Characteristics of Fuel Flow Rate of a Carburettor Engine

CHARACTERISTICS OF FUEL FLOW RATE OF A CARBURETTOR ENGINE

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Abstract

It is necessary to feed always an appropriate mixture into the cylinders for reducing the exhaust emissions from an automobile gasoline engine. Therefore, on the practical gasoline engine, we must be well known in respect of the state of pressure wave characteristics on the throat of a carburettor, by reason of, it is very large influence to the fuel flow rate.

In this paper, the authors have measured in respect of the relationship between the position and opening angle of a carbrettor, the length of the fuel injection pipe, the length of intake manifold, the engine revolution speed and fuel flow rate by used crankcase compressed two cycle engine.

Moreover, we have investigated by compaired these results to numerical calculation results on unsteady characteristics of a simplified carburettor only for the main fuel system.

Some conclusions reached are summarized as follows.

(a) The fuel flow amount from a carburettor decreases in inversely proportional to the amplitude of pulsation wave in the throat of carburettor and is partly governed by the matching condition q.

(b) When the throttle valve of carburettor is small opening, the fuel flow amount increases with the engine speed and the length of main fuel pipe, because of the inertia effect of liquid column in main fuel pipe.

(c) To prevent the variation of air excess ratio, the utilization of a Helmholtz resonator with elastic membrane is effective.

(d) When the throttle valve of a carburettor is rapidly closed, the fuel flow rate is remarkably decreased and is violently fluctuated before reaches a given value in the stationary operation. This fluctuation period is approximately equal to the natural vibration period of liquid column composed of the fuel injection pipe and the float chamber.

(e) Such a variation of fuel flow rate can be observed in the case of accelerating operation.

1. Introduction

To reduce the exhaust emissions from a carburettor engine, it is necessary, during not only steady but also transient operation of it, to feed always an appropriate mixture into the cylinders. Recently, basic researches[(1),(2),(3)] on carburettor have been actively out, resulting in considerably better understanding of its fundamental characteristics.

Since pressure wave in the intake pipe of an engine used in practice changes complicatedly according as the intake pipe system and operation condition, however, it is difficult to forecast, based on the carburettor's fundamental characteristics, fuel flow amount at each operation condition unless the realities of the pressure wave in intake pipe are understood in detail. Although many authors described, on the other hand, the amount of breathing air, they did not almost touch upon the possible effect of the pressur wave on fuel feed condition so that many problems are left unsolved.

It is possible to discuss the suction process of a four-cycle engine similarly to that of a

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two-cycle engine and dependence of the pressure wave in intake pipe on the operation condition, the wave's effect on the carburettor's character etc. may be treated in the same manner. In order to investigate the influence of various factors on the fuel feed condition of a two-cycle engine provided with an AMAL type carburettor, the author has experimentally examined the influences of position, aperture and dimension of the carburettor, the length of intake pipe and examined to some degree the relationship with the experimental and numerical-calculation results on unsteady characteristics of a so-called simple carburettor only for the main fuel system so that these data are described in the following.

2. Experimental Apparatus and Methods

2.1 Carburettor experiment

Fig.1 shows an experimental apparatus, which is composed of a Nash vacuum pump 80 NV5M (maximum flow rate 4.5 m^3/min), a surge tank, a rotary or poppet valve for producing pulsating and intermittent air flow, piping, a carburettor, a round nozzle and a surge tank for measuring air flow rate, a fuel flowmeter etc. Fig.2 shows the structure and main dimension of the carburettor to be tested, where a float chamber is separated from its frame and the main fuel pipe system is independent of the low-speed one so as to measure the respective fuels. A throttle valve of the carburettor can be finely regulated and flow resistance coefficient ϕ_m of the whole main fuel injection pipe composed of a fuel including needle bar and a fuel jet was obtained from the result of steady-flow experiment for each carburettor aperture, X. The flow resistance coefficient is given by a relation

$$\phi_m = (\alpha+\beta)/|R_e|$$

as shown in Fig.3, where α and β are constants and R_e is the Reynolds number. While α and β depend on the carburettor aperture and the flow direction, they are approximately constant for full aperture (X=0), $\alpha=30$ and $\beta=7\cdot10^3$[4].

Similary. the flow resistance coefficient ϕ_i of the idle fuel injection pipe system is shown in Fig.4. The fluctuating pressure in the carburettor throat is measured with a strain-gauge

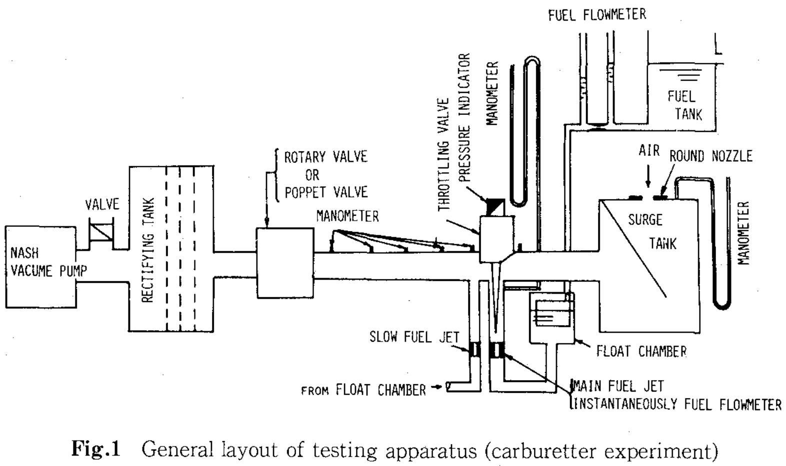


Fig.1 General layout of testing apparatus (carburetter experiment)

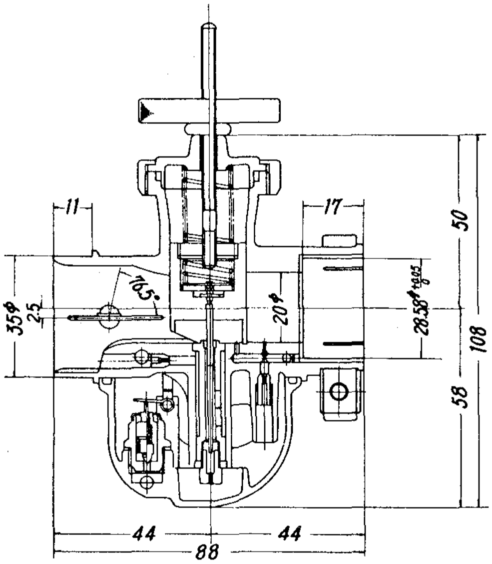


Fig.2 Test carburettor (Engine E-120)

