Electronically-Contolled Hydrostatic Fan Drive Systems

Introduction

In the internal combustion engine approximately 30% of the energy in the fuel is converted into mechanical power while the rest becomes heat energy and is lost into the atmosphere around the vehicle. Of the energy converted to heat, 35 to 45% is lost directly to the surrounding atmosphere and the rest must be extracted from the engine block by the cooling system.

For heavy-duty vehicles and equipment, engine cooling fan systems require a significant amount of horsepower and contribute to the overall noise level of the machine. Increasingly, there is a push for greater machine efficiency and quieter operation. Improving the efficiency of the engine cooling fan drive system can make a significant contribution to this effort.

Conventional fan drive systems typically overcool to insure adequate cooling at the extreme ends of the operating heat spectrum. This means that much of the power used to drive the fan is wasted. The temperature-activated, electronically-controlled, hydrostatic fan drive system can offer finer control, reducing the fan speed during times of low cooling demand, so the fan drive system can use less power. The power saved can be used to increase the fuel efficiency and the overall operating efficiency of the machine.

Hydrostatic fan drive systems can deliver greater efficiency in a wide range of vehicles and equipment including on-highway equipment such as trucks and buses, as well as construction and agricultural machinery, military vehicles and stationary power plants.

Conventional Fan Drives

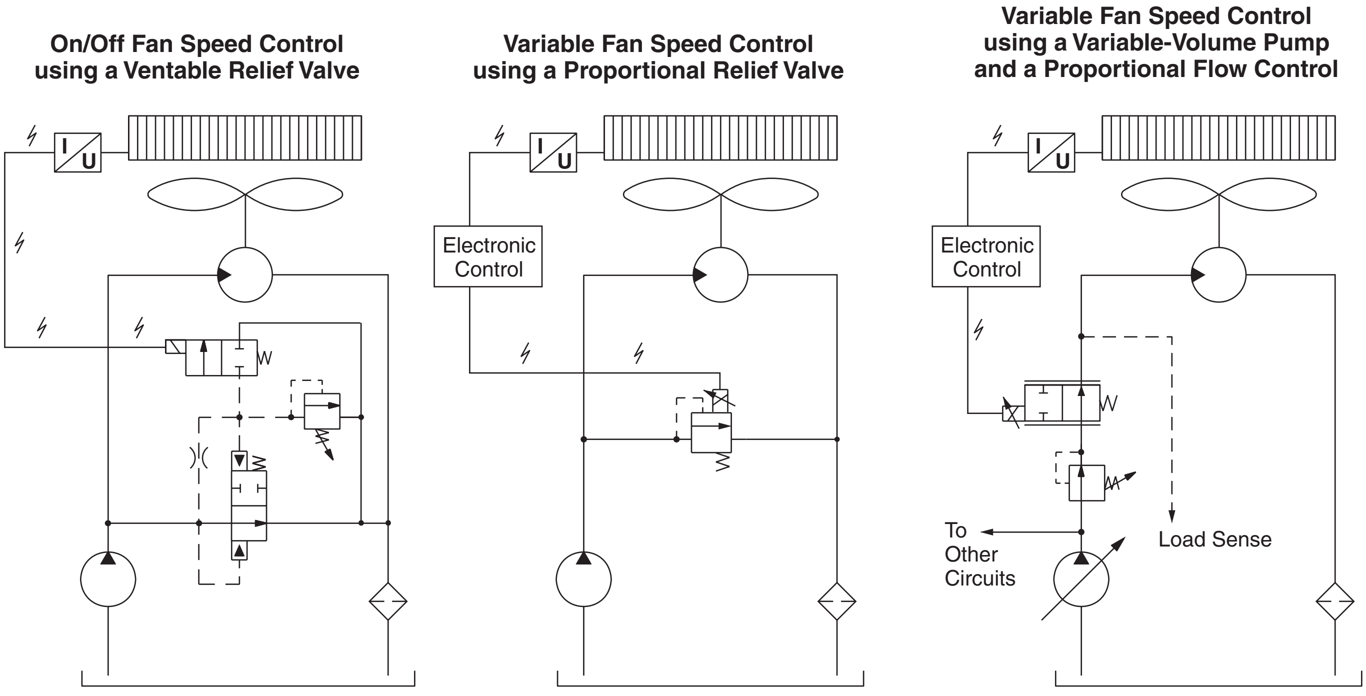
Most conventional fan drive systems — clutch drives, pneumatic drives, electromagnetic and viscous drives, and variable pitch fans — do not respond directly to engine coolant temperature, severely limiting their accuracy and efficiency.

