Title	An Experimental Study on the Behaviors of Engine Torque,Speed Response and Excessive Exhaust Smoke Density in Two-Stroke Cycle Diesel Engine under Load Cut-off Operations
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An Experimental Study on the Behaviors of Engine Torque, Speed Response and Excessive Exhaust Smoke Density in Two-Stroke Cycle Diesel Engine under Load Cut-off Operations

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Abstract – So far the studies on the dynamic characteristic of internal combustion engines have been mainly carried out on the governor system and have led to development of more efficient mathematical model for simulation and control purpose. But, there are still uncertain dynamic behaviors of the engine.

In the present study, in order to make clear the response of engine speed to the change of break load and the excessive exhaust smoke under load cut-off operations, the authors carried out some experiments. The results obtained are summarized as follows:

(1) The change of engine speed in the first half of accelerating period corresponds nearly to the characteristic of 1st order lag element and its time constant depends mainly on the characters of indicated torque, frictional torque and the inertia moment of revolving part in engine.

(2) The excessive exhaust smoke density under load cut-off operations increases nearly in proportion to the mean accelerating engine speed so that it depends on the initial conditions of engine speed, flow rate of injecting fuel, intake air capacity and temperature of combustion chamber wall etc.

1. INTRODUCTION

There are various running modes of an internal combustion engine and a considerable percentage of them are occupied by transient operations in which the engine speed and brake load fluctuate. Even in such transient running as above, it is desirable to improve the output performance and exhaust gas composition, to reduce the engine noise, to make the speed response better, etc.

The transient characteristics of an internal combustion engine have been so far studied mainly by a method of analysing, linearly as well as nonlinearly, the dynamic stability of a closed loop including the governor system[(1)~(3)].

The speed of engine is originally governed on the basis of an interaction between its governing system and the engine. For this reason, a more strict analysis can be only realized by means utilizing the detailed data obtained on the transient characteristics of the engine itself. On the other hand, it is desirable to improve the speed response of engines for vehicle and ship because these engines often run in accelerating and decelerating modes. Not only in the case of a non-supercharged engine but also in a supercharged one, consequently, analyses have been made with attention paid to the speed response of engine to the change in fuel feed quantity or brake load[(4)(5)]. Under such an accelerating or decelerating running mode that the engine speed changes near a stationary running state because of comparatively slight variation of the fuel feed quantity or brake load, an equation of motion for the engine rotating system is formulated using average values of the torque and speed of an engine during its one cycle as variables. And the responsiveness of engine speed has been

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followed by means of this equation in combination with the engine torque and the brake load characteristics obtained from stationary operation. In spite of its simplicity, this method makes it possible to know such fundamental facts that the speed response remarkably depends on the characteristics of output and frictional torque, the inertial mass of the rotating system, etc.

The fuel feed and the combustion processes of an engine, accordingly, the generation and the transfer processes of its engine torque are intermittently repeated every one cycle, but Hazell, P.A. et al.(6)(7) applied the so-called sampled data theory(8) to the torque generation process of a diesel engine. Meanwhile Bowns, D.E.(9) approximated the torque generating process with one in the form of finite-width and finite-amplitude pulse to analyse the speed control. In his analysis, Bowns changed periodically the rack of fuel injection pump and its frequency in a wide range, constructed a Bode diagram on the variation width of engine speed and made clear influences of the variational frequency and apmlitude of rack, the torque generating frequency and gain, and the brake load damping coefficient. On the other hand, there is also a different example of analysis, in which the generation and transfer processes of engine torque are supposed to be continuous from a macroscopic point of view, and the thermal response lag of the frictional torque under transient operation, the influence caused by the intermittent processes of fuel feed and combustion, etc. are collectively taken into consideration as primary response lag element(5)(10). This method is simple and convenient for gaining a general insight into the transient characteristics but it is necessary, for this purpose, to know the value of torque transfer time constant.

Therefore, in the previous paper(1), the authors examined the effects of operating conditions on the responses of the indicated and frictional torques and of the engine speed on the step change of the fuel pump's rack and on the excessive exhaust smoke. But, regarding the exhaust smoke regulation for a vehicle engine under transient operations, the so-called free or controlled accelerating operations are adopted as the simple measuring method(2)(3). For two-stroke cycle engines, in particular, the effects of operating conditions on the engine performance and the smoke character are unclear. Moreover, the engine applied for the construction or agriculture is allways operating under the load conditions with step or periodical change. Therefore, the authors carried out similar experiments to the step change of brake load to examine the effects of the operating conditions on the speed response and the excessive exhaust smoke density under load cut-off operations.

2. EXPERIMENTAL APPARATUS AND METHOD

The engine tested is a crankcase compression two-stroke cycle one (E-567) and its specification is shown in Table 1. The engine performance, as shown in Fig. 1, has such characters that the effective torque is highest at around 1600～1800 rpm and the engine speed become maximum at 2900～3100 rpm, within the range of the present experiment, owing to the effects of pressure wave in the intake and exhaust pipes. The experimental apparatus was, as shown in Fig. 2, composed of (1) a round nozzle for measuring the intake air amount in stationary operation, (2) a surge tank, (3) a manometer, (4) an intake air heater, (5) a laminar-flow type instantaneous air flowmeter, (6) and (19) manometers for measuring the intake and exhaust pressures, respectively, (7) and (18) thermometers, (8) a fuel flowmeter, (9) a test engine, (10) a rack position indicator for fuel pump, (11) an indicator for cylinder pressure, (12) electro-magnetic clutch to cut-off the brake load torque of dynamometer, (13) a dynamometer, (14) a device to measure the brake load torque, (15) and (16) engine and dynamometer speed indicators, respectively, (17) a TDC maker, (20, 21) a light absorption and a Bosch type smoke meters, respectively, (22) a microphone, (23) a fan motor, etc. Determined preliminarily by the deceleration method, the inertia-moment J of a rotating system comprising the engine tested and dynamometer is also given in Table 1. The absorbed torque characteristic T_l of dynamometer and the frictional torque T_f were determined from stationary operation experiments.

