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Low Speed Hunting of the Pneumatically Governed Compression-ignition Engine*

(4th Report, Effect of Simulated Venturi Diameter on Phase Lag of the Fuel Control Rack Response)

by Yoshihiko KAWAZOE**

The effect of venturi diameter on phase lag of the fuel control rack response has been investigated using 5 kinds of simulated venturis, which are different in size but similar in shape of flow passage to the actual subventuri, installed in an apparatus simulating the intake air flow at hunting or in a hunting engine intake system. The results show that the phase difference between subventuri pressure and suction pressure depends on the difference of size. Thus, the low speed hunting is proved to be a self-excited oscillation ascribed to the phase lag of the reduced pressure at subventuri. Furthermore, this study provides a preventive measure against hunting.

Key Words: Vibration, Hunting, Low Speed Hunting, Pneumatic Governor, Compression-Ignition Engine, Subventuri, Phase Lag, Suction Pressure, Stability, Fuel Injection Pump

1. Introduction

As shown in Fig.1, a pneumatic governor controls the fuel delivery by displacing the fuel control rack with the reduced pressure taken at a narrow passage called subventuri beside a throttle valve. The engine speed depends on the throttle valve opening. However, in a pneumatically governed compression-ignition engine its idling speed cannot remain constant in some speed range, followed by a low frequency noise of its own. This fluctuation of the engine speed is called low speed hunting[(1)~(3)]. The subventuri pressure fluctuation as well as the displacement of the fuel control rack comprises a component of the hunting frequency and a component of a higher frequency caused by the suction process of each piston[(1)].

The purpose of this study is to reveal the mechanism of the low speed hunting peculiar to the pneumatically governed four-stroke engine with 4 cylinders, and to devise its preventive measure. It was described in the 1st report[(1)] that the key factor must be the phase lag of the governing pressure taken at a narrow passage called subventuri beside a throttle valve, because the hunting disappears when the phase lag is minimized by relocating the pressure source to the common intake duct just down the throttle valve and the subventuri (Fig.2). In the second report[(4)] it was shown as the result of frequency response examination that there exists a hunting as a limit cycle of a nonlinear system, whenever the phase lag of the governing pressure is considerable. Having derived the equation of motion of the pneumatic governor system[(5)], a numerical simulation is given on the basis of equations of elements of the engine-governor system in the 3rd report[(6)]. As a result of simulation, a self-sustained oscillation develops in the case of speed control with subventuri pressure which has a retarded hunting frequency component compared with the speed fluctuation, while the hunting disappears under suction pressure control without phase lag, as predicted in the author's previous work.

It is necessary to investigate whether the phase difference between the subventuri pressure and the suction pressure is itself inevitable or incidental. The subventuri is a narrow passage 20 mm long and 10 mm in inner diameter, into which a pressure tap projects by 2 mm, while the intake duct is 48 mm in diameter; the greatest difference between the above two is in diameter size. In the present report, the effect of the venturi diameter on phase lag of the fuel control rack response is investigated using 5 kinds of simulated subventuris of different size, installed in an apparatus simulating the intake air flow at hunting or in a hunting engine intake system, where the pressure tap is connected with the diaphragm chamber of the dummy pump through a vinyl hose. Furthermore, a preventive measure against the low speed hunting is devised.

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** Associate Professor, Department of Mechanical Engineering, Saitama Institute of Technology, Okabe, Saitama.

2. Experiments Using an Apparatus Simulating Intake Air Flow at Hunting

In Fig.3 and Fig.4 are shown an appearance and a schematic illustration of the apparatus simulating the intake air flow at hunting respectively. This apparatus is designed such as to give an air flow comprising a mean flow, a reciprocating flow of a lower frequency and another reciprocating flow of a higher frequency. The higher frequency reciprocating flow in place of suction process of each piston is generated by a modified single-cylinder engine with a stroke volume 181 cm^3 driven by a direct current motor through V belt (Fig.5). The lower frequency reciprocating flow in place of hunting flow fluctuation is generated by a modified single-cylinder engine with a stroke volume 376 cm^3 driven by a three-phase induction motor through a V belt and a reduction gear of infinitely variable ratio(Fig.6). Further, in order to give the mean flow is used an electric cleaner with a suction rate 1 m^3/min. The effect of the venturi diameter on the phase lag of the control rack response of the dummy fuel pump is investigated using simulated venturis (Fig.7,8,9), which are 7,10,14,17, 20 mm in diameter and similar in shape of flow passage to the actual subventuri. In Fig.4 the rotational speed N_E of the higher frequency flow generator is set at twice the engine speed 790 rpm where a large hunting occurs, while the mean pressure $\bar{P}_1$ at the entrance of the liaison pipe is adjusted to be equal to that of the actual system by means of ball valves V_3 and V_4 ; the phase lag of the governing pressure is measured at four simulated hunting frequencies 1.0, 1.5, 2.0 and 3.0 Hz on five kinds of simulated subventuris 7, 10, 14, 17 and 20 mm in diameter. A stationary indication of pressure $\bar{P}_1$ corresponds to a stationary mean displacement of the fuel pump rack. The phase lag is measured relative to the pressure fluctuation P_3 instead of the engine speed fluctuation, because there exists no phase difference between the both fluctuations[1]. The pressures, the control rack displacement etc. are recorded on a data recorder and the phase difference is