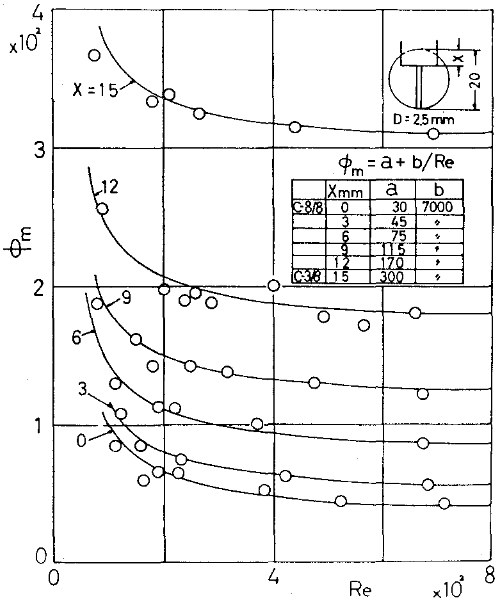


Fig.3 Flow resistance coefficient ϕ_m of main fuel pipe system

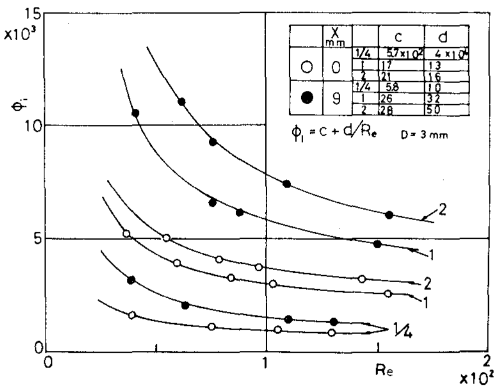


Fig.4 Flow resistance coefficient ϕ_i of idle fuel pipe system

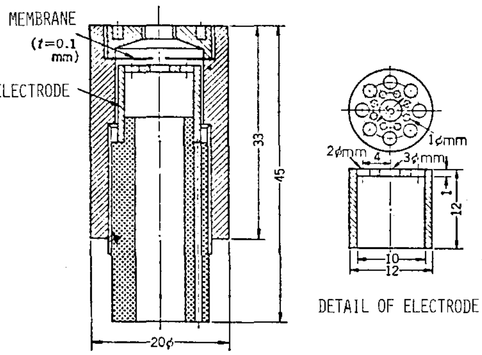


Fig.5 Instantaneous fuel flow-meter

type pressure indicator, the average negative pressure with a manometer and the instantaneous flow rate of fuel with a capacity-type instantaneous flowmeter (see Fig.5)[5], which was trially assembled by the author. In the experiment, the required sinusoidal and intermittent, half-wave rectified-one-like pressure wave are approximately given to the carburettor throat and its fluctuating pressure, the instantaneous value of fuel flow rate and its average value and the average amount of breathing air are measured. Such experiments are repeated for respective condition.

2.2 Engine experiment

2.2.1 Stationary operation

The tested engine are crankcase compression two-cycle one, which have dimensions as shown in Table · 1. The used carburettor is a standard product, which is the same as that in the carburettor experiment. The experimental apparatus is, as shown in Fig.6, composed of a round nozzle and a surge tank for measuring the amount of breathing air, the carburettor, an intake pipe, the test engine and an exhaust pipe.

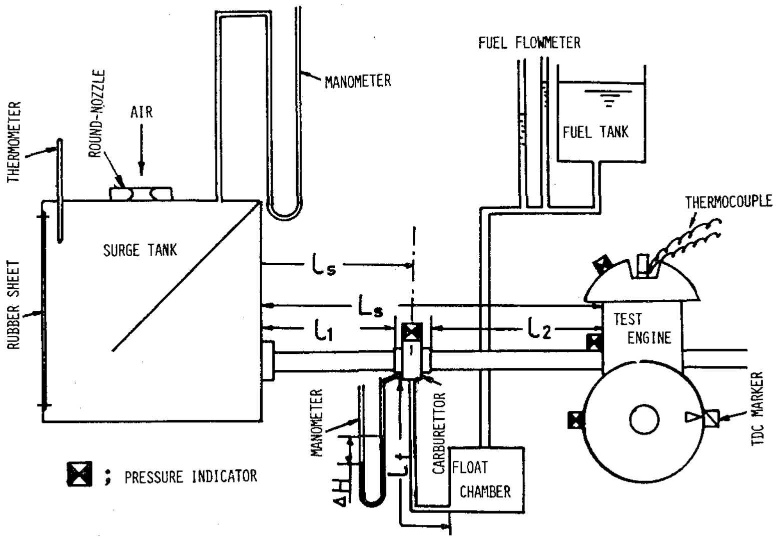


Fig.6 General layout of testing apparatus (engine experiment)

Table 1 Dimensions of test engine

Symbol		E-50	E-120
Cylinder bore × Stroke, mm		40φ × 39.8	52φ × 51
Stroke volume cc		49.8	118.9
Mean volume of crankcase during inlet open period cc		161	390
Compression ratio		7 : 1	7.28 : 1
Inner dia. of inlet pipe mm		14	20
Port timing (symmetrical)	Scavenging	±55(B.D.C.)	±58(B.D.C.)
	Exhaust	±67(B.D.C.)	±76.5(B.D.C.)
	Inlet	±60(T.D.C.)	±60(T.D.C.)

In addition, a manometer and a strain-gauge type pressure indicator are inserted for measuring average negative and pulsating pressures in carburettor throat and a venturi-type fuel flowmeter is setted between the float chamber and the fuel tank to measure the average fuel flow rate. With the float chamber separated from the frame, only the main fuel system is made to work, it length l_f being selected variably according as the experimental purpose. Another strain-gauge type pressure indicator and a top dead center are installed to measure pulsating pressure immediately before the inlet port and in the crankcase, respectively. The experimental procedure is as follows. At first, the given intake pipe length L_s, carburettor aperture C and its fitting position l_s are set and the engine is made to start by means of an electric dynamometer to enter into driving operation.

Since combustion fluctuation can cause the variations of the amount of breathing air and fuel flow rate, the engine speed is consecutively changed from 1500 rpm to 6000 rpm usually under the motoring operation and after the temperature of ignition plug seat becomes steady at each engine speed, the amount of breathing air, the fuel flow rate, the negative pressure at carburettor throat etc. are measured.

Similar experiments are repeated with the setting condition changed. The pulsating pressure at each part is further measured and recorded under a representative condition.

Since it is difficult to measure accurately a minute flow rate of fuel, the measured values easily fluctuate and such a slight variation is magnified if it is expressed through excess air

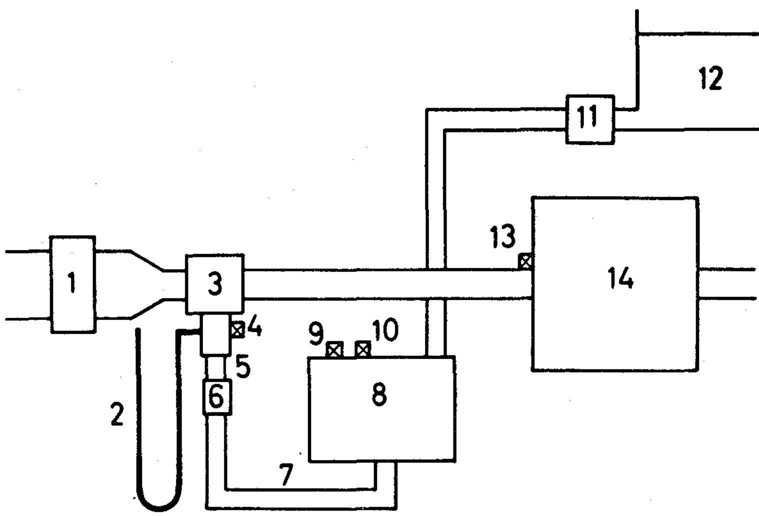


Fig.7 general layout of experimental apparatus (transitional operation)
1. Laminar-flow typed air flow-meter, 2. Manometer, 3. Carburettor
4. Capacity-typed pressure indicator, 5. Main fuel jet,
6. Capacity-typed instantaneous flow-meter, 7. Vinyl pipe,
8. Float chamber, 9. Displacement-meter for float,
10. Measuring probe of fuel level, 11. Fuel flow-meter,
12. Fuel tank, 13. Pressure indicator, 14. Test engine,

ratio, with a larger fuel jet than normal one the experiment is carried out within a range of rich mixture.

2.2.2 Transitional operation

Fig.7 shows a general layout of the experimental apparatus, which is mainly composed of a laminar-type instantaneous air flow meter(1), a capacity-type pressure indicator(4)(5) and a capacity-type instantaneous flow meter(6) for examining the behavior of fuel flow, an indicator(9) and a probe(10) for mesuring the displacements of the float and fuel level in the float chamber(8) and a test engine etc.

