizing spring, which is proportional to Q/n_t.

B.1.6 An adjustment mechanism for the buffer spring effective torsional rate is suitably graduated in terms of test speed n_t (see figure 5). A strain scale associated with the energizing spring is suitably graduated in terms of Q/n_t (see figure 3). By setting both these scales, one single injection torque pulse of any delivery value Q at any test speed n_t can be simulated.

B.1.7 Deflection measuring instrumentation measures, against a time base, the angular deflection of the injection pump mounting face about an axis parallel to the pump driven shaft and with respect to earth.

B.2 Construction

B.2.1 Figures 3 to 7 show the constructional details, vital dimensions and tolerances. Material is generally mild steel except where stated otherwise.

B.2.2 Figures 8 to 10 show the essential details of a recommended photoelectric transducer, and buffer amplifier.

B.2.3 Figure 11 shows an alternative recommended system utilising commercially available equipment.

B.2.4 Figure 12 shows the essential details of the bracket for use with injection pump adaptors for mounting base or cradle mounted pumps.

B.3 Test procedure

B.3.1 Choose a site having a solid floor extending at least under the whole of the test bench and sufficiently to one side to carry the deflection measurement equipment.

B.3.2 Fit the injection pump mounting adaptor to be tested to the test bench and fit the simulator to the adaptor using the base mounting component of the simulator if required. Set up the deflection measuring system including its display. Perform a suitable static calibration procedure to verify that indicated displacement is equal to mounting face angular displacement relative to earth. Angular displacement transducers of the types shown in either figure 8 or 11 are recommended because they can be reliably and accurately calibrated statically. But any type of angular displacement transducer having this latter characteristic is acceptable.

B.3.3 Set the simulator buffer springs to the highest speed achievable by the test bench.

B.3.4 Release the simulator flywheel several times increasing the Q/n_t setting progressively until a deflection of 0,02° is recorded. At this condition, multiply the speed setting n_t by the Q/n_t scale reading to obtain Q. Plot this point on figure 4 (see 6.2).

B.3.5 Reduce the simulator speed setting to the next lower graduation and repeat the procedure stated in B.3.4, and so on until the curve is completed.

B.3.6 Repeat B.3.3, B.3.4 and B.3.5 using all other injection pump mounting adaptors supplied for the test bench.

B.4 Comments and precautions

B.4.1 Ignore any results with the Q/n_t scale set to its maximum in which an angular deflection of 0,02° is not achieved.

B.4.2 When fitting the simulator to the injection pump mounting face to be tested first fit the bolts loosely and then apply a torque in the direction in which the flywheel rotates before tightening the bolts. This will avoid slip occurring at the interface. Should this happen however, it is clearly shown in the display diagram by a shift in location of the datum height of the trace immediately before and after the torsional shock occurs.

B.4.3 When fitting the simulator and the pump mounting adaptor, first make completely sure that there is no paint, burr or foreign matter between any mating faces and that all bolts or clamps are properly tightened. Failure to take these precautions will reduce the value of Q obtained.

B.4.4 When tightening the buffer spring clamping blocks, tighten the four bolts thoroughly in the generally accepted tightening sequence and keep the block gaps approximately equal (see figure 5).

Details of energizing spring :

