Technical Note: Active control of an engine dynamometer

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The testing and thermodynamic analysis of internal combustion engines frequently requires that they be operated through a repeatable torque/speed range. Active control techniques were applied to achieve this requirement on a compression ignition Deutz engine. The engine contains a mechanical governor which achieves constant speed operation. The problem thus reduces to the implementation of a torque control system. The hardware configuration is illustrated in Figure 1. Torque control was implemented with a standard 12 bit A/D–D/A card on an IBM-PC.

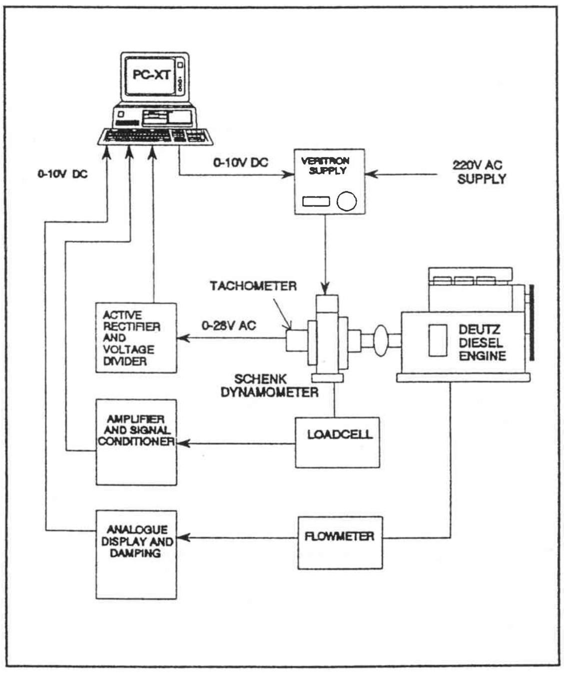

Figure 1. Overview of system set-up.

The engine torque was acquired from a torque arm loadcell attached to a Schenk eddy current dynamometer. The engine speed was acquired from a tachometer coupled to the drive shaft. The control signal from the D/A convertor was used to drive the eddy current dynamometer and to generate a reaction torque on the engine drive shaft. In this manner the torque applied to the engine could be

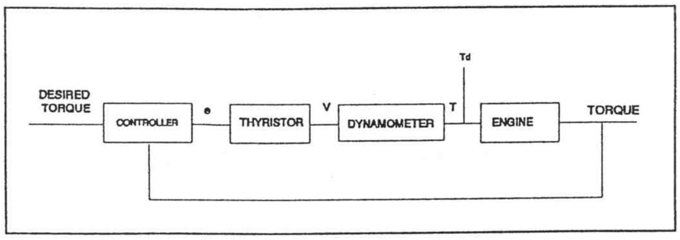

Figure 2. Constant torque control system layout.

controlled. A schematic block diagram of the system is presented in Figure 2. The open loop engine response to a step input command in torque exhibited an exponential response and consequently the engine was modelled as a first order system. Three different control strategies were implemented as illustrated by the block diagrams presented in Figure 3.

Conventional control strategies, namely PI and PID control, were implemented for comparison with a Pseudo-Derivative Feedback (PDF) control strategy. Plots of the system response due to a step change in the desired torque are illustrated on the right-hand side of Figure 3. In this figure, V_{speed} represents the output voltage from the tachometer; $V_{set\ point}$ is proportional to the desired or set point torque value; $V_{control}$ represents the control voltage which is proportional to the current generated in the eddy current dynamometer. V_{actual} is proportional to the torque produced by the engine. Although the strategies implemented result in the control objective being achieved, notable differences in the response of the engine exist. It is evident that the PI and PID control strategy results in numerator terms in the closed loop system transfer function. This increases the system's sensitivity to step input changes in the demand, and results in transient response of the command signals. The addition of derivative action in the feed forward loop amplifies this behaviour, increasing the sensitivity to the first and second derivative of the input signal. This results in a large control signal immediately after the demand change. Although derivative action in the feed forward loop provides flexibility regarding pole placement in the complex plane, and hence the ability to increase the system damping, this advantage must be assessed in the context of the demand signal and the presence of numerator 'dynamics'. In this case the added complexity of a PID controller is negated by its increased sensitivity to sudden changes in the demand signal. Phelan [1]

