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Choosing the Right Fan Drive System **Saves Fuel**

By Mike Gandrud, Senior Engineer, Advanced Systems Engineering Team for Sauer-Danfoss

When I entered the work force several years ago, I was perplexed that so many machines were designed for the lowest initial cost, with little attention to fuel and operating costs. With increases in energy prices in recent years, new engineers entering the work force are seeing a greater interest in energy saving designs. As emissions regulations tighten, and fleet managers learn of potential fuel savings opportunities, modulating hydraulic fan drives are gaining ever wider application. Modulating hydraulic fan drive systems can pay for themselves in fuel savings alone in three to 12 months depending on the duty cycle when compared to a belt drive. To understand how a modulating hydraulic fan drive can enhance your machine, first consider the constraints with which cooling systems are designed.

Cooling System Sizing Criteria

Fan-assisted or forced-convection cooling of an engine's radiator and other coolers enables the use of coolers that have a manageable size. Forced convection heat transfer is governed by the following equation:

The machine designer can choose a cooler with a comparatively larger area "A", or a comparatively higher cooler coefficient "U(m)". As a result, the machine designer may choose to integrate a comparatively larger cooler, or to force more air through a comparatively smaller cooler. Larger coolers are difficult to fit into tightly packed machines. Higher air flow rates require higher fan power, extra fuel, consume a higher percentage of available engine power, and produce higher audible noise.

$$\dot{Q} = U(\dot{m}) \cdot A \cdot (T_1 - T_A)$$

$\dot{Q}$	*Heat rejection*	*kW or btu / hr*	*Specified by engine data sheet*
$U(\dot{m})$	*Cooler coefficient*	$\frac{kW}{m^2 \cdot °C}$ or $\frac{btu}{hr \cdot ft^2 \cdot °F}$	*Determined by cooler design and mass air flow*
A	*Cooler area*	m^2 or ft^2	*Cooler area*
T_1	*Engine coolant temp.*	°C or °F	*Max. specified by engine data sheet*
T_A	*Ambient temperature*	°C or °F	*Typical maximum value ~50 °C (~122 °F)*

Cooling fans are typically sized to provide satisfactory cooling under the most severe combination of conditions that the machine could encounter. These conditions include the lowest engine speed at which the following conditions occur:

- Maximum Engine Load
- Highest Ambient Temperature
- Lowest Atmospheric Pressure
- Lowest Relative Humidity
- Highest Altitude
- Least Wind / Ram Air Effect
- Partial Cooler Obstruction

The average installed fan power for machines that operate off-highway is about 10% of the engine's rated power. Since the fan drive system will have its own efficiency, it is common for the engine power dedicated to the fan drive system to be more than 10% at peak conditions. Equipment that travels at highway speeds and has a cooler positioned in the front of the machine may require considerably less fan power since the vehicle's forward motion serves to push air through the cooler. This "ram air" effect enables automobiles to maintain sufficient cooling with one or two low-power electric fans.

Fan Sizing Criteria

Consider a fan system for a machine with a 50 kW (67 hp) engine that has a rated speed of 2,600 rpm and experiences maximum heat rejection at 2,000 rpm. We can assume that a cooler maker has designed a cooler for this engine and found a fan blade which will require 5 kW (6.7 hp) to move air through the cooler at maximum conditions.

The power required to turn a fan is proportional to the cube of the fan speed. Due to this cubic relationship, turning the fan any faster than required for proper cooling will require significant additional power. Even turning the fan 20% faster than necessary will consume 78% more power than necessary. The following table shows the relationship between fan power and speed.

$$FP = k \cdot n^3$$

FP	*Fan Power*	*kW or hp*
k	*Fan Power Constant*	$\frac{kW}{rpm^3}$ or $\frac{hp}{rpm^3}$
n	*Fan Speed*	*rpm*

Consider a fan that is driven with a conventional belt. Such a fan will turn at a fixed ratio to the speed of the engine. The belt speed ratio will be selected to turn the fan at the speed at which it draws 5 kW when the engine is operating at 2,000 rpm. When the engine operates above 2,000 rpm, the fan will also turn faster, thus drawing more than the 5 kW. If the belt ratio was selected to turn the fan at maximum speed only when the engine is at maximum speed, then sufficient cooling may not be obtained when the engine is operating below this maximum speed. Since this fan must operate at a power of 5 kW when the engine is turning at 2,000 rpm, a belt driven fan will draw 11 kW (14.7 hp) when the engine is at the rated speed of 2600 rpm. When the fan is belt driven and the engine is operating at maximum speed, the fan will require 11 kW of power, even if the engine load is light, or the ambient temperature is low. Under such a condition, the fan will draw 11 kW of power even though a fan power of much less than 5 kW would provide satisfactory cooling.

