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Controlling Engine Data: Nonperiodic Fluctuations in a Spark Ignition Engine of Motorcycle and Its Stabilization

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Cycle-to-cycle combustion variations in spark ignition engines have been a subject of intensive research for many years. Instabilities of the combustion process can be a cause of harmful fluctuations of the power output, which result in the difficulty of controlling engines. It is known that the elimination of the fluctuations of cyclic motion would lead to a 10 % increase in the power output of engines. It is thus of great importance to control the motion of engines by eliminating the fluctuations, which leads to improvement of engine performance.

We investigate the cause of combustion fluctuations by applying nonlinear time series analysis with the embedding technique1). Our analysis is for a time series of combustion pressure in the idle state, which was measured from a spark ignition engine of motorcycle under the collaboration of YAMAHA motor Co., Ltd. The experiments were carried out with a four-stroke, single-cylinder 250 cc engine. Figures 1(a) and (b) show the engine and its measurement apparatus.


(a) (b)

Fig. 1 (a) A picture of measurement in the experiment. (b) Enlarged view of the engine from another angle.

We show a time series of combustion pressure represented by crank angle in Fig. 2. Figure 3 presents the reconstructed attractor for the pressure data projected to three-dimensional space, where the delay time and the embedding dimension are determined to be 30 and 4, respectively. From these figures, one can see that the amplitude and period fluctuate. At first, these fluctuations were considered to be caused by thermal noise. However, our detailed analysis showed that the engine system has a low-dimensional dynamics with stochastic noise.

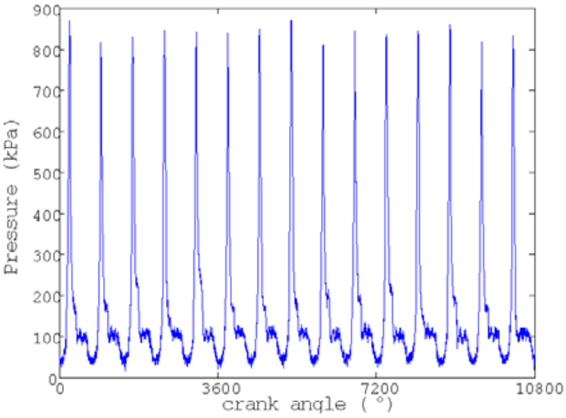

Fig. 2 A typical time series of combustion pressure.

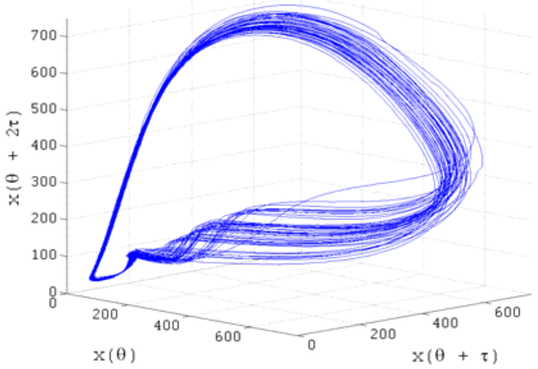

Fig. 3 Reconstructed attractor projected to three-dimensional space for the pressure data denoted by x(θ) with crank angle θ. The delay time τ is 30 unit time.

The presence of the deterministic components of the engine system means that it is possible to control the motion of engine's output by utilizing the underlying dynamics, in principle. As a first step of the study for the control, we propose a method to stabilize the chaotic behavior in engine's data by adopting Pyragas' method$^{2)}$. The characteristic of this method is that even if we do not know the equations of dynamical system concerned, we can create a periodic orbit simply by using its time series and its delayed feedback. In fact, we used the Pyragas' method to make a computer experiment for the combustion pressure data, thereby we successfully eliminated the fluctuations of the amplitude and the period in the combustion pressure data and obtained a periodic orbit from the data, shown in Fig. 4. This result suggests that the proposed method can be applied also for the control of engine's data in actual experimental process.

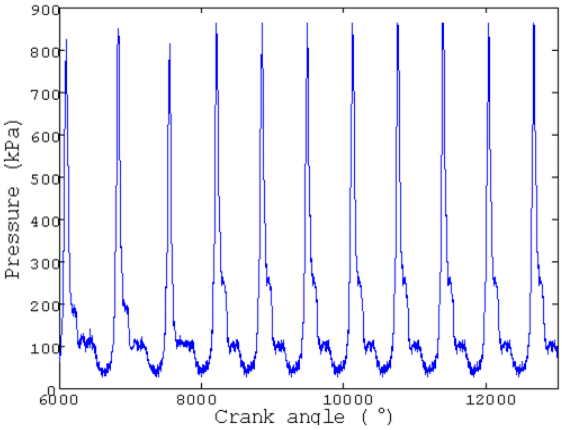

Fig. 4 Application of the proposed method to the pressure data. A period-one orbit was obtained by the effect of feedback control, which occurs at approximately 8000 ° of the crank angle corresponding to the eleventh combustion cycle.

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2) K. Pyragas, "Continuous control of chaos by self-controlling feedback," *Phys. Lett. A* **170** (1992), 421–428.