Electric fan motors may be practical for low-power applications, but typically they are not a practical solution for larger vehicles with higher fan power requirements. In these larger vehicles, a hydrostatic fan drive control system offers the best efficiency and quietest operation. Fan speed can be precisely modulated to the cooling requirements of the machine under widely varying ambient conditions and operating conditions.

Continuous & Intermittent Hydrostatic Fan Drives

On/Off fan speed control using a venting relief valve (Fig. 1a) is the simplest and lowest-cost option. The relief valve setting and pump volume determine the maximum fan speed. The signal to vent the relief valve would come from a thermal switch in the coolant. The fan cycles between "off" and "full speed." There is no modulation for intermediate conditions. Efficiency and noise-control are not as good as can be achieved with variable-speed systems.

Variable fan speed control using a proportional relief valve (Fig. 1b) is the most cost-effective solution, providing very high operating efficiency. The fan speed is varied as a function of the pressure set by the proportional relief valve. Maximum fan speed is attained when the proportional pressure control valve is at its highest setting. The relief valve will "failsafe" to high pressure so that a loss of the electrical signal causes the fan to operate at maximum speed for maximum engine cooling if electrical power is lost.



On/Off Fan Speed Control using a Ventable Relief Valve

Variable Fan Speed Control using a Proportional Relief Valve

Variable Fan Speed Control using a Variable-Volume Pump and a Proportional Flow Control

1a

1b

1b

Figure 1

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Variable fan speed using a variable displacement pump (Fig. 1c) is the most efficient and offers the quietest operation, however the initial cost of this type of system is relatively high, therefore its use is limited. In this system the pump drives the fan but also provides other functions. When the other functions require a higher pressure than the fan, a reducing valve can be used to limit pressure to the fan. A proportional flow control is used instead of a pressure relief valve. The pump could include a load-sense control which would require a sense line downstream of the flow control. In applications where the pump is completely dedicated to the fan drive, the pressure and flow control valves would typically be an integral part of the bolt-on pump control.

Description of the Variable Fan Drive System using a Proportional Relief Valve (Fig. 1b)

In the internal combustion engine the coolant temperature is controlled by an axial or radial fan which is driven by a hydraulic motor. The flow to the hydraulic motor is provided by a fixed displacement pump which is driven by the engine. The hydraulic motor is controlled by a proportional relief valve in the bypass leg of the circuit. The maximum fan speed is achieved when the proportional relief valve is at its highest setting.

The HydraForce proportional relief valve models used in these applications are typically the TS10-27 (up to 25KW) or the TS12-27 (up to 65 KW). The power required at the hydraulic motor depends on the fan characteristics. The TSxx-27 model proportional relief valves are normally closed, so that when the power is off, the valve is at its highest pressure setting. The insures that the fan will operate at full speed for maximum engine cooling when electrical power is lost.

The minimum fan speed is attained when the proportional valve has the maximum electrical signal applied and is at its lowest pressure. Minimum fan speed is determined by the pressure drop of the system. For an axial fan, the power absorbed is proportional to the cube of the change in fan speed.