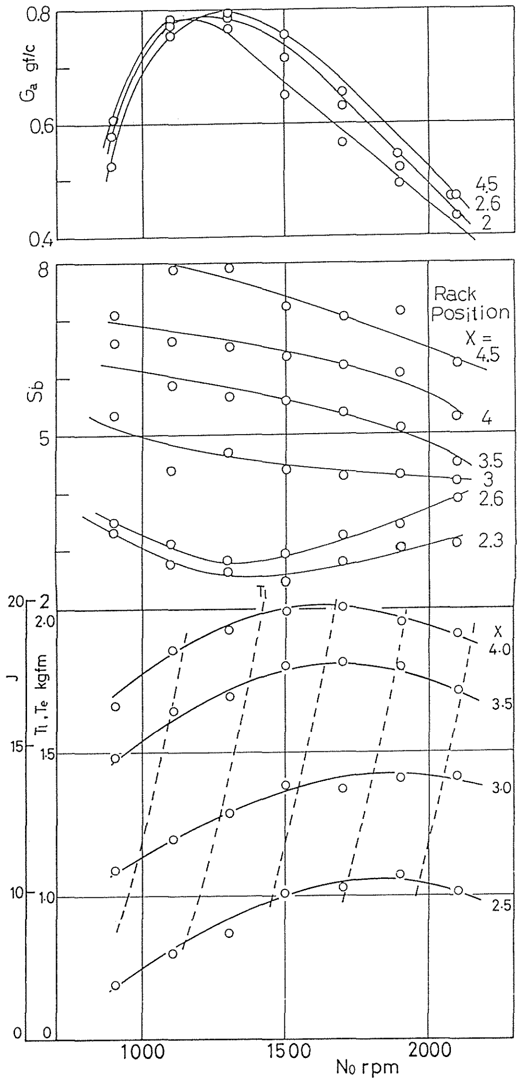

Fig. 1 Engine performance

Table 1 Specifications of test engine

Type	Diesel engine, air cooled 2 stroke-cycle
Number of cylinders	1
Bore X Stroke (mm)	85 X 100
Displacement vol. (cm^3)	567
Compression ratio	23
Combustion chamber	Swirl type
Output (max) (kW/rpm)	7.36/2000
(J/rpm)	3.63/1700
Scavenging	Crankcase compression, loop scavenging
Valve timing (°CA) inlet	52 TDC
exhaust	71 BDC
scavenging	56 BDC
Inertia moment of rotating parts (kg·m^2)	0.843 (0.086 kgfms^2)

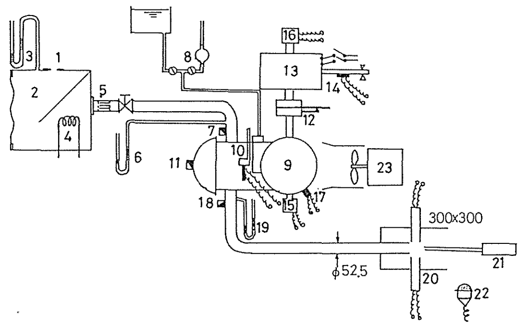

Fig. 2 Experimental apparatus

An experimental procedure is as follows.

At first, the engine was operated for about 15 minutes while keeping the given values of the effective torque, the engine speed and the temperature of combustion chamber wall. And then the flow rates of intake air and feed fuel, the temperature and the pressure of intake air and of exhaust gas and the exhaust smoke density were measured respectively and the cylinder pressure was recorded. Subsequently, fixing the rack of fuel pump, a source of electric power for the dynamometer or the clutch was cut-off to carry out the free accelerating operations. The period of cut-off was detected by an electrical index. The change of engine speed was determined from both the output of a small generator fixed to the engine shaft and TDC puls, and the effective heat release rate was calculated on the basis of the cylinder pressure recorded on a data recorder. The exhaust smoke density was measured with a PHS typed light-absorption smokemeter set at the open end of the exhaust pipe (its diameter d_e = 52.5 mm).

Above mentioned experiment was carried out over wide range of the initial conditions before the beginning of load cut-off operation, i.e., the engine speed N_0, the effective torque T_{e0}, the intake air amount G_{a0} and the temperatue of combustion chamber wall t_{w0}.

The inertia moment of the revolving part composed of an engine and a dynamometer and that of an engine only, obtained by means of the deceleration method(4), were equal to 0.086 and 0.019 kgfms^2 (0.843 and 0.186 kgm^2) respectively.

3. EXPERIMENTAL RESULTS AND CONSIDERATION

Supposing the cut-off of brake load as input and the change of engine speed as output, the engine speed response and excessive exhaust smoke under load cut-off operations are experimental considerated.

