



# Hydraulics

## Fan Drive System Application Guide

## Introduction

Selection of the proper pump and motor size for your fan drive system will require careful consideration of many factors. The most basic decision process is to select a fan drive motor displacement based on fan torque requirements and then size the pump for the required max fan speed. However, there are many other factors which must be considered to achieve a cost-effective, reliable, and properly controlled system.

This guide is intended to provide sufficient information to enable the user to analyze the cooling needs of the system, define the critical performance characteristics, and specify the cooling system hydraulic and control components necessary for an efficient cooling system.

*This guide will discuss the following issues:*

*Fan System Specification issues*

*Cooling System Power Requirements*

*Fan Selection Criteria and Critical Performance Factors*

*Hydraulic Motor Selection*

*Pump Selection Criteria*

*System Control Options*

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## Cooling System Specification Issues

### Vehicle Cooling System Testing

Airflow in the actual vehicle system may be different from fan curve data, and system cooling may vary from analytical values. Because of system differences, testing must be performed for verification of the vehicle cooling system performance in real world conditions.

### Fan Speed and Corresponding Torque Curve

Without this information it is impossible to properly size the system.

### Minimum Engine Speed vs Cooling Power Requirements

In order to size the pump it is necessary to know the minimum engine speed that still requires maximum, or significant, cooling levels. The minimum engine speed at which full fan power is required is referred to as "trim speed." Fan trim speeds at low engine RPM will drive increased pump displacements due to motor flow requirements. It is possible that an operating condition other than maximum cooling would drive the pump size. For example, if an application required 12 HP at a minimum engine speed of 1200 rpm, but 10 HP at a minimum engine speed of 800 rpm, the 12HP condition would dictate the pump size.

### Duty Cycle and Expected System Life

System life goals must be considered when designing the system and selecting components. The duty cycle must include cooling power, fan speed, engine speed, and percentage of time at various load conditions.

As an example:

	Fan Power	Fan Speed	Engine Speed	% of Life
<b>Condition 1</b>	21 HP	2800 RPM	1800 RPM	4 %
<b>Condition 2</b>	14 HP	2200 RPM	1400 RPM	25 %
<b>Condition 3</b>	6 HP	1500 RPM	1400 RPM	46 %
<b>Condition 4</b>	6 HP	1500 RPM	800 RPM	25 %

With the duty cycle information, pump and motor bearing life calculations can be developed and compared to system targets.

### Fan Curve

A fan curve is a plot of input torque vs. fan speed. It is important to recognize the fan curve is based on laboratory acquired data.

### Pump Drive Options

While direct drive of the pump is preferred, it is not always possible because of vehicle space or mounting pad availability. When belt-driving a pump, it is important to consider the impact of external side load on pump shaft bearing life, and how these side loads can be minimized, and how pump life can be optimized.

### Fluid Selection and Cleanliness

For optimum system life, proper fluid selection, maintenance, and system cleanliness are critical. Eaton fluid recommendations are detailed in Eaton Technical Bulletin 3-401.

## System Cooling Power Requirements

### Engine Heat Rejection

This value is typically identified in the engine specification documentation to serve as an application reference point. However, each vehicle system and duty cycle will have specific cooling requirements.

## Selection of Radiators & Hydraulic Coolers

Proper sizing of cooling elements must take into account engine data as well as installation characteristics. The following data is typically required by a radiator manufacturer in order to size a product for a specific application.

Heat load rejected to coolant - expressed in "British thermal units per minute" or BTU/min. This data is found in the engine application data sheet and relates to the engine heat dissipated to the engine cooling fluid (coolant).

Coolant fluid flow - expressed in "gallons per minute" or "liters per minute." This data is also found in the engine application data sheet and relates to the flow rate of fluid through the engine's cooling circuit (sometimes referred to "jacket water circuit").

Coolant fluid type - expressed as a percentage of water and another solution. Typically a mixture of 50% Ethylene Glycol (E.G.) and 50% water, but sometimes found in different ratios.

Top tank temperature - expressed in degrees Fahrenheit or Celsius. This is the desired maximum coolant temperature exiting the engine (or entering the radiator). This temperature is specified by the engine manufacturer in the engine data sheets.

## Fan Selection Criteria and Critical Performance Factors

Knowing fan motor options and their capabilities/limits is important when making the fan selection to insure some flexibility in motor selection.