3. Experimental Results and Considerations

3.1 When carburettor aperture is large

3.1.1 Tuning of residual pulsating wave and fuel flow rate

When intake pipe length L_s is kept constant ($L_s=88$ cm) and the carburettor with aperture C-8/8 (α/β in a symbol C-α/β expresses hereinafter aperture area ratio) is brought close to the engine side, the amount of breathing air G_a changes with the carburettor's position by 1 to 2 % only of delivery ratio K but the fuel flow ratio G_f is, as shown in Fig.8, remarkably decreased and it further is varied widely at a particular engine speed N.[6] Fig.9 shows the experimental result of Fig.8 rearranged in terms of $G_f/\sqrt{\Delta H}$ for the purpose of making more vivid the influence of residual pulsating wave. Fig.9 also comprises the maximum value ΔP^* of positive pressure wave, determined from oscillogram of pulsating pressure at the carburettor throat as well as the cycle number of pulsating wave in the intake pipe during one revolution of engine (from an intake opeing, I.O. to that in the next intake process).

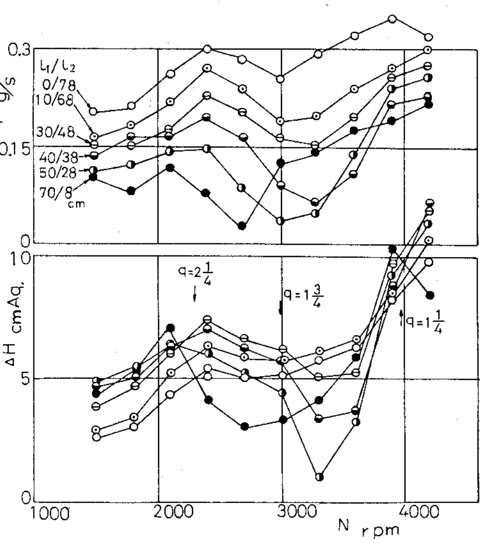


Fig.8 Fuel flow rate G_f, negtive pressure in carburettor throat ΔH and engine speed N (Engine E-50)

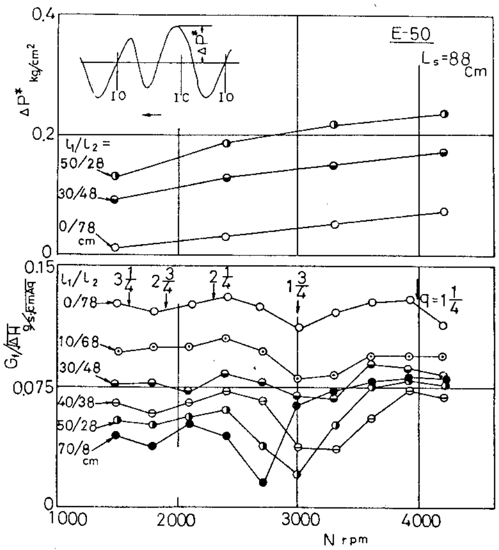


Fig.9 ΔP^*, $G_f/\sqrt{\Delta H}$ and engine speed N (Engine E-50)

In the figure, $G_f/\sqrt{\Delta H}$ curve changes approximately at a specified value of engine speed, its ups and downs appearing near q=n+1/4 (n=integer such as 1,2,…) and q=n+3/4, respectively. Generally, a pulsation coefficient q^* is given by the following formula :

$$q^*=15 \cdot a/N\ (L_s+\Delta l) \qquad \cdots(1)$$

Where a : propagation velocity of pressure wave within the intake pipe [m/sec]

N : engine speed [rpm]

L_s : intake pipe length [m]

Δl : corrected length of pipe end [m]

When $q^*= n + 1/4$, the negative residual pulsating wave and the inlet opening I.O. overlap so that the negative-pressure period of the intake process lengthens as shown in Fig.10.

When $q^*= n + 3/4$, the negative-pressure period shortens on the contrary because the positive wave and I.O. overlap. In the former, for this reason, fuel outflow is promoted, while in the latter it is prevented. Since q^* corresponds to the above-mentioned q, it can be seen that undulation of the $G_f/\sqrt{\Delta H}$ curve depends on the tuning of the residual pulsating wave. If a carburettor is mounted at open end of the intake pipe, influence of such a residual pulsating wave is comparatively, slight, as can be seen on the $G_f/\sqrt{\Delta H}$ carve, Fig.9, for $l_1/l_2=0/78$ (Engine E-50, L_s=88 cm) as well as on an excess air ratio carve (E-120, L_s=88 cm), Fig.11, even in the case of a longer intake pipe. Since the wave's amplitude is decreased for shorter intake pipe, its influence is gradually lowered and not almost observed at L_s=16 cm

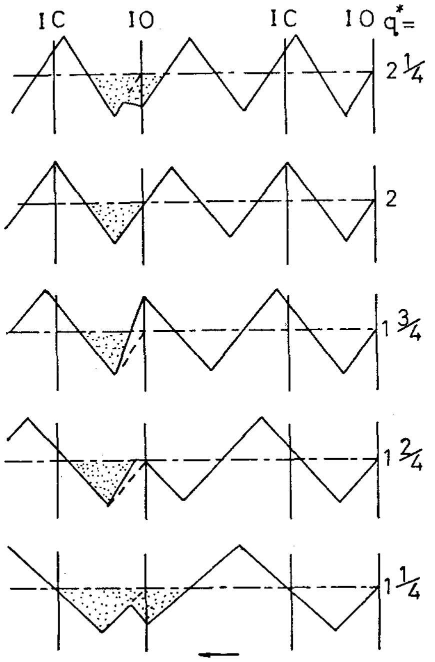


Fig.10 Pulsation factor q* and superpose of pressure wave

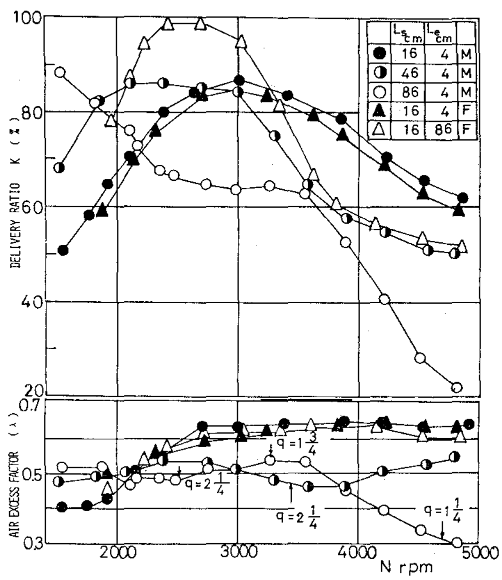


Fig.11 Delivery ratio K, excess air ratio λ and engine speed N (Engine E-120) Symbol M : motoring, F : firing

(see Fig.11).

For either motoring or firing operation (comparison between the marks ▲ and ● in Fig.11), values of the excess air ratio are, even when the exhaust pipe length L_e is lengthened and the delivery ratio K remarkably is changed, almost unchanged only if parameters L_s, l_s C etc. of the intake pipe system are the same.

3.1.2 Carburettor position and fuel flow rate

In the experimental results shown in Figs.8, 9 and 12, even in a range of $q > 3$, the fuel flow rate G_f and the value of $G_f/\sqrt{\Delta H}$ are more decreased the more the carburettor approaches the engine side. This tendency can be recognized within all the engine speed range and its amount is considerably large.