Symbols:

J = inertia moment of revolving part

t = time or time constant

T = torque

N = engine speed

G = weight velocity

Y = position of handle for controlling absorbing torque of dynamometer

X = rack position of fuel pump

Where, small letters n, τ, g, y, x show the changed value from an equilibrium state, suffix 0 is the value at an equilibrium state, suffixes i, e, r and l the indicated torque, the effective torque, the frictional torque and the absorbing torque, suffixed f, a the states of fuel and intake air, respectively. Let us consider that all variables N, T, G_f, Y, X are equal to the sum of all equilibrated values N_0, T_0, G_{f0}, Y_0, X_0 and all changed values n, τ, g_f, y, x.

3.1 General Characters of indicated and frictional torques

Within the range not exceeding 2000 rpm, the indicated torque T_i obtained from the clyinder pressure under load cut-off operations increases with the engine speed and its value is nearly equal to that of steady state as shown in Fig. 3. However, T_i in the latter half of accelerating period ($N>2000$ rpm) fluctuates violently and then its mean value coincides not always with the steady state T_i. For example, the experimental value for the initial speed $N_0=1100$ rpm with the full opened valve is larger than that of steady state operations [see Fig. 3(a)], whereas the value under the throttling air is slightly smaller than that of the latter [see Fig. 3 (b)]. It will differ depend on the effects of the throttling air on the temperature of combustion chamber wall, the intake air amount, the mixture formation, the ignition process etc. under respective operations. The change of frictional torque τ_r, which involves the pumping loss in crankcase, under load cut-off operations can be determined from the equation of motion for the engine revolving part, $J\dot{n}=\tau_i-\tau_r-\tau_l$ with the measured value τ_i, the product $J\dot{n}$ and the operating condition $\tau_l=0$. The rearranged value T_r instead of τ_i, as shown in Fig. 3 with dotted line, hardly coincides with the value, solid line, under steady operations obtained from the subtraction of T_e from T_i. Though the pumping loss in crankcase is closely related to the delivery ratio(8), the intake air amounts obtained with a lamminar type instantaneous flowmeter(9) under both operations were nearly equal to each other. As suggested from the fact(10) that the frictional torque in the same engine depends mainly on the cylinder pressure, the engine speed and the temperature of lubricating oil and from the report(11) on the temperature of a gasoline engine under transient operations, it seems that the response lag of the frictional torque is due to the thermal lags of the cylinder wall, the lubricating oil etc. Although it is difficult to estimate an accurate value of the respone of frictional torque to the step change of fuel feed amount t_{rg} because its behavior is complex, a rough estimate is about 3 to 10 seconds(1) for the tested engine.

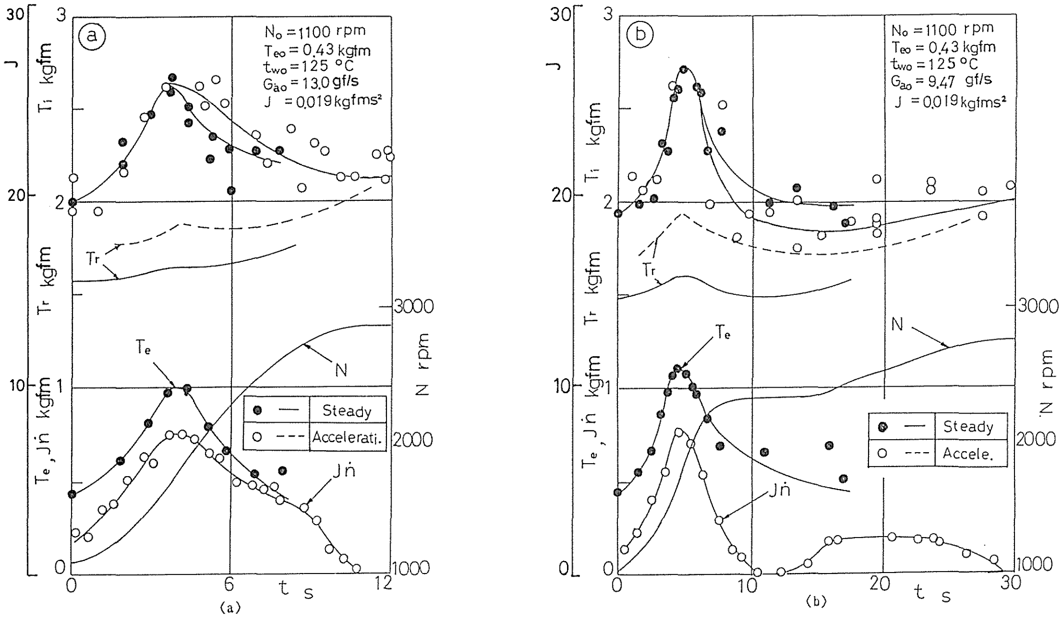

Fig. 3 Behavior of T_i and T_r under load cut-off

3.2 Response of engine speed

3.2.1 General character of load cut-off acceleration

The change of engine speed $n(t)$ in the first half of accelerating period corresponds nearly, as shown in Fig. 3, to the character of 1st order lag element, but $n(t)$ in the latter half is largely affected by the initial conditions, N_0, T_{e0}, t_{w0} and G_{a0}, and consequently the so-called two steps acceleration such as C curve in Fig. 3(b) and 4(b) and the two slopes acceleration such as B curve in Fig. 4(b) are observed. To make clear the cause, $n(t)$ in the models of indicated torque τ_i as shown in Fig. 4(a) is calculated from the equation of

