PS-19 Problem of Safe Control of a Lean Burn Gas Engine in Marine Application

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1. Introduction

Natural gas fuelled engine is a promising successor of Diesel engine, owing to lower emissions and fuel cost. However, the marine application imposes vast requirements on transient responses, such as ship maneuvering requires fast response to the load demand, at rough weather engines are exposed to large load fluctuation, etc. Moreover, engines can be coupled to a fixed pitch propeller (FPP) or controllable pitch propeller (CPP) specifying various modes of operation. In respect that the gas engine combustion process differs from that in Diesel engine, the load acceptance is subject to specific limitation due to a knock phenomenon. Thus, for the gas engine to be efficient and safe propulsion unit, it is necessary to consider the problems related to unsteady operation and develop countermeasures.

In this study the experimental data obtained from the lean burn gas engine of Yanmar AYG20L were used to develop a simulation model suitable for purpose of control algorithm development, also the engine model unit can be used as a part of global propulsion or power plant model. At present stage the model was validated against experimental data and various control algorithms were analyzed and checked towards robust and safe control of gas engine.

2. Experimental setup

Experimental setup includes the lean burn gas engine with pre-chamber spark-plug ignition system. The engine is coupled to a synchronous generator with resistors load. The engine main particulars are listed in Table 1.

For the purpose of data acquisition and performance analysis the engine was equipped with various sensors connected to a developed data acquisition system as shown in Fig.1. This engine is not equipped with the turbo-compressor rotational speed sensor that is important for performance assessment. In order to overcome this problem, the contactless speed sensor was developed based on the turbo-compressor acoustic emission analysis.

Table 1 Test engine specification

Engine	AYG20L-SE (Yanmar co., Ltd.)
Type	Lean Burn / S.I. / Prechamber
Bore×Stroke	155 mm×180 mm
Gen. Power×Speed	400 kWe / 1800 min-1
Cylinder	6

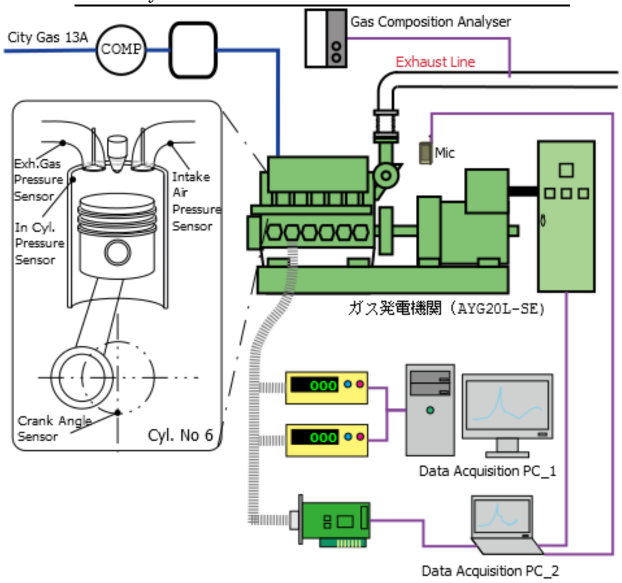


Fig.1 Engine data acquisition system

3. Engine model

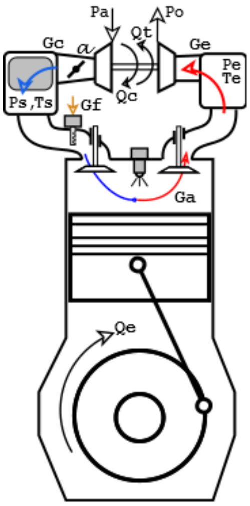
3.1 Concept and mathematical formulation

The engines are modeled with different complexities where mean value engine modeling (MVEM) is a commonly used alternative, especially in tasks of control algorithm development and powertrain simulation. In this study a nonlinear, four states and three inputs fully parametrized mean value model of engine has been developed. This model incorporates the important turbocharger dynamics as well as the nonlinear multiple input – multiple output nature of the gas engine.

The states of the model are engine speed (N_e), inlet manifold pressure (p_s), exhaust manifold pressure (p_e) and turbocharger speed (N_{tc}). The inputs are fuel gas injection duration (d_{inj}), throttle valve position (α) and generator torque (Q_g). The core governing equations of the MVEM and model concept are shown in Fig.2.

3.2 Model validation

The developed model consists of several submodels and also two control loops – engine speed control and



$$G_c = F_v(\alpha)\frac{p_c}{\sqrt{R_a T_c}}\psi\left(\frac{p_s}{p_c}\right)$$

$$p_c = f(N_{tc}^2)$$

$$G_a = \frac{z_c V_s p_s N_e \eta_c}{60 T_s R_a}$$

$$G_e = G_a + G_f = F_t\frac{p_e}{\sqrt{R_e T_e}}\psi\left(\frac{p_o}{p_e}\right)$$

$$G_f = Z_c G_{f_v} d_{inj} N_e$$

$$\frac{dp_s}{dt} = \frac{k_a R_a T_a}{V_{a.r.}}(G_c - G_a)$$

$$\frac{dp_e}{dt} = \frac{k_e R_e T_e}{V_{e.r.}}(G_a + G_f - G_e)$$

$$\frac{dN_e}{dt} = \frac{1}{I_{eng}}\left[Q_e(P_{mep}, N_e) - Q_g\right]$$

$$\frac{dN_{tc}}{dt} = \frac{1}{I_{tc}}\left[Q_t(G_e, p_e) - Q_c(G_c, p_c)\right]$$

Fig.2 Engine model

throttle valve control are included. Thus, the validity of the model and correct transient dynamic must be ensured. As can be seen in Fig. 3 the dynamic and static properties of the target engine are preserved during simulation of a generator load increase.

