

Virtual Check Valve Control for Improved Energy Conservation and Phasing Performance

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ABSTRACT

This paper describes an enhanced application of variable cam timing (VCT) systems for improved conservation of energy and phase rate performance at high temperature and low RPM conditions.

This virtual check valve control is demonstrated to provide faster phase rate at high temperature and low RPM conditions than either conventional VCT systems, or those using mechanical check valves. It offers expanded temperature and RPM operating range and further removes VCT systems from imposing burden on fuel-economy-sensitive oil pump systems. The virtual check valve concept is demonstrated in simulation. An ECU control is implemented and tested on a V6 engine.

INTRODUCTION

Automotive cam torque reacts on VCT systems in both positive and negative ways. Approximately one half of a cam torque sine wave will help to accelerate the cam in a desired direction. Meanwhile, the opposite portion of this torque wave will react against the hydraulic column to decelerate the cam, thereby losing desired motion. When the cam torque reaction acts against the phaser rotor, and the oil control valve (OCV) is open, oil is pushed back through the OCV. With a 'conventional' duty cycle command, the spool is open continuously during a transient, and the cam torque overcomes the oil pressure to reverse the oil flow. In low oil pressure conditions, the phaser movement in the commanded direction is impeded by cam torque reaction forces. The use of phasing is therefore compromised or eliminated. These conditions represent the idle and launch areas of vehicle operation, where VCT can provide a benefit if the system is made capable.

By retracting the OCV spool to the closed position during a negative cam torque reaction, the oil is more effectively secured downstream of the valve. The same can be achieved with a mechanical check valve, but commanding the OCV in this way eliminates the cost, reliability and frictional flow losses of the check valve.

SIMULATED EVALUATIONS

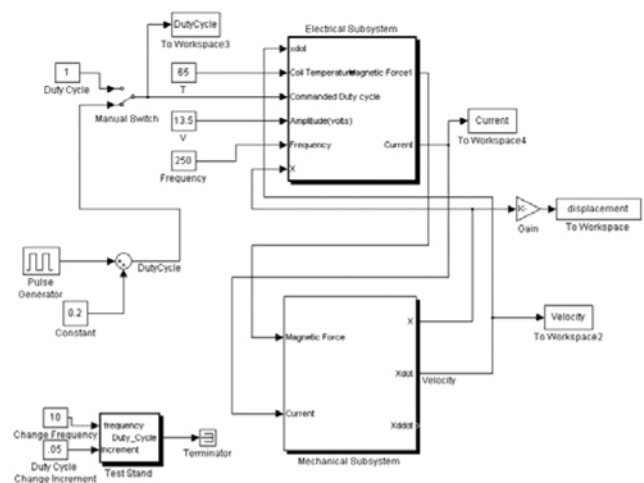


Figure 1. OCV Simulink Model

The Simulink model serves to calibrate friction characteristics such that electrical response time matches experimental performance.

Mechanical friction is difficult to predict without obtaining experimental data. During the mechanical friction testing the OCV was cycled between zero and 100% duty cycle while at 13.5 volts DC. Transitions between these extreme duty cycle levels occurred at 2 Hz. The OCV was resting on a table but had been wetted with room temperature oil. Testing

combined with Simulink analytical modeling provides a good method to create a simulation model of the system.

The Simulink model also aids understanding and system confirmation by illustrating OCV motion and electrical responses in a manner that correlates with mathematical relationships.

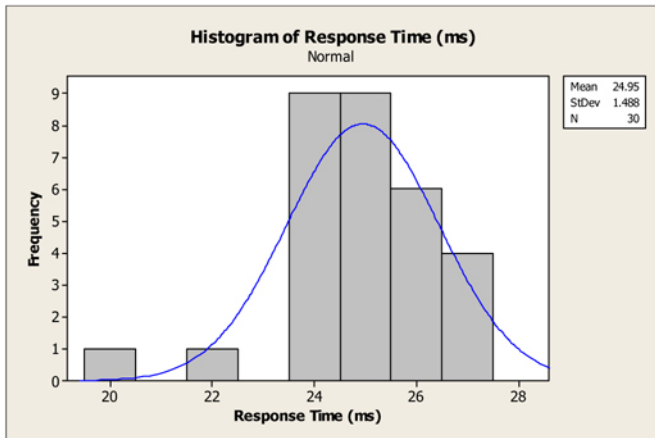


Figure 2. Physical Testing of Response Time

Average Response Times:

- OCV duty cycle from 0 to 100%: 24.95 ms
- OCV duty cycle from 100 to 0%: 8.11 ms

Figures 3 and 4 show work performed to calibrate the analytical Simulink model to match experimental results of OCV response testing.