If a typical fan can absorb 90W at 400 RPM, the power absorbed at 2500 RPM is 11KW, and at 3000 RPM the power absorbed is 19KW. (Fig. 2)

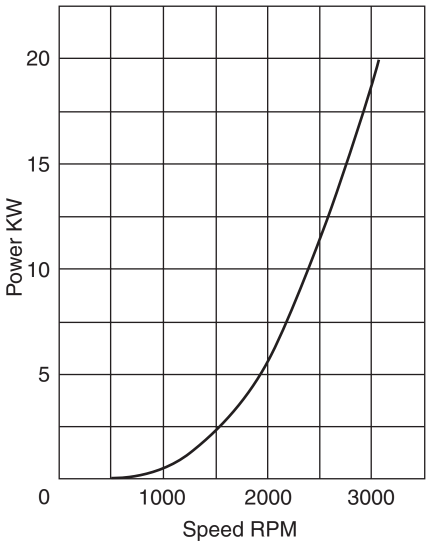

Figure 2

The noise level of the fan is also dependent on the fan speed and increases at approximately one-third the rate of the increase of the fan speed. The TSxx-27 proportional pressure control valves have a maximum pressure setting that can be factory-set to limit the pressure at the fan motor in order to limit the fan speed and the fan noise level.

An anti-cavitation check valve may be required to prevent cavitation of the motor. Cavitation can result from either a motor overrunning condition due to fan inertia, or windmilling of the fan if it is in the vehicle air stream.

A temperature sensor, an electronic control and an electrically-operated proportional pressure control valve are used to control the flow and pressure to the hydraulically-operated fan motor. The minimum fan speed is determined by the pressure drop in the system when the relief valve is in the open position.

The fan speed increases continuously (Fig. 3) between the minimum and maximum cooling power requirement as commanded by the temperature sensor and the electronic control. The maximum fan speed is controlled by the pressure setting of the proportional relief and the flow rate of the pump. Smooth modulation avoids high fan acceleration and sudden changes in noise levels, and excessive shock loading to system components. If properly sized, the fan will normally operate at an intermediate speed which will reduce noise and power consumption.

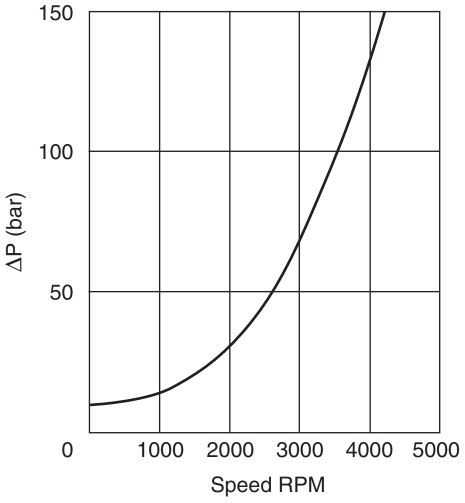

Figure 3

Advantages of Hydraulic Variable-Speed Fan Drive

Precise Control of Coolant Temperature — Fig. 4 shows a typical curve for fan speed vs. coolant temperature. The difference between the switch-on curve and the switch-off curve (hysteresis) is very small, approximately 1°C. This permits precise control of the coolant temperature with minimal temperature fluctuations, even when there are extreme changes in the engine load.

Reduced Engine Wear — Fig. 5 shows the extent to which cylinder wear in an engine in influenced by coolant temperature. Cylinder wear can be reduced considerably when the operating temperature is reached quickly and maintained.

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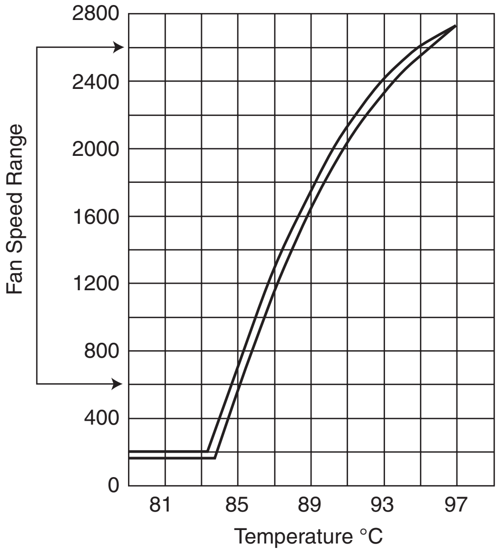