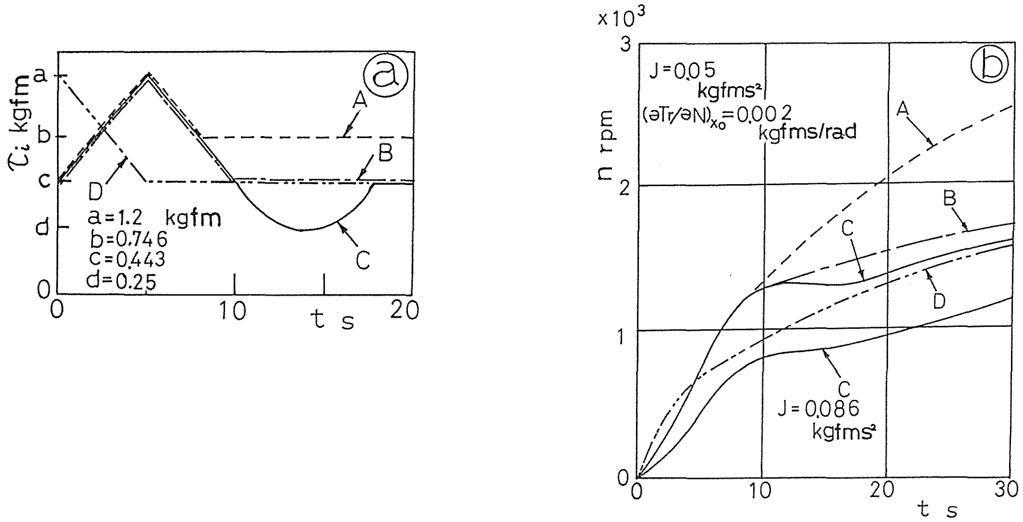

Fig. 4 Relation between τ_i and n Mark A ~ D in Fig. (a) corresponds A ~ D in Fig. (b) (a) (b)

motion for the engine revolving part with the value of τ_r and the results are shown in Fig. 4(b). It can be seen from the figure that $n(t)$ depends on not only J and τ_r but also τ_i and the formation of two steps acceleration (C curve) is due to the sunken character of τ_i in the latter half of accelerating period, whereas $n(t)$ in the first half is due to τ_i in the low revolution range. Moreover, since the maximum speed change $n(t)$ is nearly constant within the experimental range, it seems that the speed time constant t_n defined with the interval time from $n(t)=0$ to $n(t)/n(t_\infty)=0.63$, depends mainly on the character of τ_i in the low revolution range, i.e., the initial conditions N_0, T_{e0}, t_{w0} and G_{a0}.

3.2.2 Effect of operating conditions on engine speed response

To make clear the behavior of engine speed under load cut-off operations, the following notations are used,

t_n : the time constant, t_a, t_b, t_c : the times as shown in Fig. 5(a).

And the authors examined effects of the initial conditions on them.

(1) Initial engine speed N_0

The experimental values in the case that the rack of fuel pump is always fixed at a specified position { for example, at $N_0 = 1100$ rpm, $T_{e0} = 0.43$ kgfm (4.22 J) and $G_{f0} = 6.3$ mgf/c (0.062 N/c) } are shown with marks ○, △ in Fig. 5. And the values in the case that T_{e0} is always kept at 0.43 kgfm (4.22 J) are shown with marks ●, ▲ in same figure. In this figure, the value of t_n becomes shorter with an increasing N_0 because of an increase in the supplied heat energy per unit time and of a decrease in the accelerating range $n(t)$. In the same N_0, the larger T_{e0} is and the smaller J is, the shorter t_n becomes (compare ○ with △). In general, the behavior of engine speed $n(t)$ shows a two-steps acceleration and the required times t_a, t_b and t_c become shorter with an increasing N_0. But, in the range of N_0 >1500 rpm except the case that T_{e0} is small, $(t_b - t_a)$ becomes shorter and consequently a two-slopes acceleration can be observed.