Now, draw a diagram representing a relationship between the fuel flow rate G_f and the carburettor position l_s, l_s corresponding to a length from open end of the intake pipe to fuel injection port of the carburettor, estimate the value of fuel flow rate G_{fo} at a point corresponding to $l_s=0$ and plot G_f/G_{fo} against l_s/L_s, then Fig.13 can be obtained. Experimental result for various values of the intake pipe length L_s, the engine speed N, the carburettor aperture C, the fuel jet hole diameter d_h etc. of an engine E-120 are also shown in Fig.13, the fuel flow rate G_f in each case is more decreased the more the carburettor approaches the engine side. Such a phenomenon cannot be understood on the basis of influence of the residual pulsating wave under tuning condition, the general relation of a steady flow etc.,

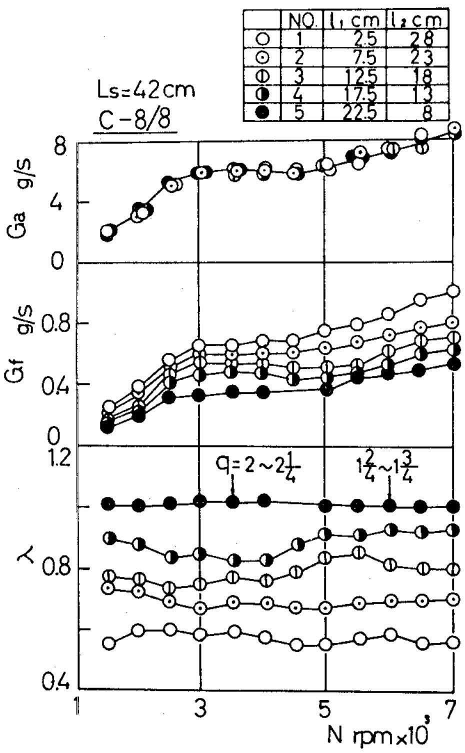


Fig.12 Excess air ratio λ and carburettor position (l_1/l_2)

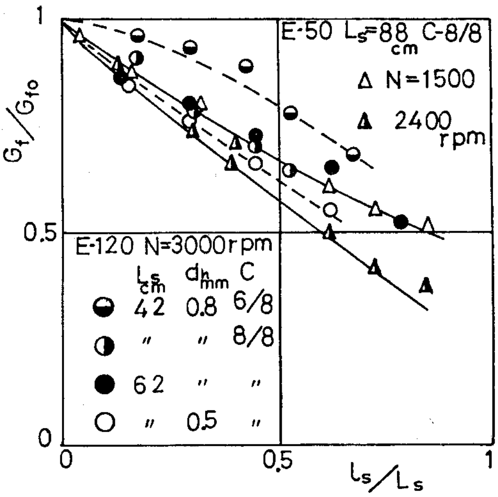


Fig.13 Ratio of fuel flow rate G_f/G_{f0} and carburettor position l_s/L_s

so that it is suggested that it is necessary to treat the flow in injection pipe as unsteady flow. In order to investigate the fuel flow rate characteristics in the case when pulsating pressure wave acts on the carburettor's fuel injection port, the values of instantaneous fuel flow rate G_{fi} have been numerically calculated and experimentally examined on a simple carburettor, which only a main fuel injection pipe works. If the influence of fuel in the carburettor's float chamber, the compressibility of fuel liquid column in the main fuel injection pipe etc. are now neglected, then the equation of motion for the fuel liquid column in the pipe is given by the following :

$$(l_f/g)\ddot{X}+(\phi_m/2g)\ |\dot{X}|\ \dot{X}+X=\Delta p_v/\gamma_f \qquad \cdots(2)$$

where

l_f : length of the main fuel injection pipe [m]

g : gravitational constant [m/sec²]

X : displacement of the fuel liquid column [m]

Δp_v : pressure difference acting on the fuel outflow port and the fuel surface in the float chamber [Kg/m²]

γ_f : specific weight of fuel [Kg/m³]

ϕ_m : flow resistance coefficient for the whole fuel injection pipe

As for the last-mentioned drag coefficient, its value determined in steady-flow experiment is to be used. While the pressure wave within the intake pipe of an actual engine is that of damped oscillation repeated every revolution, for the simplicity of problem it is here assumed that the following pressure wave of undamped oscillation :

$$\Delta p_v=\Delta p \cdot \sin \omega t+\Delta p_m \qquad \cdots(3)$$

acts continuously on the fuel outflow port and based on Eq.(2) the instantaneous value $G_{fi}=\gamma_f \cdot A_f \cdot X$, where A_f is the cross-sectional area of the main fuel injection pipe[m²], of fuel flow rate are numerically calculated by the Lunge-Kutter-Gill's method with an electronic computer FACOM-231 in the Calculation Center, Muroran Instetute of Technology to determine the average fuel flow rate G_m [g/sec] per cycle.

On the other hand, Fig.14 shows a relationship between G_m/G_{ms} and the amplitude of pulsating wave Δp and the steady negative pressure Δp_m on the basis of the value of fuel flow rate G_{ms}, calculated from the relation on steady flow, in the case, where only the steady negative pressure Δp_m acts ($\Delta p=0$).

In the same figure, G_m/G_{ms} is more decreased the large Δp is and the smaller Δp_m is, it being approximately equal to 0.42, for instance, when $\Delta p/\gamma_f=2$ m and $\Delta p_m/\gamma_f=0.6$ m. This is caused by such facts that the drag coefficient ϕ_m is a function of the Reynolds' number Re and that the fuel flow rate depends on the inertia of fuel liquid column in the injection pipe, a counterflow phenomenon due to the pulsating positive pressure wave etc., the calculated value coinciding well with the measured one (shown with ● mark in Fig.14(A), $\Delta p_m/\gamma_f \fallingdotseq 0.6$ m) in carburettor experiment. According to the numerical calculation, the fuel flow rate G_m is increased with increase in angular velocity ω[rad/sec]of the pulsating pressure wave and approaches its value G_{ms} in the case, where an average negative pressure acts, so that the influence of Δp tend to be decreased. As for an actual engine, the angular velocity ω of pulsating wave in its intake pipe is given by $\omega=2\pi a/4 \cdot (L_s+\Delta l)$ if the intake pipe system being considered to be a pipe with one end open and another closed, so that the intake pipe length L_s mainly determines ω. The results of basic analysis on carburettor will be applied to an actual engine and it is possible to conclude that the longer the intake pipe length L_s is, the larger the amplitude Δp of pulsating wave is and the smaller the angular velocity ω and that the higher the engine speed N is, the larger the carburettor aperture is and the more the carburettor approaches the engine side, the larger Δp is. Since the longer the intake pipe length L_s is and the higher the engine speed N is, the more the steady negative pressure Δp_m is increased, on the other hand, they have opposite effects to each other.

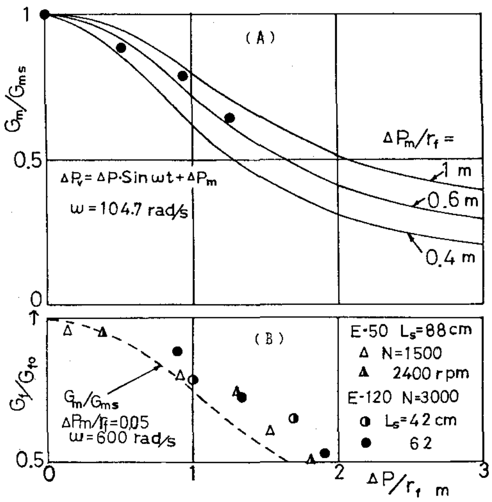


Fig.14 Ratio of fuel flow rate G_m/G_{ms}, G_f/G_{f0} and pulsating pressure wave

As can be also observed in the experimental results, Fig.13, this results in a conclusion that the fuel flow rate ratio G_f/G_{fo} mainly depends on the carburettor aperture and its position. Further, Fig.14(B) shows G_f/G_{fo}, instead of G_m/G_{ms}, determined from the results of engine experiment (Figs.8 and 13) and it is plotted with the maximum amplitude Δp (see Fig.7), instead of the pressure amplitude Δp, of pressure wave obtained from oscillogram in order to make clear the influences of Δp and Δp_m. Fig.14(B) also comprizes, with dotted line, the calculated values of G_m/G_{ms}, determined from Eqs.(2) and (3) with negative pressure $\Delta p_m/\gamma_f \fallingdotseq 0.05$ m and the angular velocity of pulsating wave $\omega=2\pi a/4(L_s+\Delta l) \fallingdotseq 600$ rad/sec, which are approximately average within the experimental range (N=1500 to 4200 rpm) of the tested engine E-50 (L_s=88 cm).