Figure 4

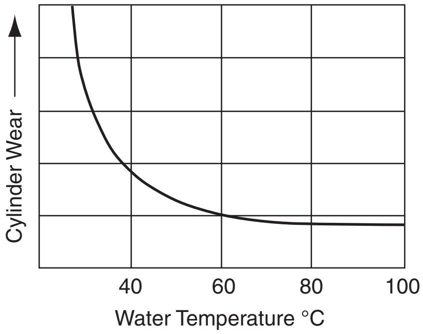

Figure 5

High Flexibility — The allows the vehicle designer to optimize the arrangement of the engine and cooling system components. A considerable advantage can be achieved here in regards to noise insulation of the engine.

Speed Modulation — Constant regulation from minimum to maximum fan speed over a temperature range of approximately 10°C (Fig. 4). This prevents abrupt speed changes which can lead to heavy loads on drive parts and high noise levels. The bandwidth of 10°C permits average cooling output without unnecessary switching between minimum and maximum fan speeds.

Maximum Speed Limitation — The proportional pressure control valve also acts to limit maximum fan speed to control power consumption and noise level of the impeller.

Energy Savings — Under normal cooling requirements the fan will operate at about 50% to 80% of maximum RPM and can go as low as 10% to 20% in cold weather climates. This results in power savings and a drop in fuel consumption. Fig. 6 shows a typical power requirement curve for a hydrostatic fan with proportional control. When the fan is running between 50% and 80% of maximum speed, the input horsepower is reduced to approximately 40% to 80% of maximum. In cold weather climates this could be as low as 15% to 20% of the maximum horsepower. The input horsepower is the result of the fan horsepower plus the mechanical and hydraulic losses of the system.

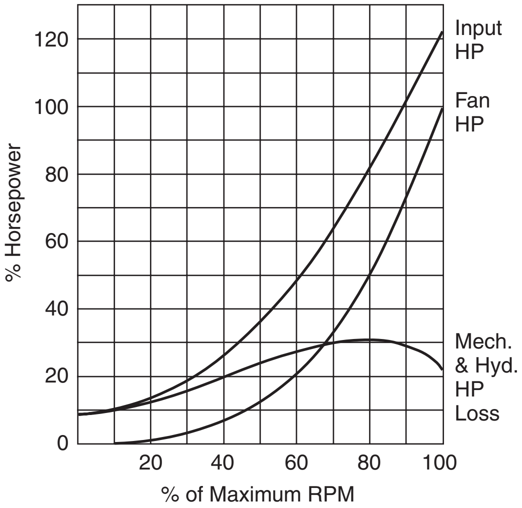

Figure 6

Electronic Control Systems and Components

Hydrostatic fan drive systems can utilize electronic controls ranging from simple single-sensor circuits to complicated multi-sensor circuits with fan speed feedback. The type of electronics used in a given application is determined by the level of accuracy and control required by the customer.

A simple two-speed control is shown in Fig. 7. There is a temperature sensor or switch and a proportional relief valve. In this system the fan will run at maximum speed when cooling demand is high, and at an intermediate speed when cooling demand is lower. The electronic control is set to wait until a signal is generated by the temperature sensor or switch before starting the fan. This allows the engine to come up to temperature before the fan starts operating.

The electronic control has a built-in ramp function which will bring the fan speed up to maximum at a controlled rate of acceleration. This reduces the startup shock loading on the fan drive components. When the coolant temperature decreases below the setpoint, the fan RPM is reduced to the intermediate speed. The fan will then cycle between the two speeds with a ramped acceleration from intermediate to maximum speed.

The proportional systems illustrated in Fig. 8 are more sophisticated, offering more precise control of fan speed. These systems can employ a separate fan module or use a signal from the engine control module (ECM). The graph in Fig. 8 shows the precise control that can be achieved with these systems. Fan speed is constantly modulating over approximately 10°C with a hysteresis of about 1°C.

