MINUTES OF THE MEETING OF THE SPECIAL COMMITTEE ON THE STANDARDISATION OF ENGINE TESTS ON DIESEL FUELS OF THE DVM 14 AND 15 APRIL 1942.

(Page 10)

Dipl.Ing. Weber:-

The cetane number is determined by the starting method of the Army Ordnance Depot (Heereswaffenamt) in a commercial engine from the firm of Humboldt-Deutz. The engine runs at a constant speed of 960 r.p.m., the intake air is heated to 80°C and the cooling water to 70°C. The measurement is made in such a way that 3 injections of 0.1 ccs. fuel are made at intervals of 1 to 2 secs. Injection is done by hand. When ignition occurs, the intake air is throttled, and it is once more ascertained whether ignition of the fuel occurs after 3 injections. The intake air is throttled down until a point is reached where ignition just occurs. The ignition limit is determined by measuring the depression brought about in the intake tube by throttling, and is then related to a mixture of cetane and α-Methylnaphthalene.

The HWA engine is very simply constructed, the accessory apparatus consisting only of a mercury manometer for measuring the depression in the intake tube, and a pre-heating device for the intake air. The measuring process does not demand any special knowledge, and can be carried out by unskilled personnel.

The range of measurement is from 20 to 100 cetane number. The objections repeatedly made to this method, that the combustion chamber becomes fouled and that lubricating oil gets into the combustion chamber, were not justified in practice.

The HWA selected this method because tests in the Technical High School at Berlin showed that it approximates to the starting behaviour of the fuel in the engine. The tests were made on 3 engines under practical conditions in the cold chamber. Since the HWA in assessing fuels must attach the greatest importance to the determination of the starting behaviour of Diesel fuels, it can only agree to the standardisation of a process on these lines.

The HWA method of measurement fulfils these requirements, as it also satisfies the further need for a standard test method for determining the cetane number in the HWA engine by the throttle process, in relation to the practical behaviour of the fuel, is extremely simple in operation, gives reproducible values and good agreement between values measured in different engines, i.e. a spread of about 1.5 cetane numbers.

The HWA engine has the added advantage that the ignition lag can be determined, by the use of the Neumann indicator.

(Page 12)

Dipl. Ing. Penzig:-

The Technical Test Station began to develop from the very beginning a special engine for measuring ignitability, using for this purpose the Type KD 15 of Motorenwerke Mannheim. This engine, with a capacity of 1 litre, is so small that it is possible to test small samples of fuel, while at the same time avoiding the restricted and unsatisfactory construction of the combustion chamber which is typical of the CFR engine. Like the I.G. test engine for determining the octane number, the I.G. test Diesel was originally intended for their own investigations. But as the engine found great favour everywhere, it was necessary to produce it in large numbers. Fortunately, many parts could be mass-produced, which facilitated the production of spare parts.

In order to measure ignitability at constant ignition delay, it was necessary to equip the engines with variable compression. All that was required was to connect the cylinder head to the cylinder, and to provide the outside of the cooling jacket with a thread, so that the cylinder head and the cylinder could be adjusted while running. For this purpose it is necessary to have a screw thread driven by a worm. The valve setting is kept constant while the cylinder is adjusted by the method already familiar in the I.G. test engine.

The fuel is injected directly into the combustion chamber. For testing fuels with zero cetane number, it is necessary to have a very compact combustion chamber. There is therefore a cavity in the piston which at the highest compression ratios represents the total combustion space.

The fuel is fed by a Bosch injection pump to the nozzle, which is constructed as a closed pintle nozzle. There is a contact on the nozzle which is controlled by the nozzle needle, and serves to indicate the beginning of injection. We made a point of constructing the apparatus so that it could be controlled by one man. On the switch panel, built on top of the three-phase motor which serves as a starter and also as a brake there is an electrical indicator, supplied by Dr. Nier, in addition to the push-button switch for this engine and the amperemeter. The observer has the screen of the Cathode Ray Tube directly in front of him, so that at any time he can assure himself that the engine is working properly. This appears to us extremely important. The hand wheel for adjusting the cylinder can be worked with the left hand so as to set the pressure rise directly at dead centre.

