RESEARCH INSTITUTE

for

MOTOR CARS and MOTOR CAR ENGINES

POLYTECHNIC, STUTTGART.

INSTRUMENT FOR THE MEASUREMENT OF IGNITION DELAY

(PATTERN 1943)

I E B.L 11

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1. The Problem.

The instrument measures ignition-delay and so assesses the quality of fuels. The ignition-delay can continually be read off a pointer-instrument calibrated in degrees crank angles.

Ignition delay means the space of time elapsing between fuel injection and start of combustion. The time of injection can clearly be determined as the moment when the needle of the nozzle is lifted. This moment of injection can also be determined with good accuracy by a simple contact device. On the other hand there are various possibilities by which to determine the start of combustion. They do not necessarily give the same results but these differences are irrelevant. The pressure diagram will in many cases reveal quite easily the start of combustion for it shows a more or less marked break at the moment when combustion begins. This fact may be used to control an automatic indicator, if suitable engine conditions are laid down for fuel tests to enforce a well-defined time of the start of a steep increase in pressure. For a pick-up, one uses as an adjustable acceleration meter an improved contact device described by Neumann* and developed by him to a practical stage. Instead of using the course of pressure, another indication of the start of ignition is the moment at which the fuel flames up. A photo-cell may be used which is exposed to the combustion flame through a quartz-window in the combustion chamber. Here a greater freedom is enjoyed as to the choice of engine conditions which facilitates scientific investigations. On the other hand long runs are generally not possible because of the danger that the quartz-window gets sooty which makes this arrangement less suitable for more fuel tests.

In order to mark the ignition delay the time lapse of these two points must now be determined. It is best to relate the time of ignition-delay to the time of one revolution, and so to express it in degrees of crank-angles.

*"inaction-indicator" according to Dr.-Ing. Neumann (Doctor of Engineering). Makers:- Rhenania-Ossag, Mineral-Oil Works, A.G., Hamburg, Harburg plant, engine test-plant.

2. The working of the instrument.

A contact fitted on the nozzle holder and operated by an elongated nozzle-pin closes a circuit. So current i_1 flows at the time t, when fuel-injection starts (Picture 2). An electrical storage device takes care that current i_1 is kept constant and is not influenced by the further motions of the nozzle-pin. This will last until the current is cut out by the accelerator-contact which opens at the start of combustion, or, in the case of a photo-cell, until the circuit is broken by a voltage-shock caused through the quick increase of light-intensity at the beginning of the combustion. This happens at the time of t_2 at the end of the ignition-delay. The complete process is repeated during the next working process. We obtain a rectangular path of current as shown by picture 2 for the time lapse or the rotation-angle ;

This current is conducted to a pointer instrument which indicates the average (mean) of the current, i.e. the value [illegible] This means that the instrument me[illegible] value :-

$C \times (t_2 - t_1)/2T = C_1 \quad (t_2 - t_1)/T$, in other words just the desired time ratio. We are therefore able to calibrate the ignition-delay directly in degree crank-angle. If the instrument has a linear current scale, the indication in degree crank-angle is linear too and for calibration it is sufficient to find out one point.

The working of the controlling circuit.

Picture 1 shows the general lay-out for the control of current i_1**. It consists of 3 valves marked R_1, R_2 and R_3. The two valves R_1 and R_2 introduce the controlling impulse whilst R_3 supplies the current for the measuring instrument.

There is no current in valve R_3 before the start of the ignition-delay. This causes therefore only a small voltage decrease in the resistance R_k which originated through valve R_2. It forms the normal grid potential of this valve. Because of the current in R_2 and its anode resistance R_a the voltage becomes considerably smaller at point A than the battery voltage, and so the grid of R_3 becomes so strongly negative that - as mentioned above - there is no current in the valve.

** An elaborate circuit diagram will be found at the end of this paper (Picture 11).

When the contact on the nozzle-needle is actuated (at the beginning of the injection) the grid of R_2 is hit by a negative voltage-shock which is adjusted in a way as to make the current in the valve disappear completely.