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## Hydraulic Motor Selection

Key inputs to the motor selection are the maximum fan speed requirement, maximum fan power requirement, maximum system pressure and motor efficiency. Different motor design types will have varying speed limits. The chosen maximum system pressure will have a direct impact on motor displacement selection and will ultimately impact the pump and fluid conveyance material selections.

### Sizing the Motor

Required Input:

$N_{m,max}$  – maximum required fan speed (rpm)

$W_{max}$  – Corresponding maximum motor output power level (HP or kW)

$P_{set,max}$  – Maximum pump pressure setting (psi or bar)

$E_m$  – Total efficiency of motor (e.g. .92)

From this information the displacement of the motor can be determined by the following equation:

$$D_m \geq \{W_{max} / (N_{m,max} \cdot P_{set,max})\} \cdot \{C_1 / E_m\}$$

Where

$D_m$  is motor displacement (in<sup>3</sup>/rev. or cc/rev.)

$C_1$  is a unit conversion factor

$C_1 = 396,000$  if values are in in<sup>3</sup>/rev, hp, rpm and psi

$C_1 = 600,000$  if values are in cc/rev, kW, rpm and bar

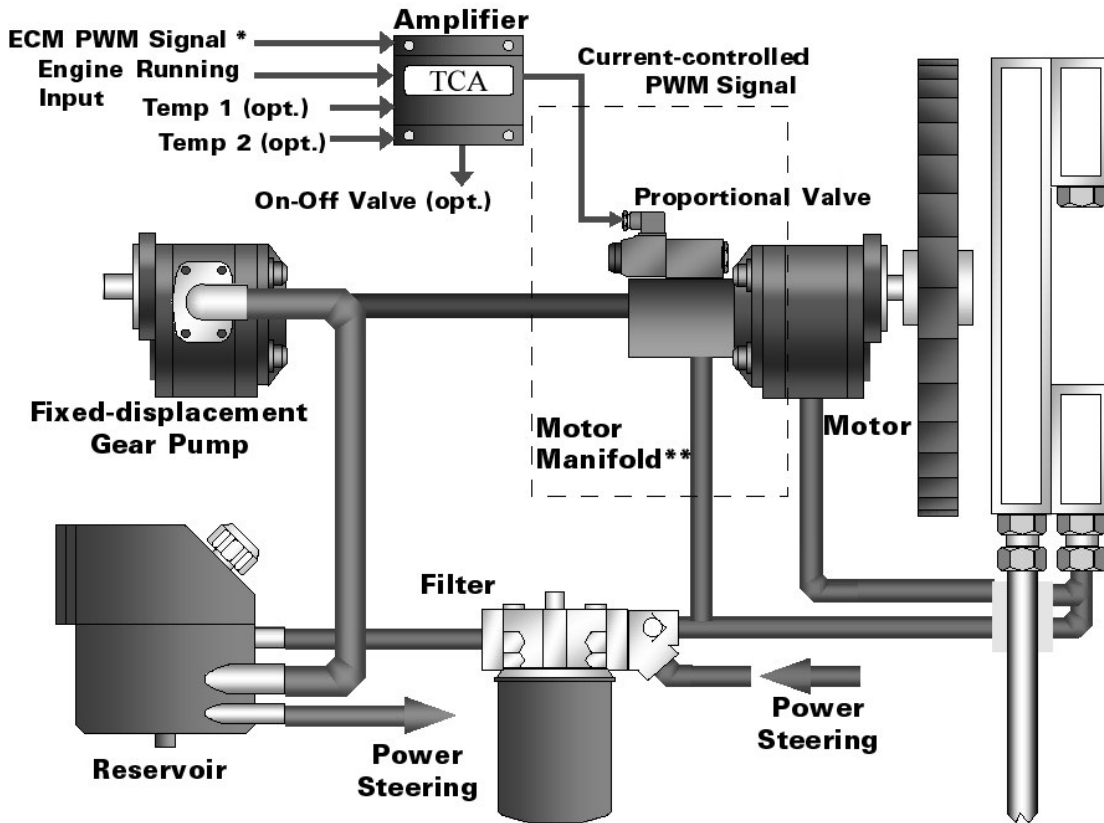


Figure 1. Fixed-displacement Pump System

\* May also be temperature, potentiometer, or other input signal, instead of ECM PWM signal.