Although the pressure wave in intake pipe is a damped pulsating one, which is repeated every revolution, the experimental values coinside considerably well with the calculated.

Consequently, the decrease of fuel flow rate G_f and $G_f/\sqrt{\Delta H}$ when the carburettor approaches the engine side is principally caused by the unsteady characteristics of the carburettor due to the increased amplitude of pulsating wave acting on the fuel injection port and this is also affected by the residual pulsating wave under superposed condition as described in the preceding section, so that it has such a remarkable influence as brings about imposible combustion at a particular engine speed.

3.2 When carburettor aperture is small

3.2.1 Engine speed and fuel flow rate

In the case of a large carburettor aperture (for example, full opening C-8/8) as described in the preceding section, the value of $G_f/\sqrt{\Delta H}$ approximately the same irrespective of engine speed, if the undulation of $G_f/\sqrt{\Delta H}$ curve (see Fig.9) caused by the residual pulsating wave under superposed condition are neglected. This is also observed from the curve of excess air ratio λ (points marked with ● and ○) in the experimental results (see Fig.15) on engine E-120. When the carburettor aperture is smaller, C-2/8 to C-3/8, as during low-load or engine-brake operation, on the contrary, the higher the engine speed N is, the more both the breathing air amount G_a and fuel flow rate G_f are increased but since the latter's increase is more remarkable, the excess air ratio λ is, as shown with the points ○, ◑ and ▲, Fig.15, gradually decreased. Fig.16 also comprizes oscillograms a, b, c, ⋯ of pressure wave at the carburettor throat under the conditions (l_1, l_2, C, N etc.) corresponding to arrows a, b, c, ⋯, respectively, on the λ curve. When the carburettor apeature is small, the pressure wave in the intake pipe is damped and the wave acting on the fuel injection port is approximately so-called half-wave rectification type negative one such as shown in oscillogram a, which is produced every revolution during the inlet period. In order to make clear the fun-

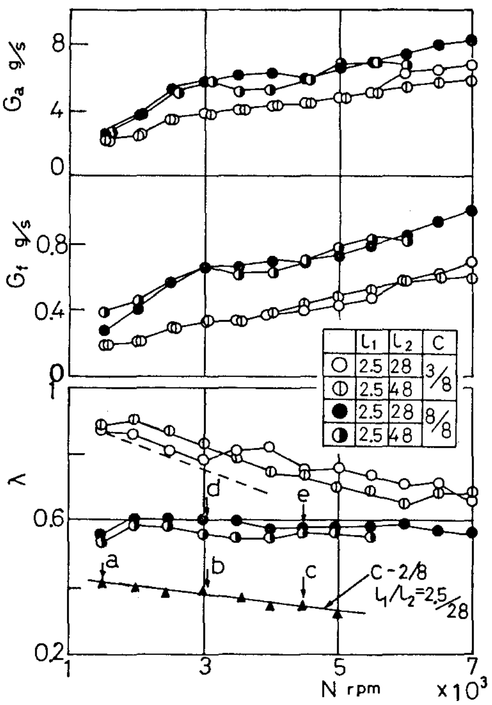


Fig.15 Excess air ratio λ and engine speed N (Engine E-120)

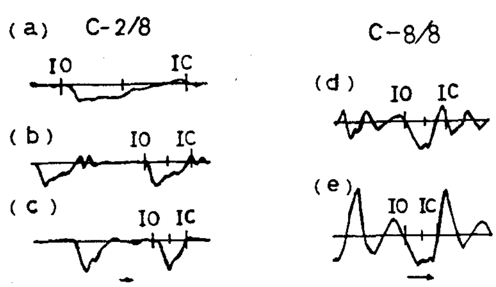


Fig.16 Pulsating pressure in carburettor throat

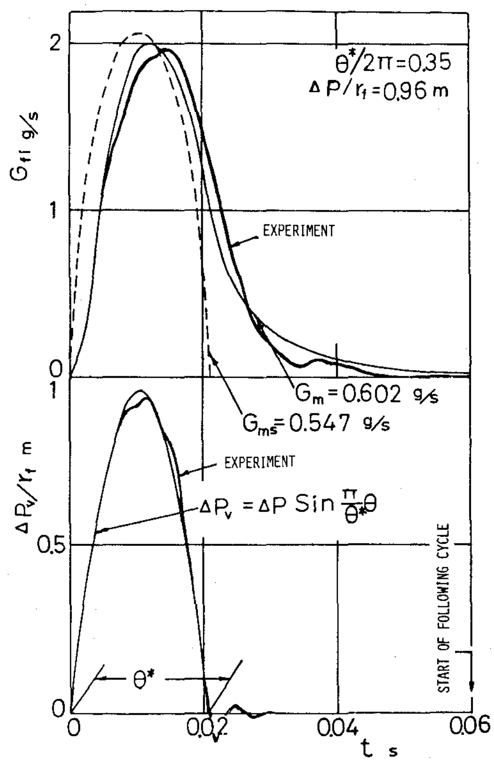


Fig.17 Instantaneous fuel flow rate G_{fi} and pressure wave ΔP_v

damental characteristics of fuel flow rate when such a pressure wave acts on the fuel injection port of a carburettor, let us assume that a pressure wave given by the following expression :

$$\Delta p_v = \Delta p \cdot \sin \frac{\pi}{\theta^*} \cdot \theta \qquad \cdots(4)$$

as shown in Fig.15, acts on the effective inlet period θ^* rad., where θ is crank angle rad.. Fig.17 shows the instantaneous fuel flow rate G_{fi}, with solid line, calculated from Eqs.(2) and (4) and those determined from a relation of steady flow with dotted line, the average fuel flow rate G_m and G_{ms} being also indicated. Although the author could not succeed in produce experimentally such a pressure wave as satisfies Eq. (4), the measured values of instantaneous fuel flow rate when the approximate pressure wave acts are also drawn with thick solid line. In Fig.17, the response of the instantaneous fuel flow rate G_{fi} toward the negative pressure wave are bad because of the inertia of fuel liquid column within the injection pipe and in particular for decelerating flow.

For this reason, the average fuel flow rate G_m is higher than that G_{ms} determined from the relation of steady flow.

Since the increase in engine speed N shortens in addition the required time of one revolution, fuel outflow does not perfectly interrupted before the intake process of the following cycle begines. Consequently, it can be concluded that the average flow rate G_m is increased in proportion to the engine speed N. This fact can be also confirmed its good qualitative coincidence with the measured values in carburettor experiment. In the next place, the average fuel flow rate G_m is calculated while the engine speed N rpm in $\theta=(2\pi N/60)\cdot t$, Eq.(4), being changed to determine G_m/G_{mo} on the basis of a value G_{mo} at $N=1600$ rpm. In order to compare with the result of engine experiment shown in Fig.15, further, the excess air ratio λ at a given engine speed is determined from $\lambda=\lambda_0\,(G_{m0}/G_m)$, where λ_0 is the value of excess air ratio under the conditions of $N=1600$ rpm, carburettor position $l_1/l_2=2.5/28$ and its aperture C-3/8, and the thus obtained values of λ are shown with dotted line in Fig.15. They coincide well qualitatively with the experimental values and it can be seen that the fundamental characteristics of carburettor affect the fuel flow rate. Since the pressure wave of the test engine is not of such a perfect half-wave rectification type negative one as that shown in Oscillogram a and its amplitude is increased to some degree as can be seen in Oscillograms b and c when the engine speed becomes higher, it seems necessary to take into consideration these influences in detail.