4. Problem of safe control

The gas engine operation is constrained by the phenomenon known as knock due to lack of air in combustion chamber and caused by turbocharger speed buildup delay. In order to improve the transient response it is proposed to use the turbocharger speed together with engine speed in generating control action. Fig.4 demonstrates the gas engine transient responses with different type controls: classic PID, proportional with stabilizing PI feedback (P+PI) and two input one output (MIMO) control.

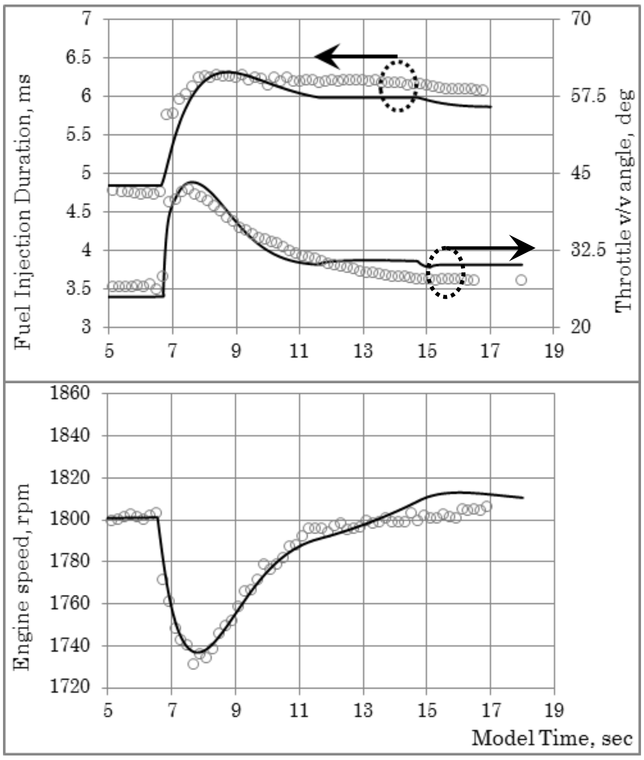


Fig.3 Transient response during step load input.

5. Conclusion

The developed model of the lean-burn gas engine is fully parametrized and is suitable for control algorithm development as well as can be used in the framework of various marine powertrains aimed at optimal control study. Finally, introduction of additional input signal favorably affects the transient response, notably the engine speed drop is reduced with no penalties in terms of air excess ratio (air excess ratio determines occurrence of knock).

References

(1) “Transient Response Behavior of Gas Engines”. Position paper by the CIMAC working group ‘Gas Engines’.

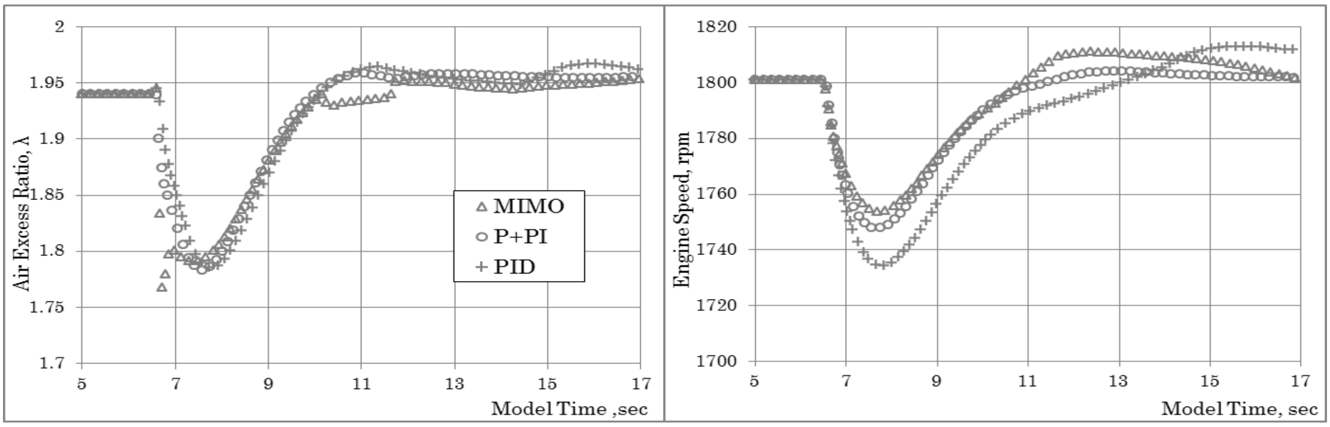


Fig.4 Effect of different control strategies on the gas engine transient dynamic