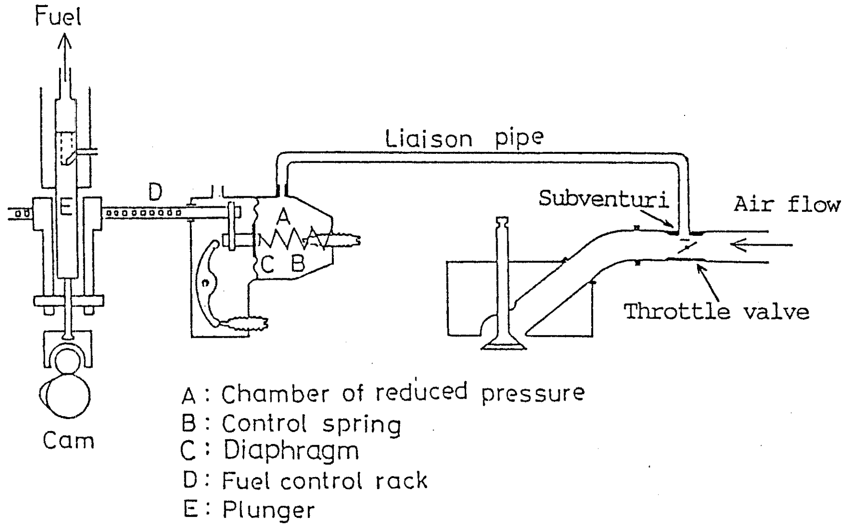

Fig.1 Fuel control mechanism of a pneumatcally governed engine.

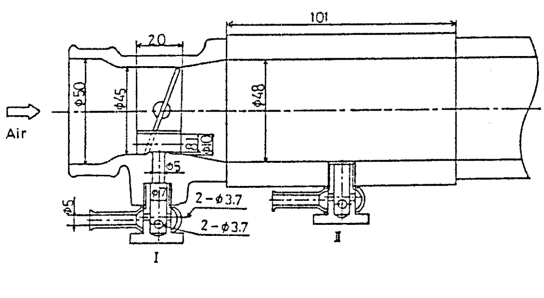

Fig.2 The structure of pressure control units.

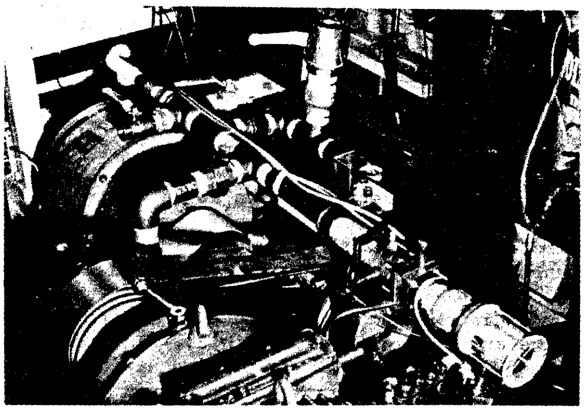

Fig.3 Apperance of the apparatus simulating intake air flow at hunting.