Consider a fan that always turns at a fixed speed, regardless of engine speed. An example of this is a fan that is driven by a fixed speed brush type DC motor. Such a fixed speed fan has the advantage that it will not draw more than 5 kW at any engine speed. The drawback of such a fan is that the machine will only rarely require a fan power of 5 kW. Poor power density and large package sizes are other significant disadvantages of electrically driven fans. Compatibility with a dusty, wet, and high vibration (off-road) work environment may be another disadvantage with electrically driven fans.

Finally, consider a modulating fan drive system. A modulating fan drive system adjusts the fan speed to match the cooling demand on an on-going basis. While a fan drive system's power capability must be selected to cool under the most severe combination of conditions, most machines rarely operate at these conditions. Fan application experts at Sauer-Danfoss and Turolla OpenCircuitGear (a member of the Sauer-Danfoss Group) have found that modulating fan drive systems commonly operate below 50% of their peak power level for 80% of the life of the machine. It is for this reason that modulating fan drive systems save a great deal of power. While it is necessary for our hypothetical application to install a fan that is capable of producing 5 kW, we find that 80% of the time a power of 2.5 kW or less is actually required.

For a particular model of machine, a unit that is operated in a warm climate will operate at a higher average fan power than a unit that is typically operated in a cooler climate.

Fan Drive Options

As described in the previous example, belt driven fans are falling out of favor for very good reasons. If a belt-driven fan is sized to properly cool a machine under all operating conditions, it will spend virtually all of its life turning faster than necessary, and thus consuming far more power than necessary to properly cool the machine.

Several companies offer electric fans for cooling applications with power levels in the range of 100 Watts to 600 Watts. Vehicles that are intended to operate at highway speeds are currently the main application of such fans. Refer back to the sample application which has a 50 kW (67 hp) engine. For proper cooling at the design point, such a machine may require approximately 5 kW (6.7 hp) of fan power. Not many machines with this size engine have space for 10 electric fans of 28 cm (11") diameter. Efficiency is another concern since most alternators that would be used to provide power to such fans only have an efficiency in the range of 50~60% under the best conditions. The cost of these electric fans and their associated alternator can also be quite high. Electric cooling fans become even more impractical for machines with engines in the 100 kW or 200 kW power range. The following picture depicts a dramatic difference in power density between electric motors and hydraulic motors. A Turolla OCG 25 cc gear motor is placed upon an ordinary 11.2 kW (15 hp) electric motor. The two motors can produce the same power level at the same speed.

Since most machines are rarely required to operate under the most severe combination of conditions, some suppliers of electric fans have sought to install fan systems that have a much lower peak power capability than traditional design constraints would require. The machine designer must ask: "Even if most of machines will never operate on a hot day in Arizona, is it acceptable for those machines that do operate in this environment to shutdown or fail?" Sauer-Danfoss dedicated several engineers to investigate electric fan drive technology over several years. After significant investigation and development work, we concluded that electrically driven fans are just not suited to the demands of machines that require multiple kilo-Watts of fan power.

The following table compares the advantages and limitations of various fan drive technologies.

Criteria / System Type	Power Density	Modulating	Responsive	Mounting Flexibility	Overspeed Noise	Average Power Waste	Practical for <1kW Applications	Practical for >3 kW Applications
Modulating Hydraulic	+	+	+	+	+	+	-	+
Variable Speed Electric	-	+	+	+	+	+	+	-
Fixed Speed Electric	-	-	-	+	±	±	+	-
Viscous Clutch	+	+	-	-	+	-	±	+
Belt Drive	+	-	-	-	-	-	+	+

Modulating Hydraulic Fan Drive Systems

Many different hydraulic circuits have been used to drive modulating cooling fans. The most common hydraulic fan drive systems use a fixed displacement hydraulic gear motor with a fixed displacement gear pump. In this system, a solenoid operated proportional relief valve is used to regulate the pressure across the motor, and thereby regulate fan speed (by controlling the torque applied to the fan). The second most common circuit uses a variable displacement piston pump with the fixed displacement gear motor. The variable displacement piston pump will typically use a proportional solenoid

