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Minimum and optimum R fuel quantity for the ring process on the Jumo Cylinder 211A.

Outline.

Tests have shown that the R fuel quantity of 5cu.mm. per stroke required for running the engine (2 to 10% of the total fuel quantity) is sufficient down to ¼ load. The quantity convenient both for performance and consumption however coincides approximately with the minimum quantity only in the full load region. In the part load region the economic R fuel quantity is higher than the required quantity. Down to about half load it is 20 to 25cu.mm. per stroke (10 to 15% of total fuel quantity), beyond that it rises up to 50 - 55cu.mm. per stroke with 2.5 air excess.
20-25cu.mm. per stroke of R fuel (equivalent to 5-15% of total fuel quantity) covers the practical operating range with 0.85 to 1.8 air excess.

Purpose of the tests.

Tests under various load conditions were carried out to determine the R fuel quantity per stroke, for various air excess ratios, producing the best performance and consumption. At the same time it was desired to ascertain the miniumu R fuel quantity allowing uninterrupted operation.

Test procedure.

Tests were carried out on the I.G. test engine fitted with a Jumo cylinder 211A. Table 1 shows the main engine data. Sheet 1, Fig. 1. shows the disposition of the nozzles.

By regulating the fuel quantity a certain load condition was obtained; the injected R fuel quantity was then gradually reduced until misfiring occurred, showing that a faultless run was no longer possible. The measurements were started at a R fuel quantity so high that a further increase produced no increase in power and a reduction of the injected quantity produced no drop in power.

Test results.

I. Minimum quantity required.

Eight R fuel control curves were plotted for eight different load conditions with constant gasoline quantity. The power is plotted in Fig. 2., Sheet 2., against the R fuel consumption. It appears that at full load (top curve) the power is not at all affected by the R fuel quantity; at 8cu.mm. per stroke it drops sharply. 7cu.mm. per stroke is the limit beyond which misfiring occurs. Reducing the power, i.e. with leaner mixture, the drop in the power curve becomes less sharply marked. On the other hand the power drop occurs earlier and earlier until at pme= 2, corresponding to λ = 4.5, the power begins to fall at 60cu.mm. per stroke. At this stage the ratio R fuel quantity to total fuel quantity varies between 40 and 50% (see also Sheet 5); any variation of the R fuel quantity therefore affects the power more than in the region of richer mixture with about 5% R fuel.

The phenomenom, that no power increase occurs starting from a certain R fuel quantity, in spite of the increased R fuel injection, cannot at first be explained. The observation of the course of exhaust temperatures (Sheet 3, Fig. 4.) shows that with increasing R fuel quantity (i.e. for a decreasing total λ) they rise considerably especially in the $\frac{3}{4}$ and $\frac{1}{2}$ load region, which points to after-burning. As the R fuel quantity decreases, they fall slowly at first; at the instant when output begins to drop more steeply, they fall suddenly, i.e. the mixture burns incompletely and reaches the exhaust unburnt. This phenomenon is more thoroughly investigated later on.

If we connect the test points obtained from the various minimum R fuel quantities (dash-dot line on Fig. 2.) we obtain for each load the required minimum R fuel quantity. Down to pme = 3kg./sq.cm. (λ = 2.1-2.2) this is about 5cu.mm. per stroke and it increases rapidly if the mixture is further weakened. In the last test without gasoline, the R fuel quantity necessary to attain idling output was 66cu.mm. per stroke. The speed however had dropped to 1,500r.p.m. To maintain idling at 2,000 r.p.m. the R fuel quantity required was about 85cu.mm. per stroke. Regarding the illustrations, note the following points: on Fig. 2. the air excess values for the various R fuel curves are referred to gasoline only, because these curves were obtained for a constant gasoline quantity. The curves which are reproduced on each sheet, are marked with small letters a to h. These are collected in a chart on Sheet 3.

2. Optimum R fuel quantity.

In order to determine the optimum R fuel quantity in regard to power and consumption, the consumption and pme figures have been plotted against air excess values for the various R fuel curves on Sheet 3, Fig. 4. In the rich mixture region and for a low ratio R fuel to main fuel, a variation of the R fuel quantity affects but little the air excess of the mixture. At first the power also remains constant, then it drops suddenly. If however the load diminishes, owing to the growing R fuel proportion the R fuel curves reach further air excess limits, and the power loops have a less curved shape. If we now draw the envelope we obtain the optimum output corresponding to each λ. A similar procedure is followed for the consumption: the curve enveloping the various consumption loops gives the curve of optimum consumption for each air excess ratio. Only as far as λ = 2.1 do the optimum values of the control curves approximately coincide with the envelopes. Beyond that the consumption rises so steeply that the consumption loops overlap; the result is that a bad point (as regards consumption) of a richer curve produces better values than the best point of a leaner curve. The envelope is inclined therefore towards the weak side of the various consumption loops.