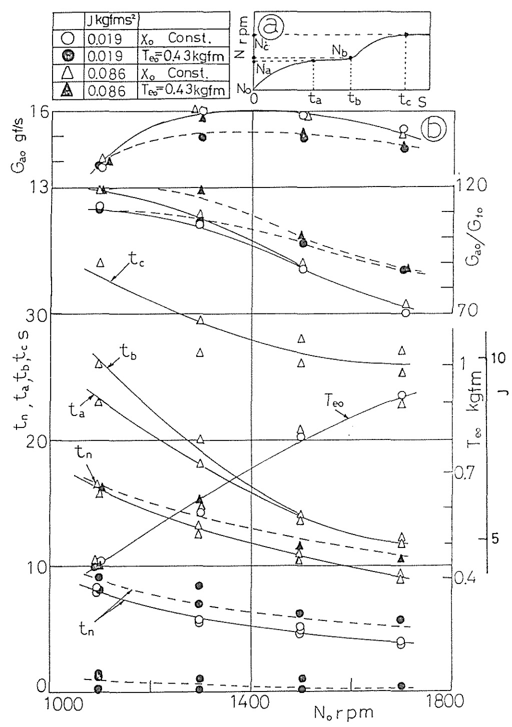

Fig. 5 Time constant t_n vs initial speed N_0

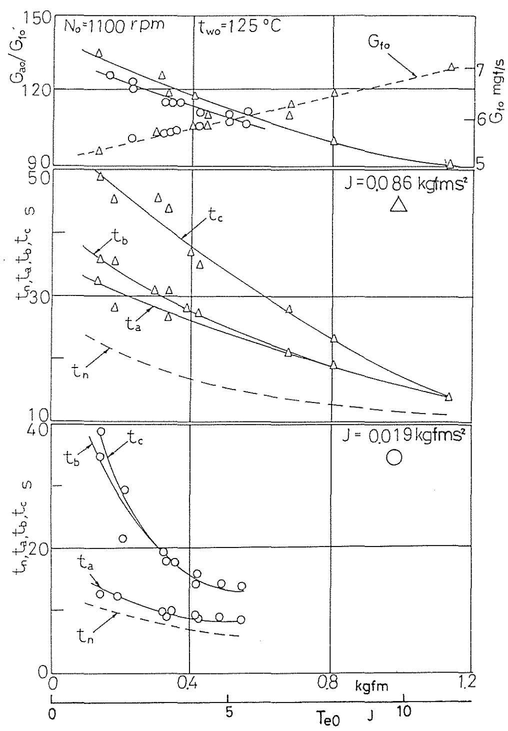

Fig. 6 Time constant t_n vs initial torque T_{e0}

(2) Initial effective torque T_{e0}

Since the larger T_{e0} is, the larger T_{i0}, i.e., τ_i becomes and the acceleration $\dot{n}$ increases as seen from the equation of motion for the engine revoluting part, t_n becomes shorter (see Fig. 6). Moreover, N_a, N_b and N_c shift to high speed side, whereas t_a, t_b and t_c become rather shorter. And consequently the two steps acceleration becomes almost extinct in $T_{e0}>0.58$ kgfm (5.69 J) and then t_a, t_b, t_c coincide with each other at $T_{e0}=1.15$ kgfm (11.28 J) so that an acceleration corresponding to the so-called 1st order lag element can be observed. Further, the mean acceleration $0.63\cdot n(t)/t_n$ increases in proportion to T_{e0}.

(3) Initial temperature of combustion chamber wall t_{w0}

Increasing t_{w0}, the wall temperature under free accelerating operations also increases and consequently promotes the evaporation of fuel and the ignition lag becomes shorter. So it is possible to expect an increasing of T_i and a decreasing of T_i, as can be conjectured from Fig. 7. Accordingly, t_n becames shorter with an increasing t_{w0} as shown with marks △ and ○, but with $T_{e0}=0.43$ kgfm (4.22 J) kept, the effect of t_{w0} is comparatively small (▲, ● marks). Although N_a, N_b and N_c are hardly altered by an increasing of t_{w0}, the required times t_a, t_b, t_c become shorter and the behavior of $n(t)$ approaches the state of 1st order lag element. It seems that such a result is caused by not only T_{e0} increasing with t_{w0}, but also the thermal response lag and the concavity of T_i curve decreasing in the high speed range as shown in Fig. 3.

(4) Initial intake air amount G_{a0}

When the rack of fuel pump is fixed at a specified position corresponding to the light load (large G_{a0}/G_{f0}) and G_{a0} is throttled by the valve, the torque (T_{e0} or T_{i0}) at initial condition increases slightly in the low speed range, whereas it decreases considerably in the high speed range. Moreover, the indicated torque T_i