Wire diameter : 3 mm
Turns : 6 + 3°
Mean diameter : 55 mm nominal
Wind clockwise
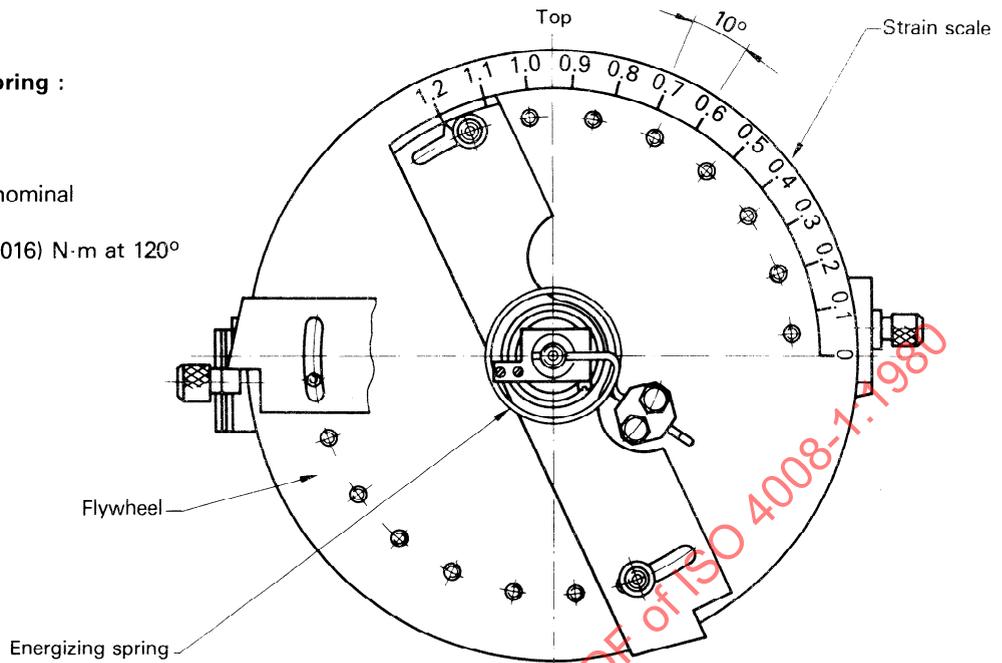Test torque : (1,607 ± 0,016) N·m at 120°

Top

10°

Strain scale

1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0

Flywheel

Energizing spring

Figure 3 — Simulator, front elevation

Dimension X	Speed n_t
68,53	5 000
66,24	4 000
62,94	3 000
60,58	2 500
57,50	2 000
53,18	1 500
46,53	1 000
41,48	750
34,26	500
22,40	250

Dimensions in millimetres

$177,7 \; {}^{+\,0,2}_{\;\;\;0}$

$88,8 \; {}^{+\,0,2}_{\;\;\;0}$

40

These faces to be case
hardened 0,5 deep

Buffer spring cantilever

30

8

14

$40 \; {}^{\;\;\;0}_{-\,0,01}$

$\phi\,14$

8

24

$\phi\,20 \; {}^{+\,0,01}_{\;\;\;0}$

60

20

4

96

6

14

Locating
block

Trough harden
1260...1340 N/mm²

22

60

Striker pad

X
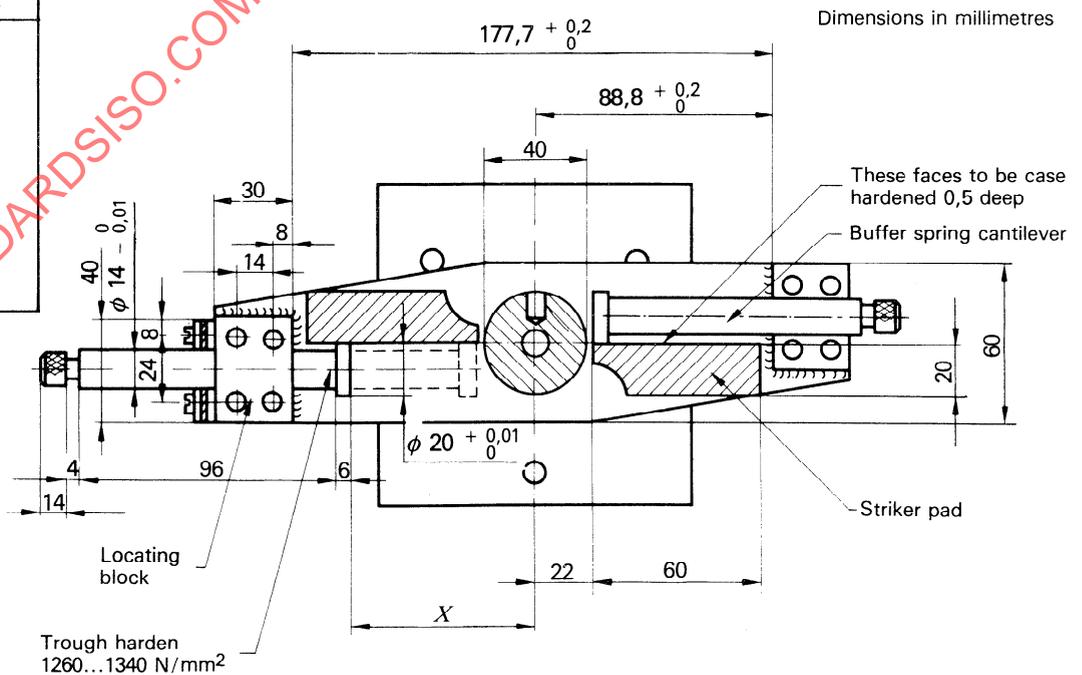
Figure 4 — Simulator, section B-B (see figure 6)