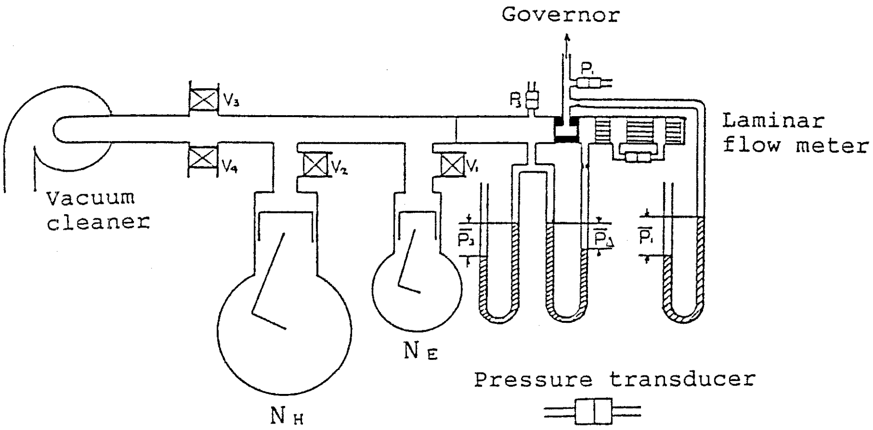

Fig.4 Schematic illustration of the apparatus
simulating intake air flow at hunting.

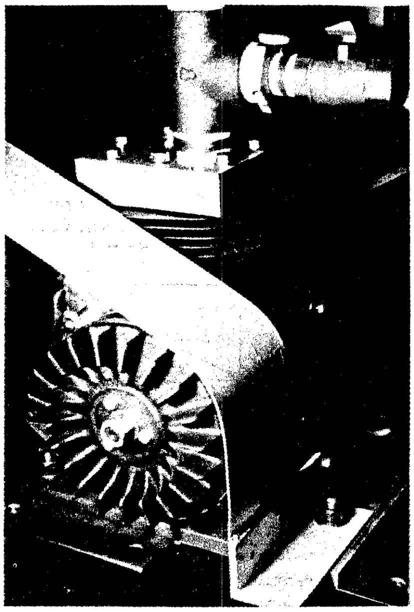

Fig.5 A generator of a higher-
frequency reciprocating
flow.

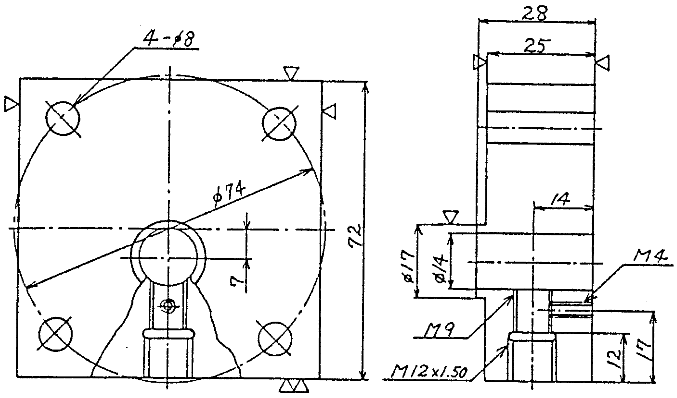

Fig.7 Simulated venturi(14 mm in diameter).

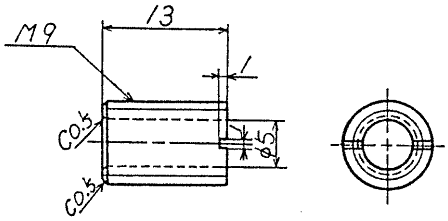

Fig.8 Pressure tap of simulated venturi.

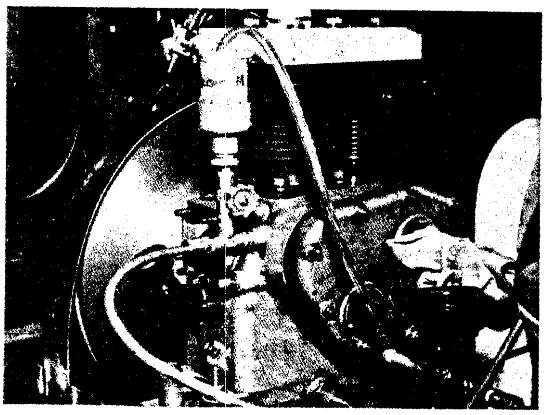

Fig.6 A generator of a lower-frequency
reciprocating flow.

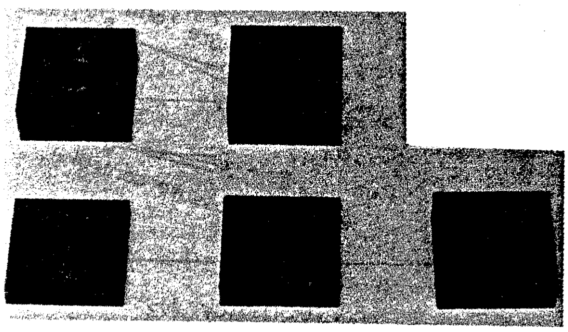

Fig.9 5 kinds of simulated venturis.

derived using a digital analyzer.