3.2.2 Length of fuel injection pipe a8d fuel flow rate

In an actual engine, the float chamber is sometimes separated from the carburettor's frame and connected to the latter with pipe to prevent choppy oil surface in the chamber due to mechanical vibration. If it is possible to consider such a connecting pipe to be rigid, then it corresponds to the lengthening of pipe length l_f in the Eq.(2). The larger the fuel injection pipe length l_f is, the more the response of instantaneous fuel flow rate G_{fi} when a half-wave rectification type negative-pressure given by Eq.(4) acts on the fuel injection port is deteriorated, its value in an accelerating flow region is decreased and its value in a decelerating flow region increased. For this reason, the average fuel flow rate G_m is increased. If $G_m/$

G_{m0} is calculated from Eqs.(2) and (4) on the basis of its value G_{m0} for the fuel injection pipe length $l_f=0.03$ m, G_m/G_{m0} is increased, as shown in Fig.16, in proportion to l_f and thus $G_m/G_{m0}=1.43$ at $l_f=1$ m. Experimental values G_f/G_{f0} obtained in engine experiment are also indicated in Fig.18. The calculated and experimental results cannot be quantitatively compared with each other because in engine experiment the pressure wave in intake pipe is not of perfect half-wave rectification type and the carburettor frame and the float chamber are partially connected with vinyl hose, but the experimental values are increased in proportion to the pipe length l_f with $G_f/G_{f0} \fallingdotseq 1.22$, for example, at $l_f=1$ m to coincide qualitatively with the calculated values. In this way, the fundamental characteristics of carburettor's fuel flow rate are also reflected in that of engine experiment.

3.2.3 Position of carburettor and fuel flow rate

While in the case of large carburettor aperture, for example, C-8/8 or C-6/8, the more the carburettor approaches the engine side, the more the fuel flow rate G_f is decreased as shown in Fig.13, in the case of small carburettor aperture, for example, C-2/8 or C-3/8, as that during low-load or engine-brake operation the fuel flow rate G_f is not always decreased.

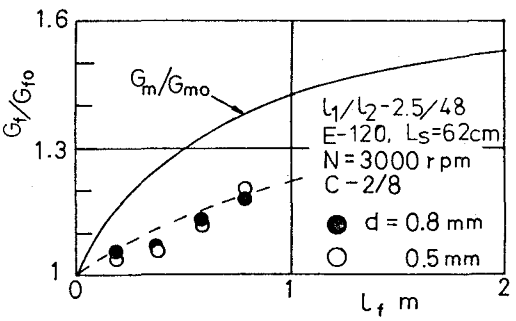


Fig.18 Ratio of fuel flow rate G_f/G_{f0} and fuel pipe length l_f (Engine E-120, Inlet pipe length L_s=62 cm)

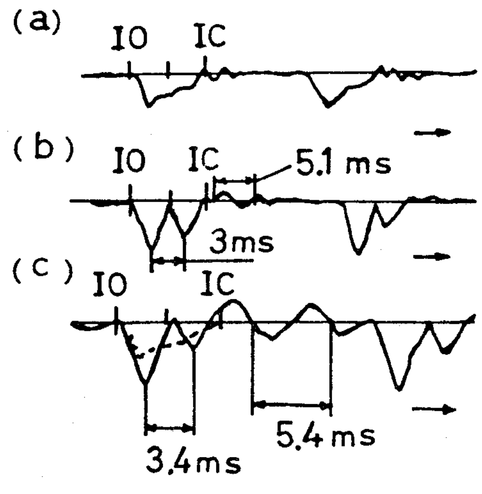


Fig.20 Fluctuating pressure in carburettor throat

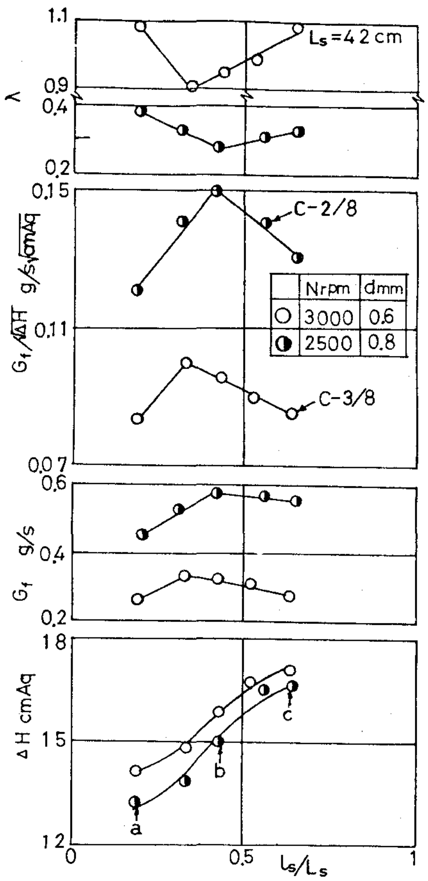


Fig.19 Excss air ratio λ and carburettor position l_s/L_s (Engine E-120)

As is shown in Fig.19 (engine E-120, L_s=42 cm), it becomes maximum near the center of intake pipe (l_s/L_s=0.3 to 0.4) and tends on the contrary to be decreased as the carburettor approaches the open end of pipe. This position of maximum G_f approaches more the open end side the larger the carburettor aperture is and coincides with the open end itself at more than C-5/8 of aperture. In the case of small carburettor aperture there is thus no relation among the fuel flow rate G_f, the carburettor position l_s and the average mean pressure ΔH and it appears that this is based on remarkable variation, according as the carburettor position, of pressure wave acting on the fuel injection port. As is shown in Fig.20, Oscillograms a, b and c of pressure wave under the conditions (l_s/L_s, N, C, etc.) corresponding to the arrows a, b and c on the ΔH curve, a pressure wave, similar to such a half-wave rectification type negative one as shown in Fig.a, acts during inlet period in the case of the carburettor lying at the open end of intake pipe (l_s/L_s=0.19) but two large negative pressure wave are produced during inlet period at $l_s/L_s \doteqdot 0.43$ (Fig.b) realized when the carburettor approaches the engine side.

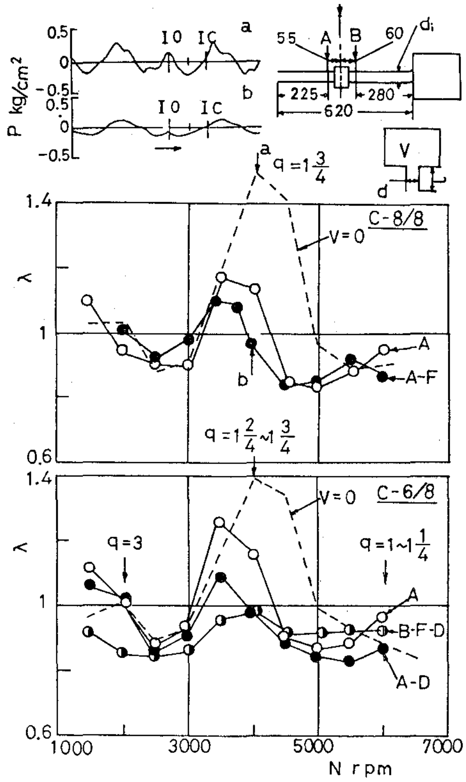
If it approaches further the engine side, a large residual pulsating wave can be observed, as shown in Fig.c ($l_s/L_s \doteqdot 0.65$), even after inlet closure (I.C.). Such a wave appears because the damping effect of throttle on the pressure wave is more decreased the more the carburettor is situated near the node of vibration system in the air column and the experimental values 5.1 to 5.4 ms of period of the residual pulsating wave are approximately equal to a value $T=4 \cdot (L_s+\Delta l)/a \doteqdot 5.3$ ms, obtained on the assumptions of pressure propagation velocity a=330 m/sec and pipe end correction Δl=2 cm (equal to the inner diameter of intake pipe d_i). As can be seen from the pressure wave of Fig.c, where that of Fig.a is also reproduced with dotted line, it appears that the pressure wave during inlet period is a resultant of two components, that is, one (dotted line) produced by the negative pressure in crankcase and the innertia of breathing air another of a comparatively short period. Its period is considerably close to a value $T=4 \cdot (L_s+\Delta l)/a \doteqdot 3.6$ ms, calculated with the distance l_s from the open end of intake pipe. This may be caused by superposition of a pressure vibration, which has a closed end at the throat of carburettor. In Fig.b, however, the experimental value 3 ms is not so close to the calculated one 2.5 ms as in Fig.c. Although the pressure wave in intake pipe is thus not simple, it appears that such a result as shown in Fig.18 is brought about because increase in negative pressure wave during intake process increases the fuel flow rate G_f and the residual pulsating wave prevents fuel outflow.