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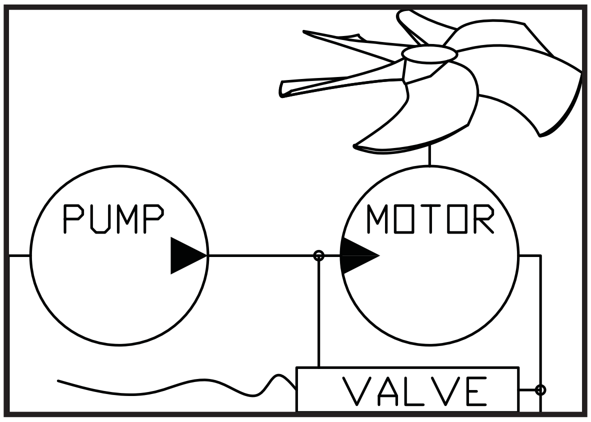
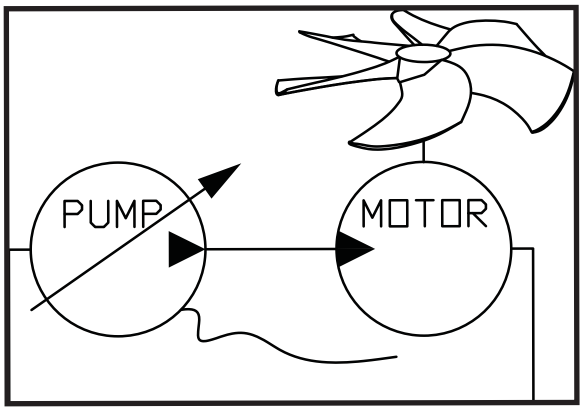
control to set the pressure which the pump produces, thereby modulating fan speed. In either circuit, the gear motor must be specially designed for use as a fan drive motor.

The system which uses the variable displacement pump is slightly more efficient because it produces only the flow that is required to turn the fan at the desired speed. Due to fuel savings, modulating hydraulic fan drive systems can pay for themselves in three to 12 months depending on the duty cycle. Depending on the application, and the end user's willingness to pay a few more dollars up front for a more fuel efficient machine, the circuit with the variable displacement pump may be justified, especially in higher power machines.

Since the motor in a hydraulic fan drive system is connected through hoses, the motor and fan can be placed anywhere on the machine. Belt and viscous clutch-driven fans are restricted to mounting locations and orientations which may be connected to the engine through a belt.





The electrical current to the solenoid valve is typically provided by either the engine controller itself, the vehicle microcontroller if one is used, or by a separate stand alone fan drive controller. Many engines provide current for a proportional solenoid valve which is modulated by the engine's cooling requirement. A vehicle microcontroller such as a Sauer-Danfoss PLUS+1™ controller can be configured to receive temperature signals of critical systems and send an appropriate current level to the proportional solenoid valve. A third option is a simple stand-alone controller such as the Sauer-Danfoss Fan Drive Controller.

Many circuit variations and options are available. One such variation uses the hydraulic flow exiting from the fan drive motor to power other hydraulic functions or systems on the machine. In this way, it is possible to supply several machine functions with one pump.

Your Sauer-Danfoss and Turolla OCG representatives have several software tools available to assist you in analyzing and correctly designing a modulating hydraulic fan drive system for your application.

Reference articles:

Sauer-Danfoss has more information available online at:

www.Sauer-Danfoss.com/Applications/FanDriveSystems/

A booklet titled "Hydraulic Fan Drive Systems Design Guidelines" provides a detailed discussion of many more design considerations. This booklet is available for download on the Sauer-Danfoss website.

About the Author: Mike Gandrud is a Senior Engineer in the Advanced Systems Engineering Team for Sauer-Danfoss at the Ames, Iowa location. He has worked in various technical rolls at Sauer-Danfoss for over 14 years. Gandrud is listed as an inventor on fifteen US and international patents. He graduated from Iowa State University with separate degrees in Electrical Engineering, Mechanical Engineering, and Systems Engineering. Gandrud is conversational in Mandarin Chinese and enjoys traveling to Asia.

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