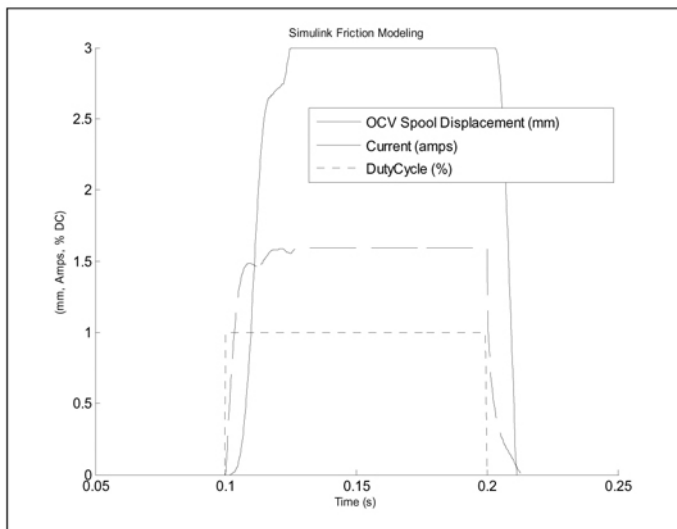


Figure 3. Simulation Results following friction tuning

During response time testing and simulation (Figure 3), the spool was stroked between its physical limits by commanding duty cycle between 0 and 100% DC discrete points.

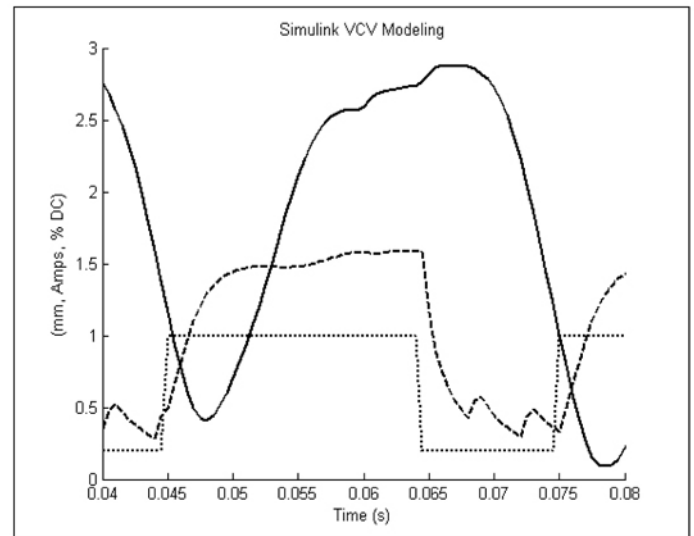


Figure 4. Simulink Results during VCV Mode (See Figure 3 for Legend)

After completing friction calibration of the Simulink model, Figure 4 shows an example of Simulink results representing possible VCV mode for OCV spool motion, current and OCV duty cycle. Ideally, the spool should fully open in presence of beneficial torque and remain fixed at approximately mid-travel (1.5 mm) in presence of negative torque. Electrical and mechanical limitations cause finite (non-zero) response times that prevent this. Therefore, the resulting VCV mode spool motion will be continuous rather than discrete and will receive unique calibrations, specific for RPM and oil temperature conditions.

AMESIM SIMULATION

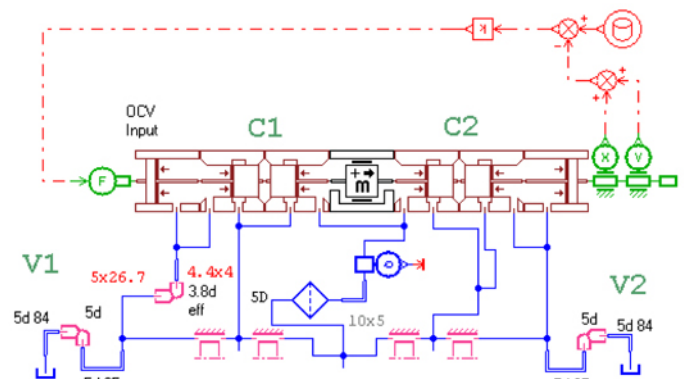


Figure 5. AMESim Control Circuit (Red) maintained OCV Spool Position equal to Simulink data

Once complete with Simulink modeling of the electrical system, the resulting spool position signal was ported into an AMESim model of the hydraulic system (Figure 5).