The injection is set to the required 18° before top dead centre by means of a small crank. As was stated in the description of the measuring method, the correct values for injection and pressure rise are marked on the Cathode Ray Tube, so that the task consists only in matching up the actual values with the correct values by turning the hand wheel or the small hand crank. Once this is done, the setting of the cylinder can be read off on a small sliding scale on the cylinder head, or an instrument with a circular scale. Since the relationship between the cetane number and the cylinder setting is known from the calibration curve, this concludes the measurement of the cetane number.

As regards the equipment of the engine, there is also this to say, that the crank-angle deflection apparatus developed by the Technical Test Station is fitted on the free end of the crank shaft. With the aid of this a stationary diagram is shown on the Cathode Ray Tube. There are also contacts on this, which indicate diagrammatically the correct figures for injection and pressure rise.

As regards the fuel supply, two small containers are provided which allow consumption to be measured, and which are connected with the injection pump by a fuel tap. The fuel volume is adjusted by a micrometer screw.

The cooling system is an evaporation system (Verdampfungskühlung).

A small container is arranged above the cylinder head, and above this is a cooling coil for the water vapour. The cooling temperature is the same as the boiling point of the water. But the cooling devise is so arranged that it can be set for various cooling temperatures by simply adjusting the water level. The cocks which serve the cooling device are constructed in a block, in which is also a fine filter for the cooling water of the quartz pick-up. The cetane number is generally measured with an uncooled quartz pick-up. At higher loads, however, such as occur in other tests, it may be necessary to use water-cooling, and experience has shown that it is advisable to use specially purified water.

As you know, with the I.G. test engine it is not a question of a new apparatus, for much has been learnt about it during its six years of development, and is incorporated in the present model. On the test bed you will see the type which has been in use up to now, and will be able to judge the progress which has been made.

As already mentioned, the electrical indicator is an important aid in determining the cetane number. The stationary pressure diagram enables us to read off the ignition lag directly. Also, every deterioration of the engine, whether in the injection system by air locks or stoppage of the nozzles, or by bad combustion due to defects of the piston and the valves, is detected at once by the Cathode Ray Tube. The electrical indicator, which was formerly perhaps considered as an instrument for purely scientific investigations, but is actually no harder to operate than a radio apparatus, has proved its worth with us and in numerous quarters where our apparatus is in use. The one objection to the electrical indicator is that it depends on mains current. This may become a handicap for making investigations as quickly as possible in some places. For such cases we have constructed the I.G. test Diesel in a very simple form, with the three-phase motor replaced by a self-exciting direct current motor. The engine is started by a hand-crank, and can serve as a source of direct current. Instead of the indicator there is an inertia pick-up provided by Dr. Neumann, which gives the ignition lag directly on the fly-wheel by means of a storage battery and a rotating neon tube. For simplicity and independence of its surroundings, this apparatus is hardly to be excelled.

I should only like to add that the I.G. Test Diesel is an extraordinarily adaptable apparatus, as is already proved by the fact that many people not only use the Test Diesel to measure the cetane number, but actually have recourse to it for general investigations.

The demand for a small handy engine for general investigations is now extremely large. We should not forget that such engines serve not only for acceptance tests, but for routine supervision of production.

This supervision does not consist merely in testing samples from current production. Experience has shown that questions arise during production which have to be thoroughly investigated before it is possible to consider altering production methods. Also, if the initial substance is changed, questions can arise which can only be answered after thorough investigation. Therefore not only research institutes and technical schools, but also manufacturers, require a test installation which, without being too bulky, is suitable for carrying out all manner of fuel tests. As the demand for such a machine is now becoming insistent, we considered ourselves called upon to design a test engine on which all kinds of tests can be made, except octane ratings. This test installation consists of a test Diesel, which can be braked with a water brake and started with a three-phase motor. Cetane numbers can be measured on this engine, with the water brake running idle, and the three-phase motor acting as the brake. It is possible to carry out measurements of load and consumption with the engine operating on the Diesel cycle and equipped for this purpose with a larger fuel container and the water-brake. The engine can also be operated on the Otto cycle for general test purposes, the fuel being injected during the suction stroke, and with magneto ignition. These tests can be made not only with a normal aspiration but also with supercharging by using an expansion device for the compressed air, an electrical heater for the boost air, and a silencer. To provide for the high mean pressures of about 22 atm there is a specially powerful cooling system for the cylinder and the silencer. The water brake is of such efficiency that it can absorb the high torques which occur.