\*\* See Manifold Design and Considerations on page 8

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**Motor Speed Check:** When the pump displacement is selected, the rated speed of the motor should be compared against the required speed of the fan. Maximum motor speed should not exceed motor rating.

If the maximum required fan speed is too high, investigate alternative series of motors, or investigate smaller displacement motors in conjunction with a higher pressure pump series.

## Hydraulic Pump Selection

The choice of a fixed-pump system (Figure 1) versus a variable-pump system (Figure 2) is typically a choice between system initial cost and system efficiency. A fixed-pump system is usually a

simpler, lower-cost system. A variable-pump system will generally have a higher initial cost, but offers ongoing energy savings and creates less system heat.

A variable-pump system reduces the pump displacement to match the flow needed for cooling, while a fixed-pump system puts excess flow to tank, creating heat and excess energy loss. Typically, fan systems below 10 HP will use fixed pumps, while systems above 20 HP will use variable pumps. Variable-pump systems are generally quieter. Other factors for this selection include pump space constraints and customer preference.

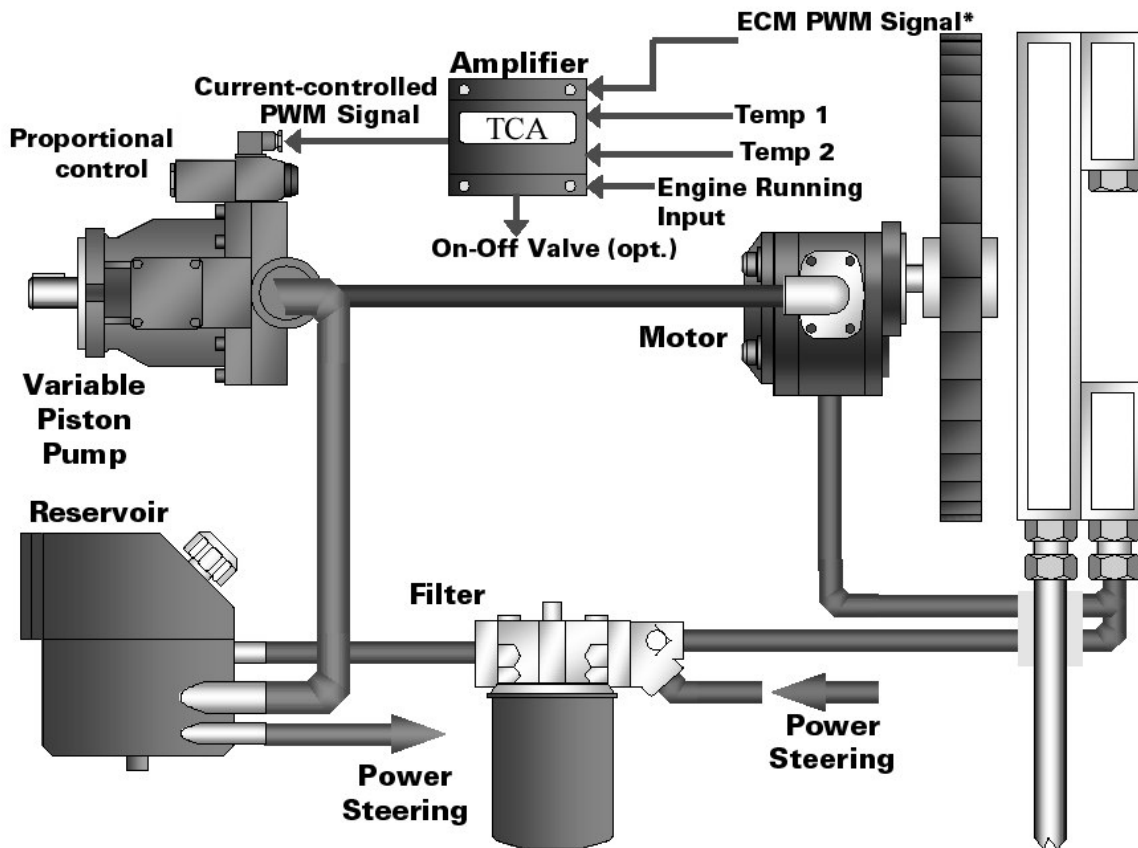


Figure 2. Variable-displacement Pump System

\* May also be temperature, potentiometer, or other input signal, instead of ECM PWM signal.

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## Determining Pump Displacement

Required Input:

$D_m$  – Motor Displacement (in<sup>3</sup>/rev. or cc/rev.)