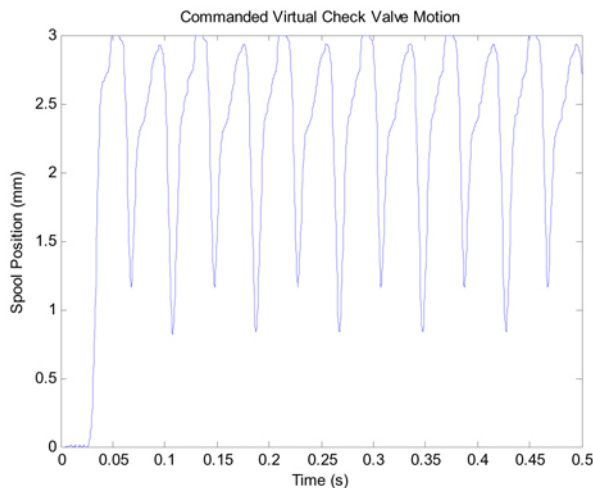


Figure 6. Commanded OCV Spool Motion (Output from Simulink to AMESim)

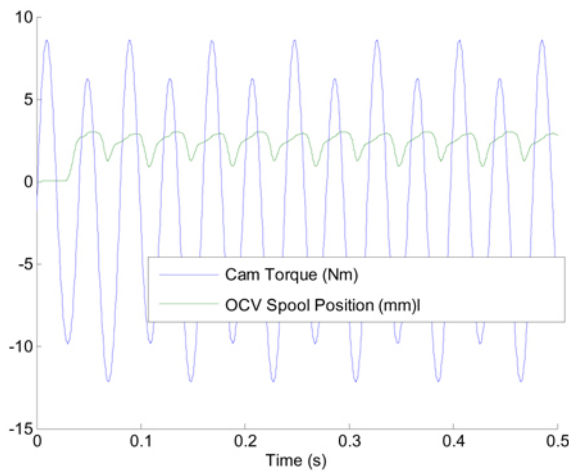


Figure 7. Orientation of OCV Spool Motion (1) to Cam Torque (2), AMESim Data

Using AMESim hydraulic simulation, spool motion is closely aligned with the mechanical cam torque reversal. As a goal, the spool should fully open to housing ports when torque direction is positive while closing the port when torque direction is negative.

Table 1. Simulation Runs & Performance

	Simulation Run #		
	1	2	3
Description	Virtual Check Valve	No Check Valve	Production Check Valve
Traditional Check Valve	None	None	Present
OCV Spool Command	By VCV Motion	Full On ¹	Full On
Simulated Performance			
Ave. Rate (crk°/s)	45.1	38.4	47
% Change	-4%	-18%	Baseline

Simulation Conditions

- L4 Intake Advance Command Motion
- RPM: 750
- Oil Temperature: 150°C
- Oil Aeration & Grade: 5%, 5W30, Non-Synthetic

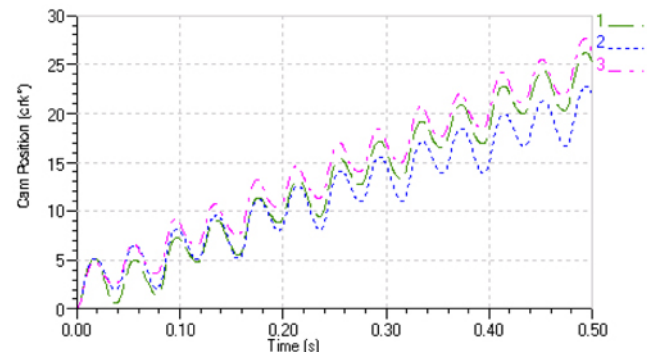


Figure 8. AMESim Simulation of Cam Position (Simulation Runs 1, 2, 3)

Phase rate is calculated as ratio of total phase position change divided by total time.

The OCV response time is only fast enough for VCV at low engine speed, but VCV control is used only at the combination of low speed and high temperatures. At operating conditions beyond this low pressure condition, the phasing control reverts to conventional OCV operation.