The same results are reached by plotting the power against the consumption, as on Sheet5, Fig. 4. The enveloping curve shows here the minimum consumption for a given power.

The points at which the R fuel control curves touch the envelope are the points of maximum power or of minimum consumption for any load condition. As however the curves obtained experimentally touch the envelope over a longer interval especially for a high air excess, in each case the portion of maximum proximity between R fuel control curve and envelope was chosen and its length was drawn in the curves on Sheet 2. For the whole load range covered a region of optimum power is thus obtained. Following the same procedure for consumption the limits of optimum output and minimum consumption mainly coincide; a common region was therefore indicated. As regards output, it is the best naturally to keep to the right hand limit i.e. the engine runs on R fuel quantity at which the output no longer rises: minimum consumption is attained when output is rather lower according to the left hand limit. Fig 2, Sheet 2, shows that only in the full load region is it possible to run the engine on the minimum R fuel quantity; generally a considerably greater R fuel quantity is necessary to achieve economic operation. Only in the rich region the gasoline air mixture is so easily inflammable that a very small source of ignition can start the combustion. The leaner becomes the mixture, the greater must be the R fuel quantity to penetrate the whole combustion chamber and bring sources of ignition everywhere. In very lean mixtures the minimum and economic R fuel quantities approach each other again; here the gasoline consumption is insignificant. R fuel is the basis of power, and with sufficient air excess a large quantity burns better than with a rich gasoline mixture. The engine runs approximately on the Diesel system. If we examine the curve of the pre-injection angle (Sheet 5, Fig. 6 & 7) we see that in the case of rich gasoline mixtures the pre-injection angle of R fuel increases as the R fuel quantity decreases. The dilution with gasoline and the consequent reduction of inflammability is decisive. In the lean region (from a total $\lambda = 1.9$ onwards) where we approach the Diesel cycle, the ignition lag of the R fuel is independent of the quantity and the pre-injection angle remains constant at about 90° crank angle.

If we plot the air excess figures of the various tests against R fuel quantity, we obtain the curve represented in Sheet 2, Fig. 3. This gives the minimum and economic R fuel quantity for any given λ value. If we imagine the various R fuel control curves extended for a progressively reduced R fuel quantity, at 0 cu.mm./stroke of R fuel they reach the ordinate at a λ value that coincides with the λ value referred to pure gasoline, as computed in the tests. On sheet 6 the ratio R fuel quantity to gasoline quantity is plotted against the air excess for each test. It shows that the minimum R fuel proportion remains below 5% up to $\lambda = 2$; the economic proportion however starts at about 5% and goes up to 60-80% in the very lean region. The ratio R fuel to gasoline is shown on Sheet 6, Fig. 8 & 9, the proportion of R fuel to the total fuel quantity on Sheet 7, Fig. 10 & 11. The minimum R fuel quantities are again indicated by a dash-dot line, the economic proportion by a shaded area. Up to ½ load (equivalent to $\lambda = 1.8$) the minimum ratio R fuel to total fuel remains below 5%, the economic ratio below 15%.

TABLE 1.

Shown on Page 4.

TABLE 1.

Engine Data.

Main fuel	CV2b + 0.12%Pb H_u= 10,000kcal/kg.
Main fuel nozzle	Bosch DV2313/4 45° pintle type
Main fuel pump	Bosch PZ1/100 V 635A
R fuel	R300(H_u=6,880kcal/kg. 0.91kg/lt. theoret. air consump. = 9.33kg/kg.
R fuel nozzle	Bosch DV2311(single jet nozzle 0.4∅
R fuel pump	Bosch PE 1D, 6mm. piston ∅
Compression ratio	1:8
Valve timing	Intake opens 13°bTC Exst.opens 46°bBC Intake closes 48°aBC " closes 32°aTC
Pressure at the throttle valve	760mm. Hg.
Injection angle gasoline	350 crank angle aTC
R fuel	optimum
Oil Temperature	80° to 90°C.
Engine speed	2,000rpm.

Sheet 1. Fig. 1.

Nozzle arrangement.
(R fuel control curves on Jumo 211A)

Sheet 2. Fig. 2 & 3. Sheet 3. Fig. 4. Sheet 4. Fig. 5.

R fuel control curves.

Sheet 5. Fig.6.

Pre-injection angle.

Sheet 6. Fig.8 & 9 Sheet 7. Fig.10 & 11 Sheet 8. Fig.12&13.
R fuel control curves.