Through this, point A takes the same voltage as that of the battery, ,d this shifts the voltage of the grid of R_3 so far as to cause the real value of the current (i_1) - regulated by the control E - to flow into R_3. It is considerably greater than was the current in R_2 and leads to a voltage decrease of R_k which blocks valve R_2 permanently. Therefore this new state remains when the controlling impulse has gone.

When combustion starts a positive voltage impulse hits the grid of valve R_1 via the pressure controlled contact or via the photo-cell and the inter-connected amplifier "V". Whilst normally this valve carries no current it becomes now for a short time penetrable and as a consequence there is a voltage decrease of R_a which blocks valve R_3. This eliminates the high voltage of R_k. Valve R_2 will now carry the current and continues through R_a to block the current of the instrument constantly.

This arrangement makes it possible to start the circuit in the instrument by a voltage-impulse from the nozzle-needle, and by a second voltage-shock, viz., when the combustion starts, the circuit is broken again.

In order to get a smooth reading from the instrument in spite of the fact that the current is transmitted in jerks, a smoothing choke consisting of a resistance and a capacity is introduced into the circuit.

The accuracy of the reading.

The accuracy of the measurement depends upon the exactness with which start and finish of the ignition delay can be found, and also it depends upon the accuracy of the pointer-instrument. A delay in measuring the exact instant of injection is unavoidable as there must be a certain play of the contact, and therefore the nozzle needle has already permitted a certain opening when the contact closes. This delay is below 0.5° crank-angle. On the other hand a certain minimum height above the maximum value reached in the compression diagram is needed to cause the blocking impulse, or, in the case of the photo-cell, a certain minimum brightness of the light falling on the photo-cell, so that here too there is a small delay.

Both influences cancel each other to a large extent so that we determine the time value of the ignition-delay within less than 0.5 crank-angle of the true value.

The relative accuracy depends upon variations which may take place in determining the instant of injection and the start of combustion. It depends further upon the accuracy with which the real value i1 of the instrument current can be regulated. This accuracy is about ±1%. Variations may occur during the start of the injection by a contact distance each time regulated in a different way. But these variations remain sufficiently small when regulating skillfully. During the beginning of combustion the variations depend essentially upon the different pressures which occur during the various working processes. But the pointer-instrument was designed with some inertia and - given an even run of the engine - these differences are eliminated to a large extent. This means that the amount of the remaining fluctuations no longer depends upon the pointer-instrument but on how evenly the engine can be ... on the test fuel. Under favourable circumstances it is possible to keep an ...ition delay constant for approximately a quarter of an hour to ±2° if for instance it was adjusted to 15° crank-angle.

In the case of the photo-cell there is an additional source of error, viz., the clouding of the quartz-window. Clouding of the window and a slower increase of the light-intensity result in delay of the quench-impulse. For the instrument needs a certain minimum intensity of the light which falls upon the photo-cell in order to release the control. So the ignition delay shown is too great. By a switch-device on the instrument (one position:- "Measure" - one position:- "Test") we can find, however, if the value shown is still within the permissible limit of error. When switching-in the difference of the two values of the ignition-delay which had been measured should remain below ≈1.5° crank-angle. The result of the measurement can be improved within these limits by subtracting half of the measured difference from the smaller value (Position "Measure"). The reason for this is that - when switching over to "Test" - the amplifying effect behind the photo-cell decreases to a certain point, and as we also may suppose the brightness of the light to increase in an approximately linear way until the instrument is released this leads us to the rule given above.

3. The instrument.

The instrument is shown on picture 3. In its centre is the pointer with a scale up to 30° crank-angles. This has always been found sufficient. On the right is the switch with the positions:- "Off" - "Calibrate" - "Measure". On the left there is a button which regulates the controls:- "Measure" - "Test", mentioned above. (Necessary only when using the photo-cell).