$N_{m,max}$  – Maximum required motor speed (rpm)

$E_{m,v}$  – Volumetric efficiency of the motor (e.g. .87)

$E_{p,v}$  – Volumetric efficiency of the pump (e.g. .87)

$R_{gp}$  – Ratio of the pump to engine speed, (Gear or Pulley ratio)

$N_{e,req}$  – Minimum engine speed at which max cooling is required (rpm)

$$D_p \geq D_m \{N_{m,max} / (N_{e,req} \cdot R_{gp})\} / (E_{m,v} \cdot E_{p,v})$$

While the max power and speed condition is the first point to check, it is also necessary to check cooling levels at other engine speeds. For example, if a system requires 18 HP of cooling at a minimum engine speed of 1400 rpm, and 12 HP of cooling at a minimum engine speed of 800 rpm, it may be the lower speed which determines the size of the pump.

## Determining Maximum System Pressure

The required maximum system pressure is identified using the equation below. In a variable-pump system, the system pressure is limited by the pump control (pressure compensator). In a fixed-pump system, the system pressure is limited by the system relief valve. In either case, all components must be chosen such that the required maximum system pressure does not exceed individual component ratings.

Required Inputs:

$D_m$  – Motor Displacement (in<sup>3</sup>/rev or cc/rev)

$W_{max}$  – Maximum motor output power level at max-required speed (HP or kW)

$E_m$  – Total Efficiency of the motor (e.g. .80)

$N_{m,max}$  – Maximum Required Fan Speed (rpm)

$$P_{set} > \{W_{max} / (N_{m,max} \cdot D_m)\} \cdot \{C_t / E_m\}$$

## Shaft Side Load on the Pump

Direct drive of the pump is always preferred. When the pump is not direct-driven, the effects of the shaft side load should always be considered. Shaft side load directly affects bearing life. The effect on bearing life is the primary reason to minimize side load. Consult Product Engineering to calculate the effects of shaft side load. The following is important information to have available.

- Pump speed
- Pump maximum pressure
- Preferred pump orientation
- Belt tension on tight side (load & direction)
- Belt tension on loose side (load & direction)
- Identify automatic or manual belt-tensioning system
- Distance from pump mounting face to belt centerline
- Layout of the drive system, including pulley sizes

There are two basic types of belt-tensioning systems. The *manual tensioner* simply stretches the belt to a certain preload. Under a load, the belt will stretch even more, and all of the increased length will go to the slack side. This increased length on the slack side can cause belt slippage. For that reason, the belt preload for a *manual tensioner* will always be more than for an *automatic tensioner* on the same drive system.

An *automatic tensioner* uses a spring on the slack side of the belt to maintain slack-side belt tension and belt contact to the pulley. Because of this automatic adjusting under load, the belt preload can be much less, significantly decreasing the amount of shaft side load imposed by the belt-driven system.

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## Selecting Control System Schemes

Two methods of control are offered:

1. Interface the fan drive system to your engine control module to execute the cooling strategy exactly as directed by the engine control module.
2. Define your own cooling logic using up to three temperature sensor or other inputs that we implement with fan drive electronic control.

By adding electronics to an Eaton Hydraulic Fan Drive System, users can tailor the system to their needs. Fan drive control parameters can be tailored through a user-friendly graphical user interface (GUI).

The GUI walks the designer through the definition process with real-time graphical feedback to clearly indicate the system's response to each modification. System data can also be graphically monitored and saved to a database to verify actual results.

When the cooling logic is fully defined, resulting parameter are saved and used for exact system duplication for your production application.

## Electronic Controllers

Two different electronic controllers are used in fan drive applications. Both controllers can accept CANbus or RS232 signals, or operate in a 12V or 24V system. (Factory configurations)

The simpler controller, known as Two-Channel Amplifier (TCA), is a depopulated version of the more complex Maestro controller. With 4 configurable inputs and 2 PWM outputs, the TCA can interface with a variety of system components and drive up to 2 proportional valves. The TCA controller is fully potted and is specifically designed for mobile environments. The Maestro controller, on the other hand, can handle up to 10 inputs and 4 PWM outputs. The Maestro has been designed for in-cab mounting location.

## Fan Drive Controller Application Guide

Controller choice help you optimize a fan drive system for your application. The table below lists potential applications for both the TCA and Maestro electronic controllers.