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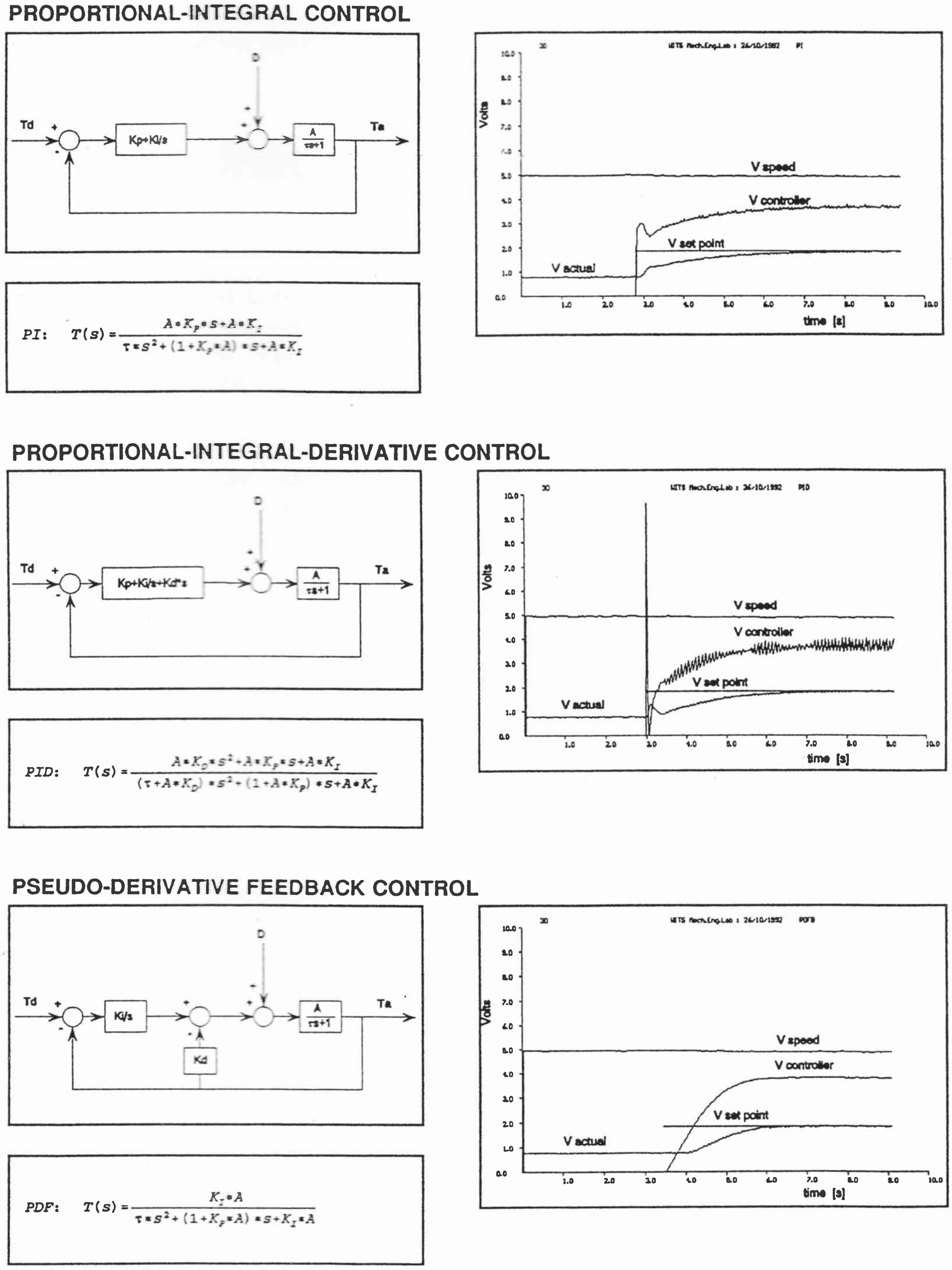

Figure 3. Control strategies applied.

proposed the concept of pseudo-derivative feedback action, to eliminate numerator terms in the system transfer function, whilst retaining control over the coefficients in the denominator of the transfer function. Pseudo-derivative feedback results in a system response which is insensitive to rapid changes in the demand, providing a smooth control action. Although it introduces a rate dependent term in the denominator of the transfer function, it does not require the explicit evaluation of the rate of the controlled signal, and is consequently simple to implement. In the absence of numerator terms in the closed loop transfer function, the system response depends solely on the roots of the characteristic equation. Consequently pole placement can be applied confidently to achieve the desired response specifications.

In the case of the Deutz engine, the response time of approximately 4 s to steady state as achieved with the PI and PID algorithms was reduced to 2.5 s with PDF control. In addition a smooth control action was achieved eliminating transients which would otherwise be applied to the engine by the torque dynamometer.

Note: This work was extracted from MV's fourth-year design project.

References

[1] Phelan R. *Automatic control systems.* Cornell University Press, Ithaca NY, 1977.