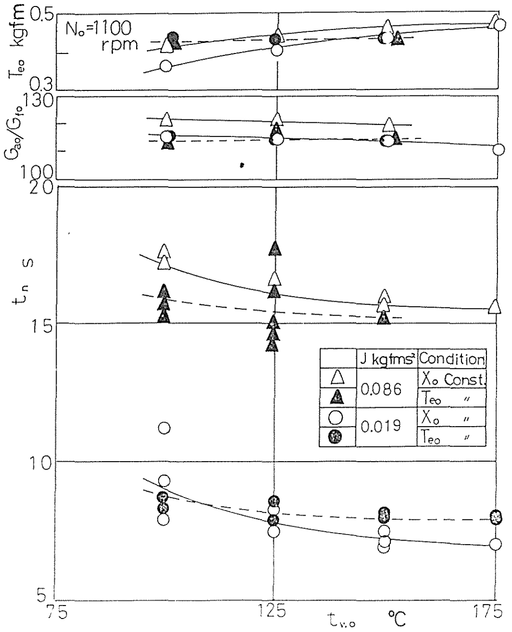

Fig. 7 Time constant t_n vs initial temperature t_{w0}

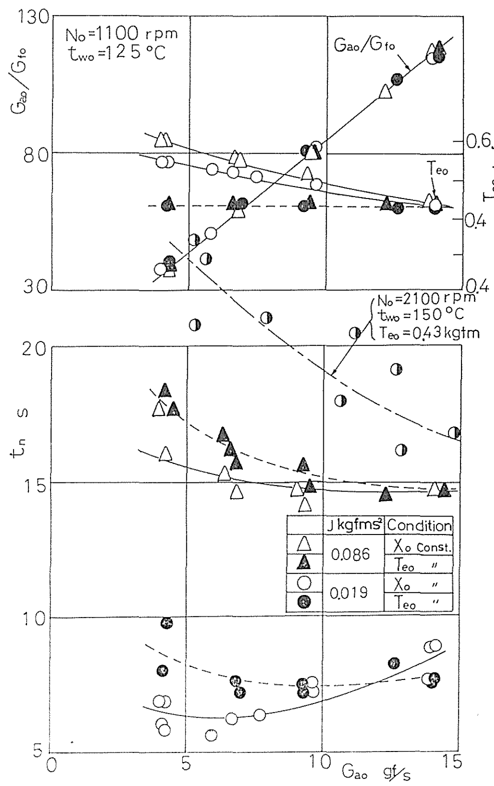

Fig. 8 Time constant t_n vs initial intake air amount G_{a0}

under free accelerating operations is smaller than that under steady operations in the high speed range as pointed out in Fig. 3 and this tendency becomes remarkable with a decreasing G_{a0}. Consequently, in the load cut-off experiment under the light load, the behavior of $n(t)$ due to G_{a0} is mainly influenced by the increased T_{i0} and the decreased T_i in the latter half of accelerating period. Since the effect of the fomer becomes smaller with an increasing J, t_n for the large J, marked with ▲ in Fig. 8, is hardly changed with an exception of G_{a0} = 4 gf/s in spite of the increment of T_{e0}. This tendency can be seen also for N_a, N_b, t_a and t_b. On the other hand, the behavior of $n(t)$ for the small J, marked with ○, is easily affected by the character of T_i so that t_n becomes shorter with a decreeasing G_{f0}. With T_{e0} = 0.43 kgfm (4.22 J, ▲ and ● markes) kept, however, G_{f0} decreases with G_{a0} so that T_i decreases gradually with an increasing $n(t)$ under accelerating operations and consequently t_n, t_a and t_b are hardly changed. As mentioned above, the behavior of $n(t)$ depends on N_0, T_{e0}, t_{w0} and G_{a0}, and these factors affect the exhaust smoke density.

(5) Comparison between experimental and calculated values

Fig. 9 shows the experimental and calculated values of t_n for the initial condition, N_0 = 2100 rpm (t_{w0} = 150°C), which can be approximated as $t_i = (\partial T_i/\partial N)_{x0} \cdot n$ from T_i curve in Fig. 3. In other words, using $(\partial T_i/\partial N)_{x0}$ etc. for each initial condition which is determined from the performance curves under steady operations and the response lags t_{rg}, t_{ig}, estimated at suitable value, the values of t_n calculated from Eqs. (8) to (10) in the previous paper(1) are shown in Fig. 9 with dotted and solid lines respectively. According to the figure, the experimental values coincide quantatively with the calculated ones in consideration of t_{rg} and t_{ig}. Therefore, the effects of each transfer element on the speed response under load cut-off operations can be obtained by calculating Eqs.(8) to (10) in the previous paper.

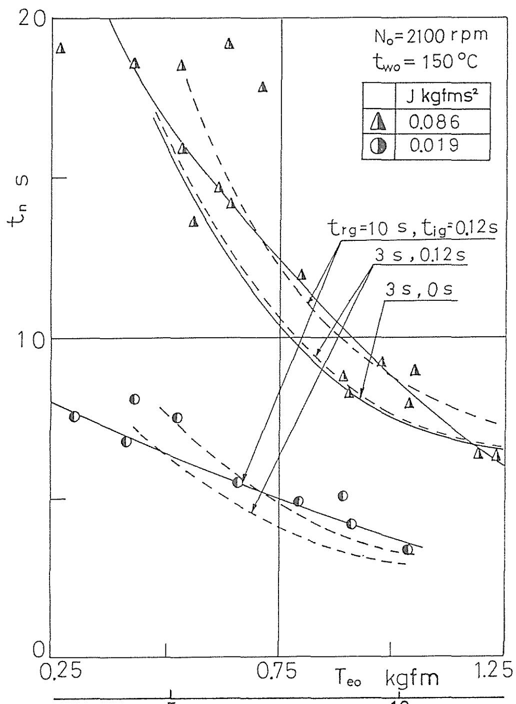

Fig. 9 Comparison of experimental value and calculated one

3.3 Exhaust smoke character under load cut-off operations

3.3.1 Excessive exhaust smoke

Since the smoke formation in diesel engines depends on not only the macroscopic ones, in particular, the exhaust smoke character under load cut-off operations has many unknown points. The cylinder pressure at every 400 cycles and the exhaust smoke density at every 200 cycles among the continuously recorded experimental results are shown in Fig. 10. In the figure, the maximum light-absorption ratio $\Delta L_m/L$ increases from vicinity of 80th cycle, reaches a peak at 120 to 130 th cycle and after that $\Delta L_m/L$ decreases gradually to the steady state after about 200 cycles.

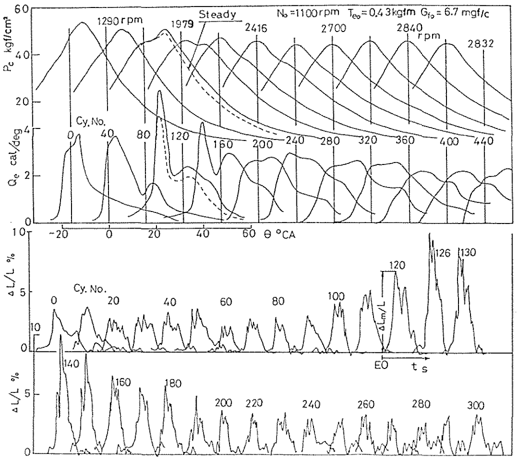

Fig. 10 Behavior of Q_e and $\Delta L/L$ under load cut-off operation

Though the rack position is fixed, such an excessive smoke formation as this is observed. On the other hand, the maximum effective heat release rate obtained from the cylinder pressure increases largely from about 80th cycle to 120th cycle and its value is higher than that under steady operations. The engine speed at about 120th cycle is about 2000 rpm, which corresponds to such engine speed that the indicated torque and the exhaust smoke density under steady operations are maximum and also the difference between $\Delta L_m/L$ under the load cut-off operations and steady ones becomes maximum. Therefore, although the excessive smoke formation is affected by the smoke formation character of tested engine under steady operations, it seems that its formation depends mainly on the temperature response lag of the combustion chamber wall, which invites a large ignition lag, a rapid combustion, a local lack of air, a cycle-by-cycle variation of combustion and consequently and excessive smoke formation. The amplitude and the formation period of such an excessive smoke are so closely associated with the acceleration n that it is influenced by the initial conditions N_0, t_{w0} and G_{a0}.