Since pressure in the intake pipe changes complicatedly according as the conditions concerned and affects also the fuel flow rate, so that it is impossible to forecast the rate under each operation unless the pressure's particulars are well understood.

3.3 Resonator and fuel flow rate

it is said that when the intake pipe of an engine is longer and the carburettor is nearer the engine side, addition of Helmholtz resonator to the inake pipe can contribute to the damping of pulsating wave and be thus effective to the improvement of excess air ratio. In this research on a two-cycle engine, for example, Alfred Jante[7] has proposed a resonance speed $N_r=60 \cdot \nu$ based on tuning of the natural frequency ν of air column in a Helmholtz resonator with the inlet number N/60 into the engine and described that a resonator of natural frequency ν can improve the excess air ratio curve within a range of engine speed, higher than N_r.

If a Helmholtz resonator is used to make flat the excess air ratio curve in a range of higher-speed than the minimum engine speed assumed to be N=1500 rpm, let us take the resonator's dimension d=2 cm and l=5 cm and pressure propagation velocity a=330/sec, then from $N_r=60 \cdot \nu$ and $\nu=(a \cdot d/4\pi) \cdot \sqrt{\pi/V(l+\pi d/4)}$ the volume can be approximately calculated to be $V=2.07\times10^4$ cc. Although the author used two resonator, $V=2.1\times10^4$ and 1.3×10^3 cc. and confirmed its effect, such a resonator with large volume violently vibrates so that its practical application is difficult. For this reason, the author prepared another resonator 52.9 $\phi\times54$ mm of a volume, equal to that of engine's stroke volume $V_h=118.9$ cc. and investigated the effects of the resonator mounted on an engine and of an elastic (rubber) diaphragm covering the resonator's closed end. The experimental results are shown in Figs.21 and 22, where in the case of the engine E-120, $L_s=62$ cm, $l_1/l_2=22.5/28$ cm, the pulsating pressure wave becomes larger and the



Symbol	Condition of resonator		
	Fixed position	Elastic membrane	Entrance pipe diameter
A	A (see Fig.)	without	d = d (Inlet pipe dia.)
A-F	A (")	fixed	d = d
A-D	A (")	without	d = (1/2)d
A-F-D	B (")	fixed	d = (1/2)d
V = 0	without resonator		d = 0

Oscillograms a, b and the pressure wave under the conditions corresponding to the arrows a, b on the λ curve

Fig.21 Excess air ratio curve and Helmholtz resonator

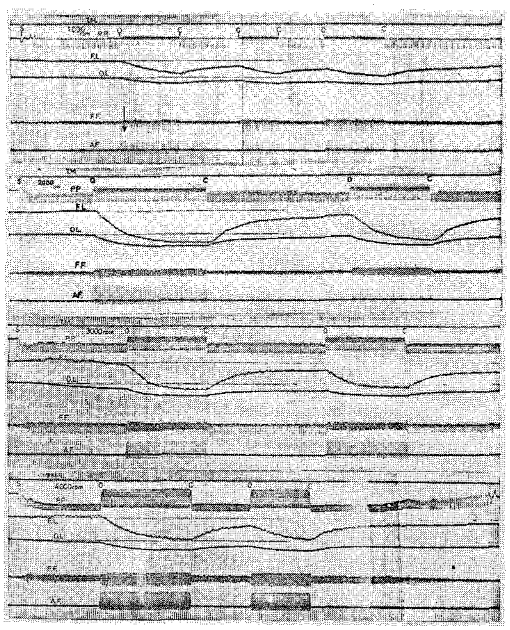


Fig.22 Behavior of various factors in transient operation

A. F. : air flow rate, F. F. : fuel flow rate

O. L. : fuel level in float chamber, F. L. : float

P. P. : Inlet port pressure, T. M. : top dead center mixture does weaker ($\lambda \fallingdotseq 1.5$), as is shown in Oscillogram 1, near N=4000 rpm (q≒1 · 3/4) but if the resonator is mounted at A, immediately before the carburettor, the pulsating pressure wave is, as shown in Oscillogram 2, remarkably damped and the influence of residual pulsating wave on the fuel flow rate is also reduced so that it is possible to prevent, to some degree, the mixture's weaking ($\lambda \fallingdotseq 1.2$). The value of engine speed, corresponding to a peak of the excess air ratio is shifted near N=3500 rpm, because the equivalent length of the whole intake pipe system is lengthened and the period of pressure wave increased(7).

Suitable throttling of the inlet of resonator (marked with symbol D) and attaching of elastic diaphragm (marked with symbol F) can reduce further variation of the excess air ratio curve to attain approximately the required object. On the contrary, attention should be paid to a fact that in an engine utilizing a breathing-air inertia effect to increase the maximum delivery ratio, resonator also reduces the inertia effect(8).

3.4 Transitional operation and fuel flow rate

when the engine speed is kept constant and the throttle valve of a carburettor is rapidly opened or is rapirly closed, the instantaneous air flow rate, the instantaneous fuel flow rate, the variation of fuel level in the float chamber, the movement of float and the pressure wave before inlet port are simultaneously measured. A typical oscillogram of them is shown in Fig.23. In this figure, when the pressure wave before inlet port has changed as a result of opening of the throttle valve, the breathing air and the fuel begin to flow in after a while, and then the fuel level in the float chamber and the float do to be lowered. At this time, the float follows the fuel level with a retard of about 0.3 sec. and about 3 sec. is necessary to reach a stationary condition.

Since this period is, consequently, accompanied the lowering of the fuel level, the outflow of fuel must be affected. If the fuel flow rate is calculated from Eq.(2) while the influences of fuel level and the characteristics of the drag coefficient in the carburettor throat and the fuel injection pipe being taken into consideration, the fuel flow rate (G_f g/s) reaches, as can

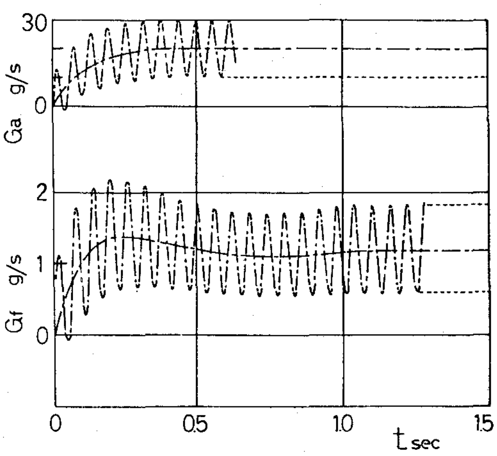


Fig.23 Fuel flow rate during carburettor opening

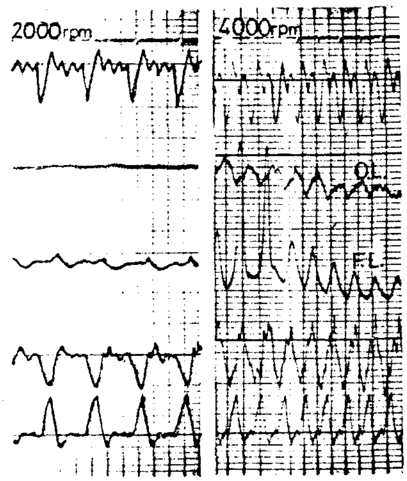


Fig.24 Characteristics of carburettor (F. L., O.L.)