In the bottom-centre is the rotary-switch. It sets the current i_1 to a definite value previously fixed for the purpose of calibrating the instrument. Furthermore we see at the bottom right the sockets M_1 and M_2 which connect the instrument with the nozzle contact and the Neumann contact controlled by the pressure increase.

In front of the instrument we see on the left the photo-cell in its holder with the cable connected to its socket. There is also a quartz-window insertion for the test fuel engine and a nozzle holder with a contact head.

Picture 4 shows a section through the quartz-window enclosed in a metal casing. Picture 5 shows a section through the contact head for the needle of the nozzle.

Picture 6 shows the inner structure of the pressure controlled contact and at the same time we can see how it is fixed to the test fuel engine.

The body H with the contact K_1 is thrown off the membrane when the steep increase in the pressure starts. Mass M tends to remain at rest because of its inertia so that the contact opens as soon as it exceeds a certain maximum value of acceleration adjustable through the tension of the spring F.

4. The operation of the instrument with the fuel test engine.

(a) Preparing the instrument for use.

At first the valves are put in. The instrument is taken out of its box and the valves are put into their sockets according to their markings. Then the instrument is put back into its box. It is now ready to be connected. It is fixed near the engine - shock-proof if possible, i.e., not on a common foundation. If this is not possible it might be suspended by springs or put on a rubber mat. Now the instrument is connected to a 220 A.C. supply. The socket M_1 is connected to the contact head on the nozzle by means of a varnished cable either direct, or if the engine already has leads, we connect terminal M_1 to the plug-box. We also connect plugs M_1 and M_2 of this box. Now the engine switch: "Glow-lamp" - "instrument" allows us to use the nozzle contact either for indicating the start of injection on the fly wheel glow-lamp or for measuring the ignition-delay. Socket M_2 is connected with the plug of the Neumann contact, if this contact is used. The earth at the rear of the instrument is connected to the body of the engine. The tumbler-switch at its side should be in position "S" if the FKFS nozzle contact is used. The socket on the bottom right-hand side at the front is not normally used. We want it only if we wish to connect a cathode oscillograph (cf.para.4e).

(b) Adjusting the nozzle contact.

The nozzle holder is usually supplied with its comtact-head - picture 5 - and a regulated injection-pressure. In case another holder is supplied we must at first remove the normal pin on top of the needle and replace it by the longer pin. Then part "a" of the contact-head is screwed on to the holder. Now we check the injection pressure and obtain the right value by putting washers in.

After having fixed the holder ready for use, we screw the contact-head "b" on (with the knurled ring loosened). The lead is connected with the socket. Now the tumbler-switch on the dash-board of the engine is brought to the position: "Glow-lamp", and the contact-head is screwed down until the indicator-lamp on the fly-wheel lights up constantly. Then we screw the contact-head slowly back until the constant indication fades to just a luminous band showing the duration of injection. From this position we go still farther back for one or two graduations (contact distance of 1/80 or 1/40 millimetres) and finally fix the contact-head by tightening the knurled ring. This ends the adjustment of the contact. It is possible that the contact distance changes a bit in the beginning with new contacts, which have not been fully run in. Then we must make another adjustment a little later, in the same way as above.

(c) Insertion of the quartz-window and suspension of the photo-cell.

It is best to insert the quartz-window after the engine is heated up by running, or to exchange it before measurements are taken. The window is put in one of the two borings of the cylinder at an angle of 45° in an oblique position pointing downwards. If running with direct-injection which is usual in the case of fuel tests, it is just below the nozzle (in the rear of the engine, see picture 7). In order to fix the window we use a frame attached to the photo-cell holder, in later patterns we use a quick-fastener. The photo-cell and the cable must be protected against shock, and it is therefore suspended by springs. But care must also be taken that the cable does not touch the engine on its way to the instrument. If it should be necessary to support it, it should be done by springs. We should protect it all against bright light from the outside (daylight etc.). If necessary it should be covered because a disturbing voltage might be produced which would result in faulty measurements.

