ABSTRACT

A commonly occurring control problem is the regulation of speed in all types of rotating machines. An electrical generator is connected to a pneumatic reciprocating engine. The engine speed is to remain constant for a variation in electrical load on the generator. The experiment consists of two phases, the interfacing of the computer and control software with the steam engine apparatus, and the analysis of various operating characteristics of the engine. In order to use classical transfer function to analyze the system, inherent non-linearities must be compensated. These non-linearities occur due to static friction in the motorized air valve and the non-linear behavior of fluid flow in valves. Two basic means were used to compensate for these non-linearities and to make the overall system linear. They were dither signals and linearizing feedback.

The two phases of the experiment were performed, the goals of which were to become familiar with the non-linear components, control of air valve position, and to measure the engine time constant.

INTRODUCTION

The objective of this experiment is to illustrate the principles of controls and to introduce the students to the control problems encountered in the industries. One of the most common problems is the regulation of speed in the rotating machines. In order to maintain a steady voltage supply from the generator it is important that the engine speed be held constant or as close as possible to some reference level.

The engine apparatus is an in-line four cylinder reciprocating engine operated by compressed air at 30 psi. The air entering the system is initially filtered in a reservoir of oil. The air is then passed through a filter where particles greater than 25 microns are filtered. Speed regulation for a small air engine is considered in this experiment. The basic control problem is to manipulate the position of the motorized air valve in such a manner that the engine speed is held constant against changes in the mechanical load and variation in the air supply pressure. As the air engine apparatus is equipped with instrumentation, we can measure the air valve position and the engine speed. The control input is the voltage applied to the valve drive motor via the "valve motor input" on the control box. All signals and input are buffered and scaled to allow direct connection to the analogue computer (10v scale).

Different experiments were carried out using DC voltage supply, oscilloscope and square wave generators.

THEORY

The basic control problem is to manipulate the position of the air valve in such a manner that the engine speed is held constant against changes in the mechanical load and variation in the air supply pressure. The overall system is approximated by use of linearizing techniques by the transfer function shown in Figure 1.

\[ \begin{align*}
N(s) &= \frac{g_2}{s^2 + \Delta} \\
U(s) &= \frac{g_1}{s(s + \Delta)} \\
N(t) \text{ is the engine speed output and } U(t) \text{ valve motor input.}
\end{align*} \] (1)

Fig. 1 Basic System Transfer Function
The engine speed is detected electrically by a light sensitive and light emitting diodes mounted on the axis of the slots. When slot lines on the flywheel disk lines up, current in the light sensitive diode increases and the engine shaft rotation generates electrical pulses. The pulse rate is directly proportional to the shaft speed. Thus, both the input and the output of this system are voltages.

The overall transfer function can be split into two first order systems because the actual valve position \( X(t) \) can be directly measured by displacement transducers. This is essential in linearising the inherent non-linear characteristic of the valve drive motor. Due to static friction in the gears and valve seals, a finite input voltage is required before the valve begins to turn. This gives rise to a dead band characteristic which can be dealt in two ways: by the use of dither signal or by linearising feedback.

The dither signal approach is a procedure wherein a high frequency periodic signal is added to the input so as to modify the non-linearity. If the input is a constant, the dithered output \( \frac{dx}{dt} \) will approximate the average output over one cycle of the dither signal because of the inherent filter of the valve due to its mechanical inertia.

Figure 2 shows square wave dither signal of amplitude \( E(d) \) which is equal to the deadband \( d \). The dither signal gets rid of the deadband at the expense of halving the gain, thus making valve and dither linear as shown in Figure 3.

\[
\frac{dx}{dt} = \text{slope } k_{1/2} \quad \text{output}
\]

\[
\text{dither constant input of } u_0
\]

\[
\text{(Note: } E_0 + d)
\]

Fig.2 Effect of Dither \((E + d > u)\)

The second alternative of handling non-linearity is by local feedback. This feedback system is shown in Figure 4.

Fig.3 Effect of Dither

\[
X(s) = \frac{g}{1 + \frac{k}{k_1}}
\]

where \( u(s) = \) the voltage applied at "demanded value position"
\( x(s) = \) the voltage sensed at "actual valve position"

The overall transfer function for the system with the multi-loop feedback is shown in Figure 5.
The advantage of the multi-loop feedback is that the engine speed controller can be set up and the design can be accomplished by the root locus procedure. The root locus for the system without local feedback round the valve is shown in Figure 6.

Fig. 6 Air Engine Root Loci.

This limits the closed loop response to a constant for high gain. For significantly high gain the closed poles are complex such that closed loop characteristic equation is:

\[ s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \]  \hspace{1cm} (3)

The proportional gain \( k_2 \) \((k_3 = 0)\) is selected so as to give a required damping coefficient \(\zeta\). Proportional action will result in steady state error for the output and the input signal. According to final value theorem the steady state error for this system is zero. Thus the system is stable.

**OBJECTIVE OF EXPERIMENTS**

Measurement and Analysis of various operating characteristics of the engine.

1. Determine the relationship of engine speed versus valve position voltage.
2. Determine relationship of engine speed versus engine output voltage.
4. Determine time constant of engine and steady state error.

**EQUIPMENT**

2. Engine speed control box.
3. Model 1601 regulated DC power supply.
4. Voltmeter 2 Nos.

**TYPICAL PROCEDURE**

1. Before starting the experiment, make sure that valves of the engine are closed.
2. Now set the apparatus (engine) to run at 30 psi.
3. Slowly open the valve by applying voltage.
4. At a voltage of +9 volts, the valve is fully opened and the engine runs at full speed. Let it run for few seconds at full speed, so that it stabilizes.
5. Now close the valve by applying negative voltage in steps of 1 volt and record the engine speed from the tachometer to the corresponding voltage.
6. Repeat the procedure.
7. Draw characteristics graphs of the engine.

**EXPERIMENTAL RESULTS**

Experiment (1) results are shown in Figure 7.

![Engine Speed vs Valve Position](Fig.7 Engine Speed Vs Valve Position)
DISCUSSION

Various characteristics of engine control system were determined. The cut off speed of the engine was 900 rpm at a valve position of -0.08 volts.

The relationship between speed and analogue speed output was found to be linear.

The gain values of the valve were determined to be 0.2145 with the influence of the dither signal and 0.45 without its influence.

The deadband width characteristic of the valve was measured as (+/-) 0.36 volts to either side of the midrange valve position.

The steady state valve position error was found to decrease as closed loop gain increased and when a dither signal was applied.

Finally, the engine time constant and system gain were measured and determined to be $T = 1.8$ secs and $gain = 2.07$.

SUMMARY

The intent of the engine control system experiment was to develop experiments on the CE7 Steam Engine Apparatus for incorporation in mechanical engineering laboratory. This goal was achieved by first determining the engine characteristics. Secondly the engine was interfaced with IBM PC Computer. The software allowed us to implement values to various variables in order to control the speed of the engine. We then performed the analysis in order to determine the operating characteristics of the engine and values of other control variables.

ACKNOWLEDGEMENTS

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REFERENCES

(2) Dorf, Richard C., Modern Control System, Addison-Wesley.