In Fig.10 is shown the phase lag of the rack displacement response in the case of $\bar{P}_1$=370 mm H_2O (3.63 kPa). It is seen that the phase lag decreases with an increasing simulated venturi diameter in the frequency range from 1 to 3 Hz. This supports the fact that the phase lag of the reduced pressure at the subventuri is large and that of the suction pressure is small. In case the simulated venturi 10 mm in diameter is used, the phase lag of the rack displacement at 2 Hz is 53 degrees, while the one at 2 Hz on the actual engine under subventuri pressure control is from 53 to 64 degrees (53 degrees at 800 rpm) as shown in Fig.11[(4)], which indicates that the above two are in good agreement. Further, in case the higher-frequency flow generator is switched off, the fuel control rack stops to move due to the static friction around the rack. This can explain the disappearance of hunting in a narrow range of speed at an engine experiment with a small 25 Hz dynamic damper added to the rack[(1)]: presumably owing to an increased damping of the rack resulting from a decreased higher frequency motion affected by the dynamic damper.

3. Investigation Installing Simulated Venturi in an Engine Intake System at Hunting

As shown in Fig.12, a simulated venturi is added parallel to a throttle valve-subventuri assembly on the tested engine, with the pressure tap of the simulated venturi being connected with the dummy pump; the phase lag of the control rack response of the dummy pump is measured at 750 rpm where a large hunting occurs under subventuri pressure control. The solid line in Fig.13 gives the measured phase lag against the size of simulated venturi, where the hunting frequencies from 1.2 to 1.4 Hz are shown beside the curve. The constant engine speed means that the mean values of the subventuri pressure and the displacement of the fuel control rack are constant. As

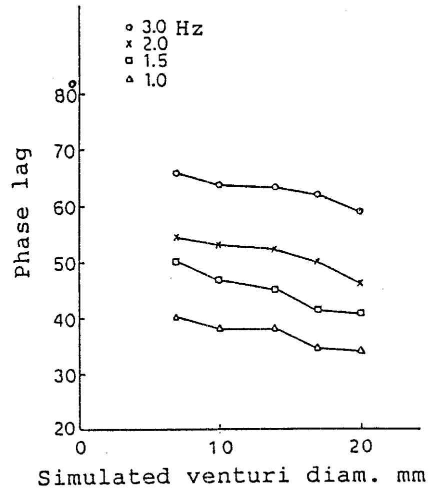

Fig.10 Phase lag of the fuel rack response versus simulated venturi diameter, on the apparatus simulating intake air flow.

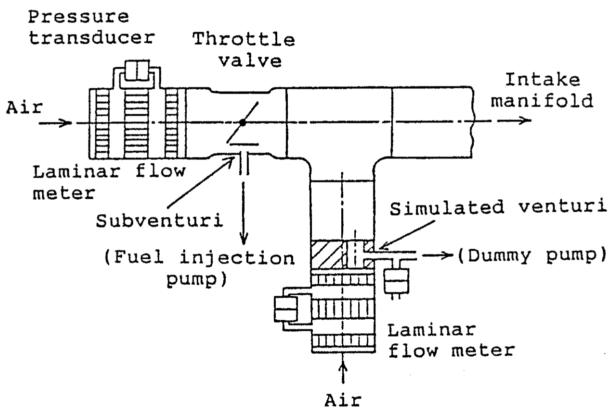

Fig.12 Simulated venturi added parallel to a throttle valve-subventuri assembly on the tested engine.

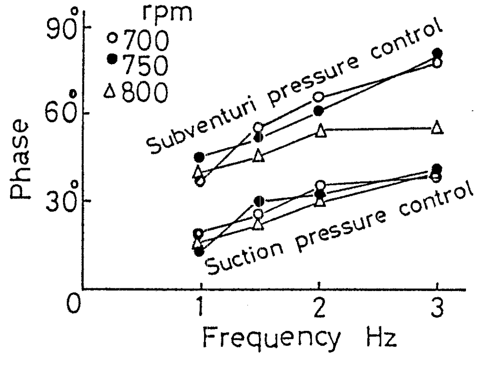

Fig.11 Phase lag of the fuel rack response versus engine speed fluctuation.