3.3.2 Effect of operating conditions on excessive smoke density

To investigate quantitatively the excessive smoke density, the authors used $\Delta L_{max}/\Delta L_s$ and A_a/A_s. Where $\Delta L_{max}/\Delta L_s$ is the ratio of the maximum value $\Delta L_{max}/L$ in $\Delta L_m/L$ curve as shown in Fig. 11(a) to the initial value $\Delta L_{s0}/L$ and A_a/A_s is the ratio of time-area A_s of $\Delta L_m/L$ curve in the accelerating period to the time-area A_s under corresponding steady operation.

(1) Initial engine speed N_0

Since the acceleration $\dot{n}$ increases with an increasing N_0, the formation period of excessive smoke density becomes early [see Fig. 11(a)] and the passing time in the speed range giving the highest exhaust smoke density under steady operations becomes shorter. On the contrary, the temperature response lag of the combustion chamber wall etc. increases, and consequently will affect the excessive smoke character A_a/A_s. According to the experimental results for each N_0 (see Fig. 11), becomes the highest at a specified N_0 and the smaller and the larger the acceleration, the higher A_a/A_s becomes. In this case, since the engine speed at $\Delta L_{max}/\Delta L_{s0}$ shifts to the lower side, there is no linear relation between $\Delta L_{max}/\Delta L_{s0}$ and A_a/A_s.

(2) Initial effective torque T_{e0}

With an increasing T_{e0}, G_{f0} increases and G_{a0}/G_{f0} becomes recher as shown in Fig. 6. Thus the exhaust smoke density under steady operations, i.e., A_s increases and the A_a under load cut-off operations increases because of an increase in acceleration [see Fig. 6(a)]. But, the value of A_a/A_s increases only a little. In this case, when T_{e0} is larger, the engine speed at the maximum value of $\Delta L_m/L$ becomes lower and the period of excessive smoke formation becomes shorter.

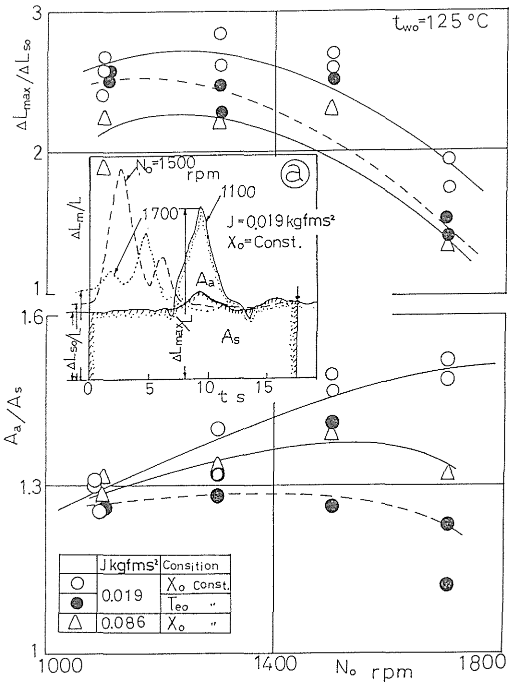

Fig. 11 $\Delta L_{max}/\Delta L_{s0}$, A_a/A_s vs N_0

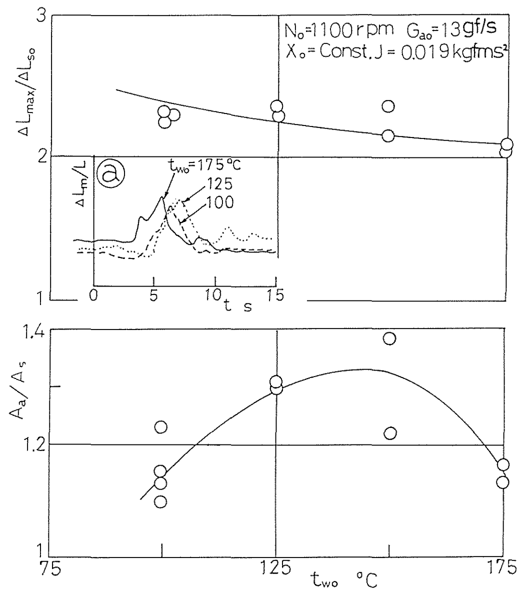

Fig. 12 $\Delta L_{max}/\Delta L_{s0}$, A_a/A_s vs t_{w0}

(3) Initial temperature of combustion chamber wall t_{w0}

If the rack of fuel pump is kept at a specified position (X_0 = const.), T_{e0} increases with t_{w0} within the range of the present experiment as shown in Fig. 7, and consequently the acceleration of engine and the time ratio of the excessive smoke formation period to all the accelerating period increases so that A_a/A_s tends to increase with t_{w0} (see Fig. 12). On the other hand, with an increasing t_{w0}, the thermal response lag becomes shorter and the control effect on the excessive smoke increases. Consequently, a value of t_{w0} giving the maximum value of A_a/A_s exists, for example, t_{w0} = 175°C. In this case, the relation between $\Delta L_{max}/\Delta L_{s0}$ and A_a/A_s is nonlinear. And the engine speed at which a value of $\Delta L_m/L$ reaches the maximum point, which are nearly constant regardless of t_{w0}.