Dimensions in millimetres

Figure 5 — Simulator, section A-A (see figure 7)

NOTES

1   The angular relationships do not necessarily relate from one view to another.

2   Accuracy must be such that the striker pads touch both buffer spring cantilevers simultaneously within 0,03 mm, irrespective of the radial location of either cantilever and with all eight bolts tightened.

3   The flywheel spindle to be set angularly so that the torsion spring has zero stress at the moment when the cantilevers strike the pads.

4   Locating blocks to have at least 90 % surface contact with cantilevers.

5   Speed setting graduations to be made according to the table in figure 4.

Dimensions in millimetres

Figure 6 — Simulator, side elevation

Dimensions in millimetres

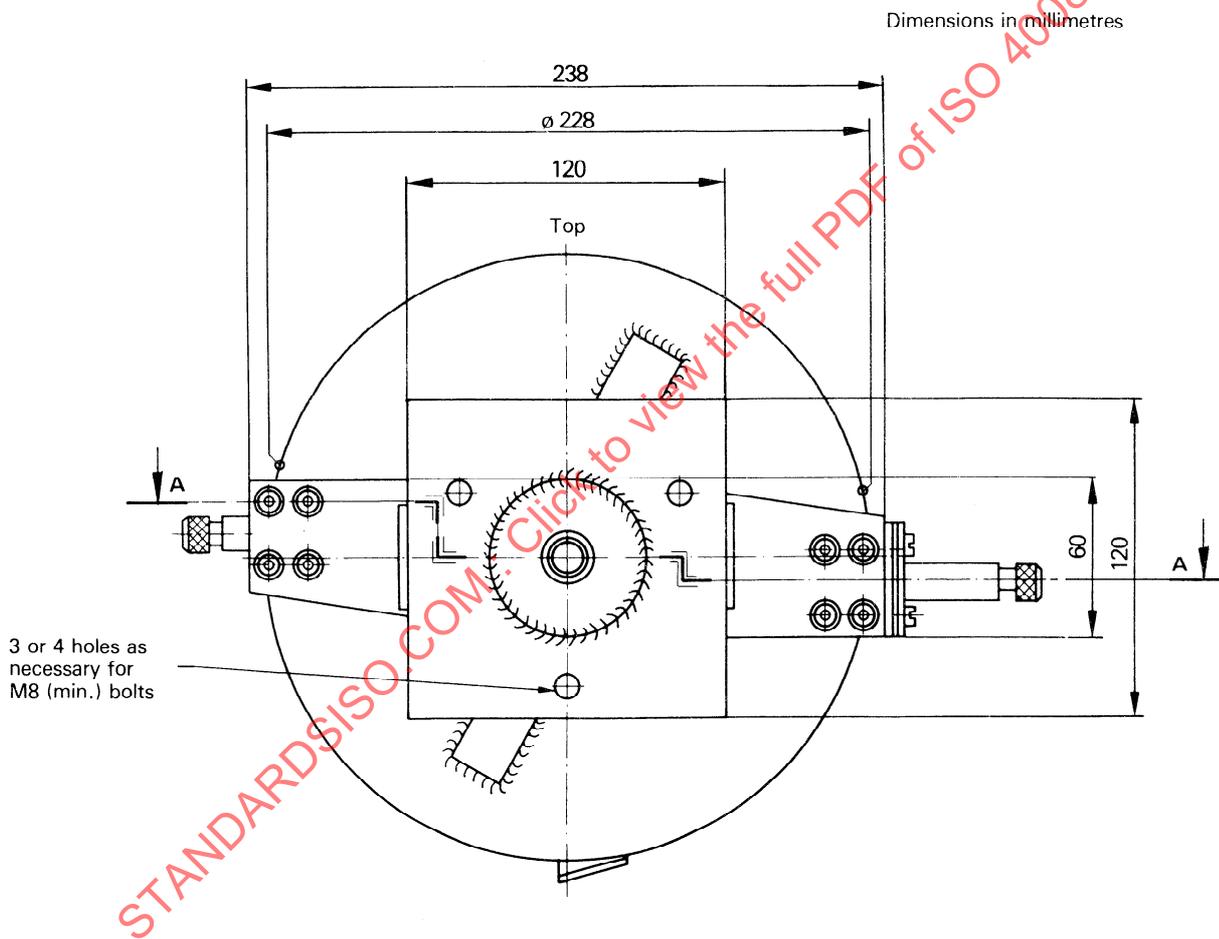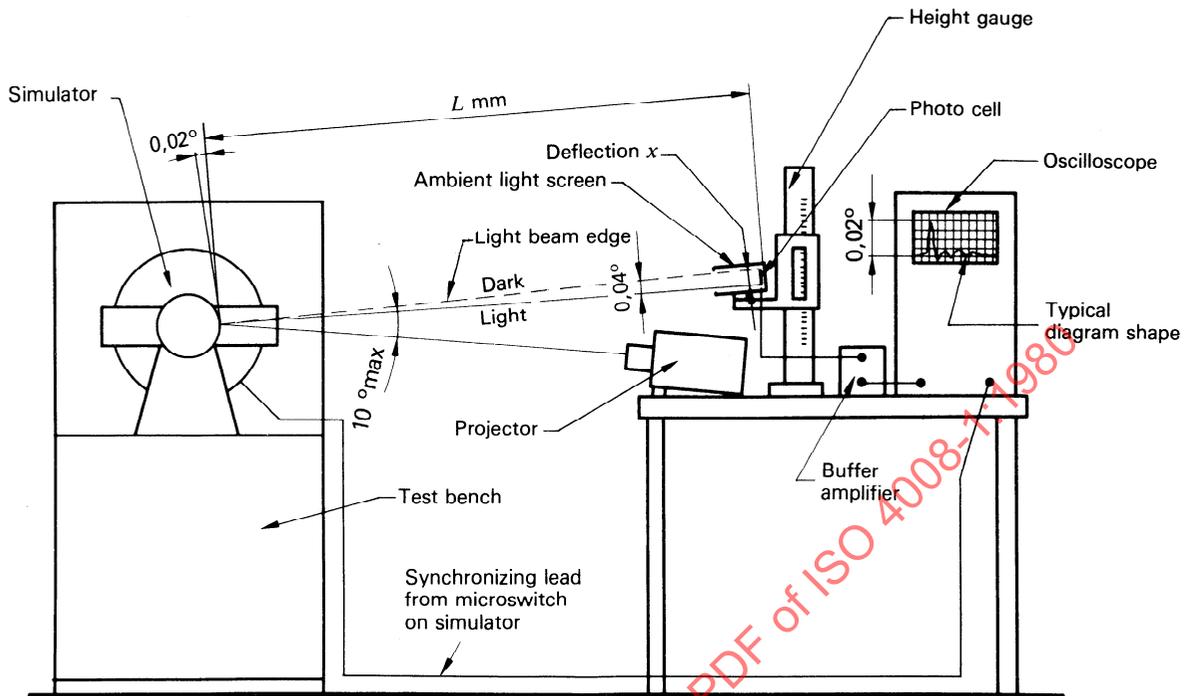**Figure 7 — Simulator, rear elevation**