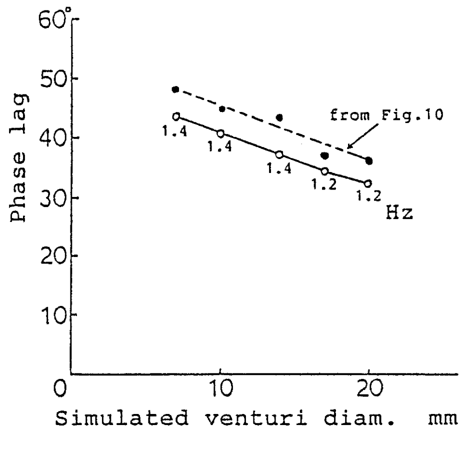

Fig.13 Phase lag of the fuel rack response versus simulated venturi diameter at hunting (750 rpm), on the system shown in Fig.12.

in Fig.10 the phase lag decreases with an increase of the diameter of the simulated venturi. The broken line in Fig.13 is derived from the experimental data in Fig.10 by interpolation to find the phase lag corresponding to the frequency value shown beside the solid line in Fig.13. The phase difference between the two lines in Fig.13 is as small as 5 degrees. In Fig.14 are plotted the phase lag measured on the intake duct 48 mm in diameter at frequency response test under suction pressure control, the one on a duct system 39 mm in equivalent diameter and also the results in Fig.13. On the engine system with a duct 39 mm in equivalent diameter occurs a low frequency hunting but in a narrower speed range (from 740 to 780 rpm) with smaller amplitudes of fluctuation than those on the normal hunting engine. In the case of 48 mm in diameter, however, the phase lag is very small and no hunting occurs: the phase lag of the governing pressure relative to the engine speed fluctuation is from 5 to 6 degrees[4].

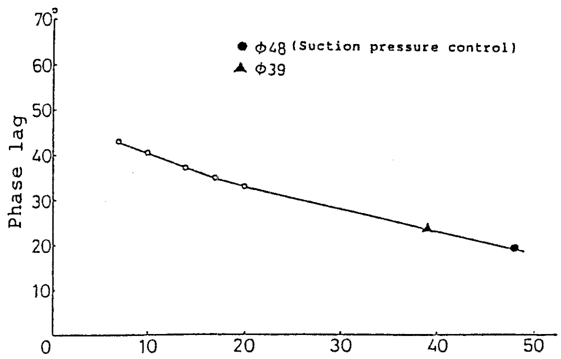

Fig.14 Phase lag of the fuel rack response versus simulated venturi diameter, proving continuity up to the intake duct 48 mm in diameter.

4. Radical Measure against Low Speed Hunting

As described in the previous reports[1][4][6], the low speed hunting occurs on a conventionally governed engine under subventuri pressure control owing to the phase lag of the pressure. However, the phase lag becomes smaller with an increase of venturi diameter, and hunting does not occur when the phase lag is minimized by relocating the pressure source to the common intake duct (48 mm in diameter) just down the throttle valve and the subventuri.

Thus, in order to prevent the hunting the subventuri parallel to the throttle valve should be detached and the governing pressure should be taken from the intake duct directly after the throttle valve, on which a circular hole 10 mm in diameter is given. This must be a radical measure attaching the true cause of the low speed hunting.

5. Conclusions

The main results are summarized as follows:

(1) The effect of venturi diameter on phase lag of the control rack response of the dummy fuel pump has been investigated using 5 kinds of simulated subventuris, which are different in size but similar in shape of flow passage to the actual subventuri, installed in an apparatus simulating the intake air flow at hunting. When the mean value of the governing pressure is kept equal to the actual system, the phase lag decreases with an increase of the diameter of simulated venturi.

(2) A simulated venturi was installed parallel to a throttle valve-subventuri assembly on the tested engine, with the pressure tap of the simulated venturi being connected to the dummy pump. The phase lags of the control rack response of the dummy pump were measured at 750 rpm, where a large hunting occurs under subventuri pressure control. The result was the same as mentioned above in (1).

(3) Thus, it is a feature of the subventuri attributed to the difference of diameter that the phase lag of the governing pressure taken at the subventuri 10 mm in diameter is large and that the one taken at the intake duct 48 mm in diameter is small. If the duct diameter is reduced to 39 mm, the phase lag somewhat increases and a low frequency hunting occurs in a narrower speed range with smaller amplitudes of fluctuation than those on the normal engine system under subventuri pressure control.

It can be concluded that the low speed hunting phenomenon peculiar to the pneumatically governed engine is a self-excited oscillation ascribed to the phase lag of the reduced pressure at the subventuri. Furthermore, it has been shown that hunting can be prevented when the governing pressure is taken at the intake duct instead of the subventuri.

The discovery of both the cause of the low speed hunting and its radical counter-measure would promote reappreciation of the pneumatically governed engine.

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