(4) Initial intake air amount G_{a0}

The exhaust smoke density under steady operations depends mainly on the air-fuel ratio and it increases with throttling of only G_{a0}. Similarly, the excessive smoke density under load cut-off operations increases remarkably with throttling G_{a0} as shown in Fig. 13. Since the residual gas increases with throttling of G_{a0}, the temperature of charging air rises and the evaporation of fuel is promoted, and consequently it is expected to control the abnormal smoke. Accordingly, although these effects are not simple, the experimental values of A_a/A_s and $\Delta L_{max}/\Delta L_{s0}$, as shown in Fig. 13, become minimum at about G_{a0} =9 gf/s.

(5) Excessive smoke density A_a/A_s and mean acceleration $n(t)/t_n$

To clarify the effects of the initial conditions on the excessive smoke formation, the experimental values A_a/A_s under load cut-off operations in the case of small moment of inertia (J=0.19 kgfms^2) and large accelerations are plotted versus $n(t_n)/t_n$ in Fig. 14. If a fixed rack of fuel pump is kept, A_a/A_s for each value of t_{w0} and G_{a0} increases in proportion to the mean acceleration $n(t_n)/t_n$ with some exceptions. But the state under load cut-off operations is affected by the initial conditions, N_0, T_{e0}, so that the slope of straight line is changed as shown in Fig. 14. The respective relations among the initial conditions, the engine torque character and $n(t_n)/t_n$ can be induced from Eqs.(8) to (10) in the previous paper within the range of the linear character and it is possible to make clear qualitatively the effects of these factors on A_a/A_s.

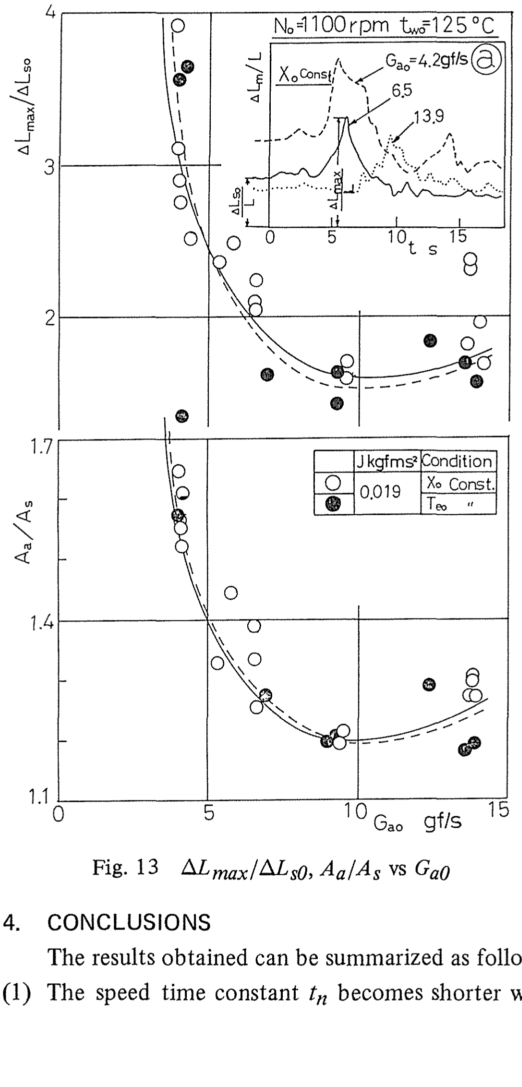

Fig. 13 $\Delta L_{max}/\Delta L_{s0}$, A_a/A_s vs G_{a0}

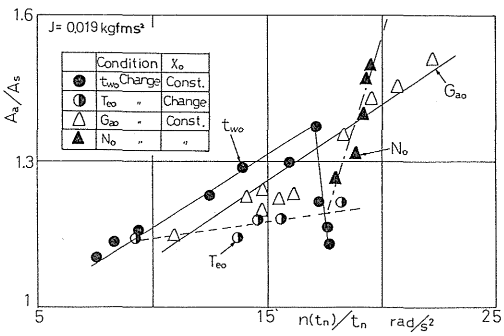

Fig. 14 A_a/A_s vs $n(t_n)/t_n$

4. CONCLUSIONS

The results obtained can be summarized as follows:

(1) The speed time constant t_n becomes shorter with an increase of the initial conditions N_0, T_{e0}, t_{w0} and

with a decrease of J.

(2) Within such a range that the indicated and frictional torques have liner character respectively, the speed time constant t_n can be calculated from Eqs.(8) to (10) in the previous paper[1] in consideration of the thermal response lag t_{ig}, t_{rg}, and the calculated value coincides with the experimental one.

(3) Using the raito of time-area A_a/A_s and the ratio of the maximum light-absorption rate $\Delta L_{max}/\Delta L_{s0}$ in order to investigate the excessive smoke, with an increasing of the initial conditions N_0, T_{e0} and t_{w0}, A_a/A_s increases, while, $\Delta L_{max}/\Delta L_{s0}$ decreases. Moreover, both A_a/A_s and $\Delta L_{max}/\Delta L_{s0}$ increase with throttling of G_{a0}.

(4) If the initial conditions, in particular, the rack position of fuel pump are the same, A_a/A_s increases in proportion to $n(t_\infty)/t_n$.

On the other hand, since the effects of various engine factors on $n(t_\infty)/t_n$ can be calculated from Eqs. (8) to (10) in the previous paper, it is possible to make clear the effects of the various factors on the abnormal smoke under free accelerating operations. But, the relation between $\Delta L_{max}/\Delta L_{s0}$ and $n(t_\infty)/t_n$ is not consistent.

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