This apparatus, known as test engine K, is of great significance in the testing of aero-engine fuels. As you know, the octane number is not a sufficient guide to the quality of an aero-engine fuel. It is therefore necessary to determine the knock limit curve, for which the boost pressure is determined at different fuel-air ratios at incipient knock. Hitherto a single cylinder test engine built of aero-engine parts, was used to carry out these tests, and, as our installations show, this method requires extremely expensive equipment. The I.G. test engine K, the nucleus of which is the I.G. test Diesel, could largely replace this. For more accurate tests recourse will doubtless be had to the aero-engine single cylinder test installation, but the test engine is quite sufficient for acceptance tests. Enquiries have already been made by people who wish to set up the I.G. test engine K in addition to the test Diesel, as conditions in the field of fuel production are so complicated that it is impossible to avoid going into engine problems.

(Page 17)

Dr. Ing. Neumann:-

For the past 8 years Rhenania-Ossag have been using a method of measurement fulfilling all requirements as regards working safety and accuracy with great economy of materials. The main difficulty in testing the ignitability of Diesel fuels in practice lies in inertia-free detection of ignition delay, which is generally defined as the time from the beginning of injection to the beginning of the rise in pressure in consequence of ignition, or else to the beginning of burning. It is assumed that you are familiar with the methods of determining this. In our case the transmitter is the so-called inertia indicator. It is controlled by the nozzle needle, and by a diaphragm in the wall of the combustion chamber. Its method of working is that the contact in the interior of a light metal tube is opened when a certain axial acceleration in an upward direction is exceeded. The opening of the contact can be read off in various ways as degrees of crank angle or per unit time.

If used to indicate the moment of ignition, the indicator, i.e. the contact spring, is so controlled that the contact only opens if the acceleration is greater than the maximum positive pressure acceleration of the compression stroke. This means that deflection of the diaphragm fitted in the wall of the combustion chamber is insufficient to open the contact without injection and consequent ignition. Even a comparatively low pressure rise on ignition (e.g. $\frac{dp}{dt} = 10{,}000$ at/s) gives a diaphragm acceleration reading sufficiently in excess of the greatest acceleration obtained during compression to be reliably distinguished from it. It makes no difference whether ignition occurs before, at, or after top dead centre. The pressure rise can be read off the pressure diagram by a practised eye to within about $2\frac{1}{4} - 2\frac{1}{2}^{o}$ crank angle. As the ignition accelerations are 9-16 times the maxima attained on compression, the inertia contact has thus already opened.

When such an inertia contact is sensitively regulated, the so-called "moment of ignition" is determined accurately enough, especially if the test conditions are selected to give values of $\frac{dp}{dt}$ greater than the above. By this method, the familiar difficulties which accompany the use of the bouncing pin and other similar devices with mechanically operated contacts, such as maintaining the clearances, condition of the contact surfaces, fatigue of the spring etc., are overcome. Above all, unlike e.g. the bouncing pin contact apparatus, it is not necessary to reset on changing the compression ratio, as the inertia indicator does not respond to the deflection of the diaphragm, but to the rate of change of its deflection, and, experience shows, only needs to be set once to the maximum compression ratio used.

The instantaneous acceleration of the nozzle needle and thus also of the inertia contact mounted on it, is so large at the moment of ignition that the injection contact is certain to open practically without inertia. Any delay which may occur is largely the same with all fuels, and can therefore be neglected.

This indicator was first used in connection with the following methods. By means of a contact brush adjustable in the direction of rotation of the crankshaft, a circuit is closed at every working stroke when the nozzle needle lifts, through a contact which rotates with the engine shaft. This circuit is broken again by the indicator at the beginning of the pressure rise due to ignition.

Next a circuit came into use enabling the injection and ignition timing to be read off a scale in degrees of crank angle, by means of a rotating neon tube. Here the inertia contacts which open at the beginning of injection and ignition are connected in the primary circuit of an ignition coil. In the secondary circuit there is a sparking plug to act as a spark gap, and in parallel with it is the neon tube which rotates with the crankshaft. It glows at the moment of ignition and injection, and this can be read off with an accuracy of at least $1/10^{\circ}$ crank angle through a slit radial to the axis of the crankshaft.