be seen from Fig.24, a maximum value at about 0.25 sec. from the beginning of fuel outflow and a minimum value at about 0.8 sec.. This value (0.8 sec) coincides well with the time (0.8 to 1.0) marked with an arrow mark in Fig.23, so that this correspond to a characteristic of a tested carburettor. And then the variation of fuel flow rate, which occurs after the arrow mark, coincides with the natural frequency period of a liquid column in the fuel injection pipe of the carburettor. If the float chamber is directly connected to the carburettor frame, the mechanical vibration from the engine body becomes more violent with the increase of engine speed. For this reason, the fuel level in the float chamber ascends and fluctuates violently as shown in Fig.25. Consequently, the cycle-by-cycle variations of the fuel flow

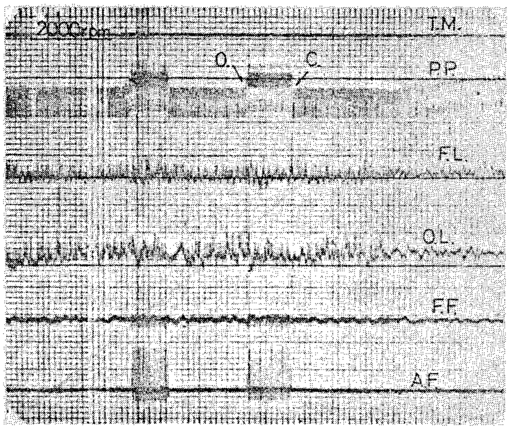


Fig.25 Behavior of float (F.L.) and fuel level (O. L.)
O : carburettor open
C : carburettor close

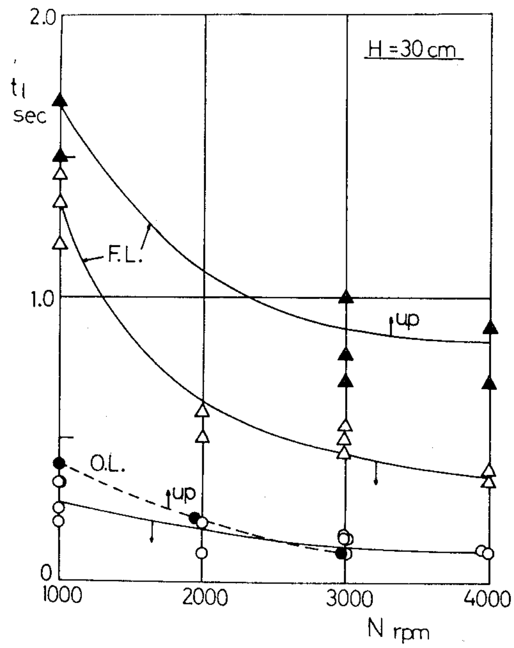


Fig.27 Response retard of float (F. L.) and fuel level (O. L.)

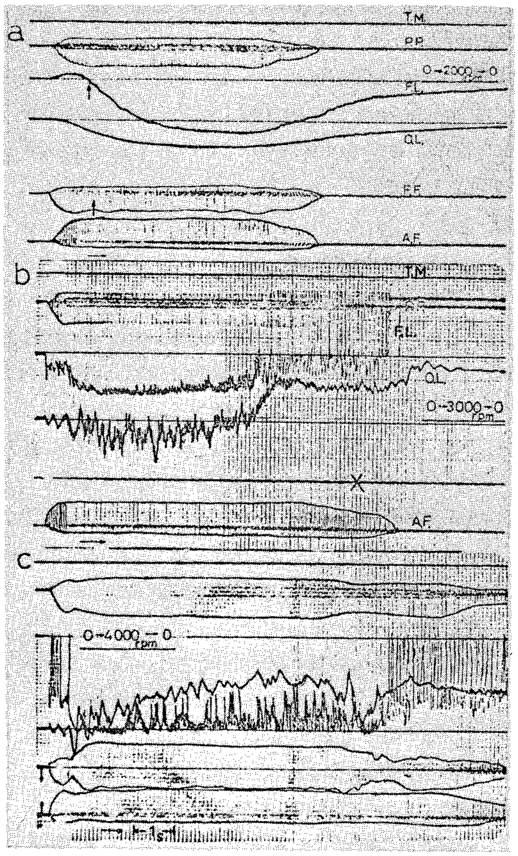


Fig.26 Behavior of fuel flow (F. F.), float (F. L.) and fuel level (O. L.) during accelerating operation

rate and the irregular fluctuation at an interval of about 0.1 to 0.2 sec. become remarkable. Even if the throttle valve of carburettor is opened and is closed in such a condition, the fuel level and the float do not almost change as shown in Fig.26. By making the electric power supply on, the rapid accelerating driving is carried out while the opening of carburettor being kept constant and the dynamometer for driving the engine being set at a position of constant rotation. Moreover, some time after that, the rapid decelerating driving is carried out by making the electric power supply off. An example of the experiment is shown in Fig.27. In the case of Fig.27 (a), the response retard of fuel level and float are remarkable and then the float is later than the fuel level, the difference between them being about 0.8 to 1.0 sec. as shown in Fig.27. Owing to these influences, the fuel flow rate is temporarily decreased at the period of accelerating operation as shown with an arrow mark in Fig.27. The same phenomenon can be observed also at the period of decelerating operation. If, on the contrary, the rapid acceleration is carried out under a condition of the float chamber directly connected to the carburettor frame, the float descends rapidly and vibrates violently while the fuel level beginning to swell and eventually ascending as shown in Figs.(b) and (c). In this case, the back flow of fuel becames remarkable. If the decelerating driving is then carried out, the float vibrates violently and the fuel level is rapidly increased so that the abnormal outflow of fuel can be observed. Such an abnormal state depends on the fixing state of the carburettor and the dimension of the intake pipe system, and that is unstable phenomenon. Since there remain many unknown matters, the authors with to continue systematically the experiment in the future.

4. Conclusion

The author experimentally investigated the influences of carburettor position, apeature, fuel injection pipe length, intake pipe length and engine speed on the fuel flow rate of a small sized two-cycle engine and carried out numerical calculation on a simplified model of carburettor. The results obtained can be summarized as follows :

(1) A larger amplitude of pulsating wave affects the next intake process and if the pulsation coefficient is $q=15 \cdot a/N(L_s+\Delta l)=n+1/4$ a negative pulsating wave is superposed on inlet port open-period (I.O.) so that the fuel flow rate is increased, while if $q=n+3/4$ a positive wave superposed on I.O. so that the flow rate is decreased. This fluctuation of fuel flow rate due to the tuned pulsating wave is not so remarkable as bring about any impossible combustion.

(2) When a carburettor is mounted to a fixed length of intake pipe, the amplitude of pulsating wave acting the carburettor's throat becames larger the more the carburettor approaches the engine side and in proportion to it the fuel flow rate is decreased. This coincides with the result of numerical calculation on the unsteady characteristics of fuel flow rate in a model carburettor.

(3) when carburettor aperture is small and pressure wave acting the carburettor throat is a so-called half-wave rectification type negative one, which is repeated every revolution, the response of instantaneous fuel flow rate with regard to the negative pressure wave is more

deteriorated due to the inertia of fuel liquid column the higher engine speed is and the longer the fuel injection pipe is.

for this reason, the average fuel flow rate per revolution is increased and the excess air ratio is decreased.

(4) In the case of a small carburettor aperture, pressure wave acting the carburettor throat remarkably changes if the carburettor is made to approach the engine side so that the fuel flow rate is not so always gradually decreased as in the case of a large carburettor aperture and it attains the maximum on the way.

(5) If fuel flow rate or excess air ratio remarkably fluctuates with engine speed, it is possible to reduce considerably such a fluctuation of the ratio with a small Helmholtz resonator, which has a suitably throttled inlet and a body made of elastic membrane.

(6) When the throttle valve of a carburettor is rapidly closed, the fuel flow rate is remarkably decreased and is violently fluctuated before reaches a given value in the stationary operation. This fluctuation period is approximately equal to the natural vibration period of liquid column composed of the fuel injection pipe and the float chamber.

(7) Such a variation of fuel flow rate can be observed in the case of accelerating operation.

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