(d) Adjusting the "Neumann" contact.

If we work with the Neumann contact it might happen that the instrument goes beyond its full pointer range when we switch over to "Measure" (see below). This means that the tension of the contact is too great, so that it does not open. In this case we decrease the tension of spring F (picture 6) until the instrument indicates properly, i.e., until it is controlled by the opening of the contact.

(e) The measurement.

Now the main-switch of the instrument is put into position:- "Calibration", and we regulate with the calibration rotating button in a way as to have full pointer throw after waiting for approximately one minute to allow the instrument to heat up. This ends calibration. Now we bring the main switch to position:- "Measure". The Test switch on our left must also be in position "Measure" (only when measuring with the photo-cell). This makes the instrument ready to operate. When the tumbler-switch on the engine is put into the position:- "Measuring Instrument" our instrument will show the ignition-delay.

(f) Use of the instrument with oscillographs.

If we connect a cathode oscillograph (with amplifier) between the earth socket and the socket at the right-hand bottom of the front plate, the cathode oscillograph will show us a current diagram as given in picture 2. This gives us a simple way of testing the working of the instrument and the whole measuring device and to find faults, if any. Besides, the current taken here, can be put into the circuit of an indicator amplifier (see fig.8), when the ignition-delay will be shown in the pressure diagram, see picture 9. The depressed section of the curve corresponds to the ignition-delay.

Adaptation to the "I.G." Test Diesel Engine and with other engines.

On the "I.G." Test Diesel Engine a contact is put upon the nozzle holder, which opens when the nozzle works. This contact can be used with the instrument when a contact-spring of normal tension is inserted (Bosch magneto make and break for motor-cycles "ZWB 9/3 Z). The small tumbler switch in the rear of the instrument must be put from "S" to "O".

Picture 10 showing a section of the cylinder-head of the engine shows a suggestion by the "I.G." how to fix the pressure contact and the quartz-window.

If we want to use the instrument with other engines, possibilities of fixing the Neumann contact or the quartz-window have to be examined individually. The quartz-window should best be fixed in such a way that a greater part of the combustion chamber may be seen - particularly the space in front of the nozzle - and that the diameter of the outlet for the light is not too small. The window will become less sooty if care be taken that it reaches a sufficiently high temperature. Consequently it will be fixed with little heat-insulation and a portion projecting if possible. Furthermore, care should be taken not to have too much oil sprayed upon the light outlet. The frame for the window - as shown in picture 10 - should simply be a conical copper or aluminium ring into which the window is only lightly pressed.

Picture 1. Fundamental arrangement of the control.

R_1, R_2, R_3 valves,
R_a common anode resistance of R_1 and R_2,
cathode resistance of R_2 and R_3,
M - measuring instrument,
V - amplifier
A - see text

Headings of diagram in clockwise direction :-

Photo-cell; pressure-contact; nozzle-contact.

Picture 2:- Course of the current (circuit) of the pointer instrument.

i_l = rest value of the anode current of R_3 (picture 1)
i_m = mean of current in relation to the ignition-delay.

Picture 3:- (view of) The instrument.

Picture 4:- Section through the quartz-window insertion on the FKFS fuel testing engine.

(a) path of jet
(b) quartz-glass
(c) metal casing
(d) outer case.

Picture 5:- Section through the contact-head on the holder at the nozzle needle of the FKFS fuel testing engine.

(a) connection
(b) contact-head
(c) knurled ring
(d) contact
(e) new nozzle-holder head
(f) spring
(g) elongated pin.

Picture 6:- Section through the contact device according to Dr.-Ing. Neumann built into the FKFS fuel testing engine.

H = Contact case — K_1 = insulated contact
K_2 = contact connected with the mass
M = inert mass — F = auxiliary spring

Picture 7:- Suspension of photo-cell from the FKFS fuel testing engine.