Up to the present, Rhonania-Ossag, in testing Diesel fuels, have used the same method as in determining the octane number in the CFR and Vario engines, i.e. determination of ignition delay by comparing its behaviour in the engine with that of fuels of known ignitability. This eliminates practically all the sources of error arising from changes, in the atmosphere and the engine.

Preference has recently been given to the even simpler glow bulb indicator, which acts as a stationary indicator of the ignition delay. The glow bulb is built into the rim of the fly wheel. The beginning of injection is indicated by a band of light, which disappears after 10° crank angle, and reappears at the beginning of ignition. With this, it is possible to use the I.G. constant ignition delay method. Then, in the engine with variable compression it is the compression ratio, and in the engine with constant compression it is the induction depression which is the guide to the ignitability of the fuel. Alternatively the reference method, the standard for octane number determination, can be used. In both types of engine the standard of comparison is then the ignition delay in degrees crank angle at constant speed at suitable settings of the compression and intake throttle.

In view of the agreement between test results in engines with and without variable compression, there is no urgent need for an engine with adjustable compression for use in current fuel investigations. Comparison of such tests, done at Harburg, Delft and Sunbury, without previous standardisation of engine conditions is interesting.

One cannot make the generalisation that measurements made by the ignition delay method on a test engine of constant compression ratio are much less accurate than those made on an engine with adjustable compression.

Comparison does not show any great differences between the values in the CFR engine, with its variable compression ratio, and those in other engines with constant compression. The values measured in the pre-combustion chamber of a Deutz-2 cylinder engine are so good, compared with the mean value for the other 8 engines, that better results are not achieved with any other test engine. To correlate results obtained in different engines, it is necessary to measure the beginning of injection and ignition practically free from inertia. It is immaterial whether a quartz pick-up with a Cathode Ray Tube is used, or a simple mechanical electrical process, such as that of Rhenania-Ossag. It is often considered preferable to use a method in which the whole course of combustion is recorded. This is true for scientific investigations, but not for the routine testing of Diesel fuels. Here it is merely a question of accurately determining two instants of time which are more clearly distinguished using apparatus which responds to the accelerations which occur. Irregularities in the injection process and in ignition are just as easily recognised here as in the complete diagram. The rate of pressure rise, which was proposed for rating fuels, depends less on the constitution of the fuel than on engine conditions such as engine speed, compression, load, injection advance, fouling etc. Thus, the complete diagram offers no great advantage in this sort of test. Also most test stations are interested only in determining the ignitability of Diesel fuels, as a check on storage or manufacture, and have not sufficiently skilled personnel for the maintenance of complicated measuring apparatus. Also it should not be forgotten that other influences, such as violent fluctuations in mains voltage, may cause very undesirable interference, which is avoided with the Rhenania-Ossag apparatus. The simple process achieves just as much with increased reliability. This is also shown by the greater reproducibility of the test results.

Whilst the accuracy of measurement and the reproducibility of the results make great demands on a fuel on the one hand, on the other hand the test time must be correspondingly long. This is already taken for granted in the measurement of octane numbers. With the Rhenania-Ossag method, the variation in repeated tests on commercial Diesel fuels, was found, on the basis of copious test material, to be under one cetane number, that is to say, the margin of error was less than ± 0.5 cetane number.

The engine with variable compression has the practical advantage that fuels from below cetane number 30 down to cetane number 10 could still be tested directly, while in the normal engine with constant compression they are tested in a blend with a known fuel of superior quality.

(Page 26)

In further discussions - during which a desire was expressed for correlation tests to be carried out prior to standardisation, and rejected by the Chairman on the grounds that it would only mean useless delay - the following decisions were reached, to be passed to the DVM for Standardisation.

1) The ignition delay process to be standardised as the basis for cetane number determination.

2) The ignition delay to be constant throughout the test.

3) The engines to be used are the HWA and the I.G. Test Diesel.

4) The ignition lag is to be kept constant either by throttling or by altering the compression.

5) The measuring instruments to be used are, Dr. Neumann's inertia indicator (Rhenania-Ossag), the Piezo-quartz indicator or the F.K.F.S. photocell indicator.

6) For cetane numbers between 30 and 70, the misfiring method with the HWA engine shall be used.