Electronic Fan Module

The electronic fan module can be designed to accept a number of analog inputs, switched inputs and PWM inputs. The module processes these inputs and produces a single output signal to drive the proportional pressure control valve.

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Two-Speed On/Off

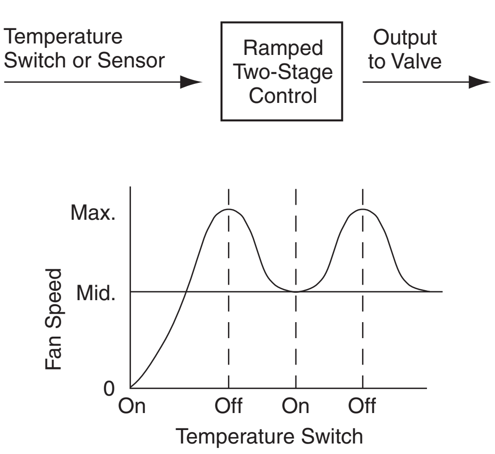

Figure 7

Examples of analog inputs:

- Coolant temperature
- Hydraulic oil temperature
- Supercharge air temperature
- Engine oil temperature
- Fan motor pressure

Examples of switched inputs:

- Retarder ON
- Air-conditioning ON

In applications where closed-loop control is required, a fan speed sensor or fan motor pressure sensor would be utilized. Closed-loop control systems are more complex and require more components, and are therefore more expensive.

Engine Control Module (ECM)

In recent years, engine manufacturers are increasingly utilizing electronic control. This has been done to improve vehicle performance and efficiency as well as to comply with more stringent emissions and fuel economy standards. The ECM monitors engine operating conditions, including engine coolant temperature, inlet air temperature, supercharger air temperature, and other parameters that could be used to control the fan drive system.

Some ECMs have incorporated a fan drive output signal. This signal is usually a PWM output that can be used to drive a proportional relief valve directly or may require some signal conditioning to be useable.

Proportional

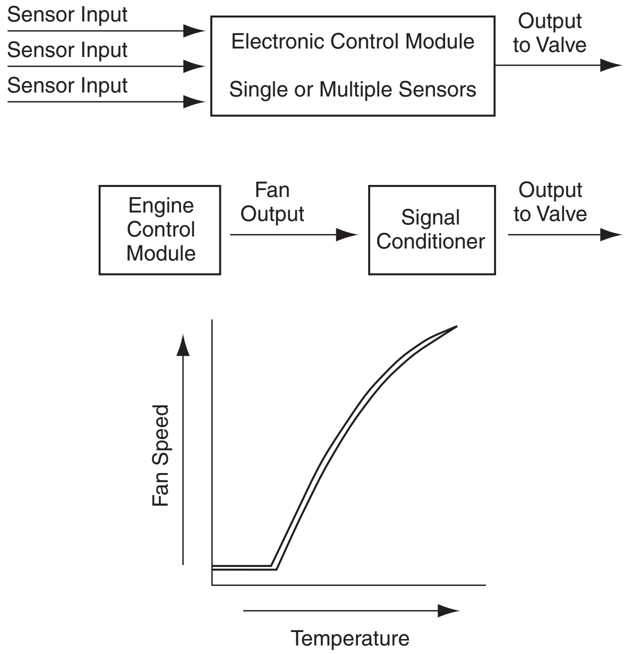

Figure 8

Applications

The major factors in applying fan drive systems are:

- Fan specifications
- Pump/motor sizing
- Proportional valve selection
- Electronic control requirements

The fan specifications will typically establish an airflow at a given RPM which will result in a horsepower and torque requirement. From this specification, the pump/motor can be selected. This determines flow and pressure requirements which will determine the proportional relief valve to be used. The electronics can then be selected and programmed based on the system requirements for the inputs and final control parameters.

Conclusion

For the machine designer, the hydrostatic fan drive offers flexibility of installation along with reduced noise and high efficiency. The reliability of the fan drive system is improved because the components operate at lower duty cycle with less shock loading.

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