Figure 8 — Sketch of preferred apparatus in use

NOTES

1 For an angular displacement of 0,02° at the simulator, the light beam deflects 0,04°.

2 0,04° at distance L mm = 0,000 7 L (deflection x at cell face).

3 Calibrate oscilloscope beam deflection to read 0,02° when height gauge is moved through 0,000 7 L mm.
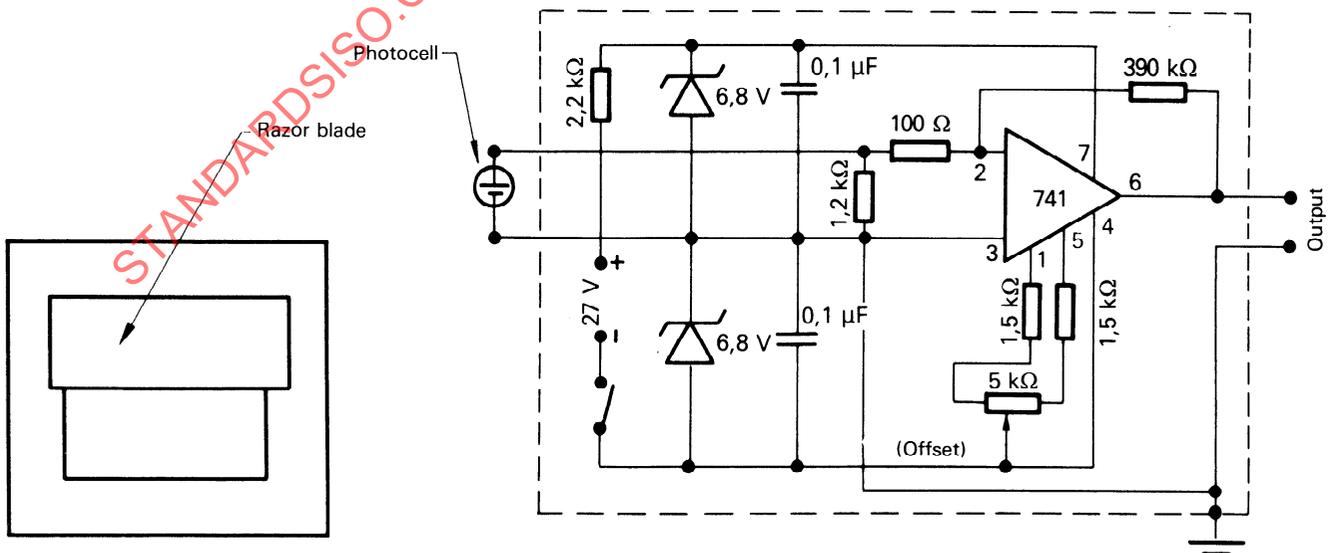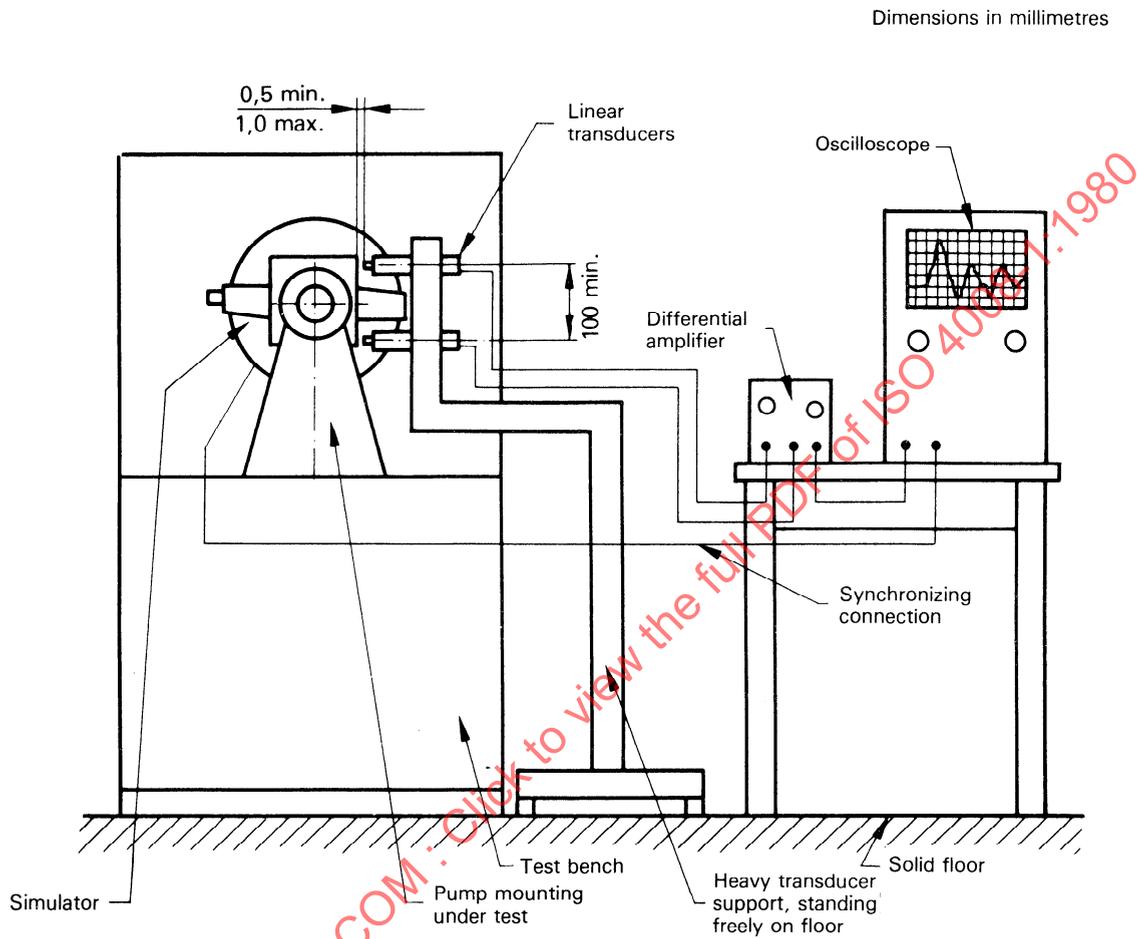

Figure 9 — Slide for projector

Figure 10 — Buffer amplifier circuit

NOTE — Figures 8, 9 and 10 show on example of preferred apparatus for measuring angular deflection

Dimensions in millimetres

Linear transducer specification :

1   Resolution : 1 μm min.

2   Operating range : 0,2 to 1,0 mm min.

3   Frequency response : 1,5 kHz min.

For an angular displacement of 0,02°, the differential displacement between the transducers is :

$$2 \pi x \frac{0,02°}{360°} = 0,000\ 35\ x\ \text{mm.}$$

Calibrate the oscilloscope trace to read 0,02° when the differential displacement between the two transducers is 0,000 35 x mm.

Figure 11 — Alternative method for measuring angular deflection