The TCA controller is generally used in on-highway vehicles; the Maestro controller, with its additional features, is used primarily on off-highway vehicles.

APPLICATION	TCA	MAESTRO
Buses	X	
Recreational Vehicles	X	
Specialty Vehicles	X	
Wheel Loaders	X	X
Dump Trucks	X	X
Combines	X	X
Large Tractors	X	X

## TCA and Maestro controller benefits include:

- Accepts signals from engine control module (ECM) or temperature sensor inputs
- Conditions ECM cooling signal
  - Filters signal noise
  - Inverts signal
  - Re-scales signal to optimize control
- Smoothly ramps between user-defined fan speed settings
- Provides minimum fan speed on start-up
- Provides zero-speed or minimum-speed setting
- Delivers maximum fan speed when control signal is missing

## TCA controller benefits include:

- Encapsulated construction allows installation in more exposed locations on the vehicle

## Additional optional benefits of the Maestro controller:

- Additional I/O
- I/O may communicate with CANbus
- Provides reverse flow option to reverse fan direction
- Indicates need for filter change
- Determines level of oil in reservoir tank
- Provides zero-speed and minimum speed settings
- Provides closed-loop control of fan with speed sensor input

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## Special System Considerations

### Anti Cavitation Check Valve

Due to the direct connection between the motor and pump, it is possible for the line between the motor and pump to cavitate. For example, if the flow coming out of the pump, which is proportional to engine speed, decreases at a rate faster than the flow being used by the motor, the inlet to the motor will cavitate. The main factors controlling whether this will occur are the rate of engine deceleration, the inertia of the motor/fan and the drag on the motor/fan. As a general hydraulic practice, Eaton Engineering recommends the use of an anti-cavitation check valve to reduce the possibility of cavitation in the circuit.

### Internal Case Drain

Since flow and pressure are proportional in a typical fan drive circuit, it is unlikely there will be instances of high pressure and low flow. This makes it feasible to internally drain pump without significantly increasing the pump temperature since during conditions of large hydraulic losses (high pressure) there is also large heat removal (high flow). Internally drained pumps do not have external connections to the drain, but rather direct the case flow back to the inlet.

While this practice saves on external plumbing required for the pump, it can make it difficult to remove air from the case, both during start up and normal operation. It also recycles flow, and therefore heat and built in contamination, through the rotating group rather than going to the filter or heat exchanger. The use of an external case drain is highly recommended by Eaton Hydraulics Engineering.

### Manifold Design and Considerations

Valve manifolds can be a major part of a fan drive system. The valve manifold is essential in a fixed-displacement pump system and is optional in a variable-displacement pump system.

For fixed-displacement pump systems, the manifold generally contains the proportional valve and bypass valve. These valves can be replaced with a single pilot-operated valve. The minimum fan speed can be regulated by limiting the maximum current or by the minimum pressure drop through the valve.

For variable-displacement pump systems, the proportional valve is usually integrated into the pump control. A separate manifold is not necessary unless other functions are required.

The valve manifold can also include:

- Priority flow for steering
- Reversing valve to reverse fan rotation
- Anti-cavitation valve
- Zero-fan-speed feature
- Relief valves (e.g. main relief valve or steering relief valve)

For fixed-displacement pump systems, the preferred manifold location is as an integral part of the fan motor. This method allows the manifold to serve also as the motor end cover and reduces the amount of hydraulic hoses and connections needed. This gives the most compact installation and, typically, is the least costly.

Sometimes space considerations require the valve manifold to be remotely located. This is totally acceptable, but adds complexity to the hydraulic lines.

### Interaction with Other Systems

In vehicles that have hydraulics systems other than the fan drive, it is not uncommon to have interaction between these systems. This interaction can range from sharing the same hydraulic reservoir and filter, to having the fan drive pump being an auxiliary pump to drive these systems when needed. It is important to understand all of the possible interactions the fan drive system could have with other systems, especially any steering or braking systems.

Typical questions would be as follows

- What system would run out of fluid first if there was a leak?
- Would the system ever have to operate in a high pressure, low flow condition which may be marginally stable?
- Could there be any sudden or severe environmental pressure changes the fan drive system was not designed for?

### External Contamination

A common problem with belt-driven pumps is shaft seal leakage due to seal damage from foreign material. Pump installations where the shaft seal is exposed to a harsh environment may require a dust shield.

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