Fan Drives in Mobile Hydraulic Applications

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Fan Drives in Mobile Hydraulic Applications

- Introduction
- Cooling System Overview
- Power Sources
- Heat Sources
- Cooling Sources
- Fan Operation
- Fan Drive Systems Overview
- Hydraulic Fan Drive Systems and Capabilities
- Advanced Hydraulic Systems
Why would I want to use a fan in my mobile machine?

- **Operator Climate Control**
  - Heating, cooling, filtering, positive pressure cabs

- **Useful machine work**
  - Venting, Drying, Cleaning

- **Removing Waste Heat**
Why do we need fan drives for cooling?

100% fuel energy

35% heat exhaust pipe

35% heat engine cooling and accessory

30% mechanical power at engine flywheel

mechanical power for useful, productive, work

10%-25%
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Introduction

- Turbo Charge Air
- Hydraulic Fluid
- Engine Water Jacket
- AC Refrigerant
- Transmission Fluid
- Power Electronics
- EGR Gases

Ambient Air
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Fan Operation

\[ T_2 = T_1 \times k \times \left( \frac{n_2}{n_1} \right)^2 \]

\[ P_2 = P_1 \times k \times \left( \frac{n_2}{n_1} \right)^3 \]
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Fan Operation

\[ P_2 = P_1 * k * \left( \frac{n_2}{n_1} \right)^3 \]

**Fan Power vs. Fan Speed**
(for a fan designed at 3000 rpm and 10 hp)

<table>
<thead>
<tr>
<th>Fan Speed [rpm]</th>
<th>Fan Power [hp]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2700</td>
<td>7.29</td>
</tr>
<tr>
<td>3000</td>
<td>10</td>
</tr>
<tr>
<td>3300</td>
<td>13.31</td>
</tr>
</tbody>
</table>
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Fixed Ratio Mechanical Fan Drive Operation
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Fan Power vs. Fan Speed

Belts are efficient, why change?

Fan Power Law = \( K \times (\text{engine speed})^3 \)

Overcooling = Power Wasted
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Fixed Ratio Mechanical Fan Drive Operation
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Break free from the fixed ratio!

Fan speed control independent of engine speed and proportional to cooling requirement!!!
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Fan Operation vs. Engine Speed

Fan curves vs engine speed, trimmed ideal situation

- Fan speed \( \sim n \)
- Fan speed \( \sim n^2 \)
- Fan speed \( \sim n^3 \)

Engine Speed [rpm]

Pressure [bar]; Power [kW]

- Fan speed untrimmed
- Fan speed (trimmed)
- Pressure untrimmed
- Fan motor pressure
- Fan power x 10
- Fan power untrimmed x 10

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So what if I save power on this fan drive system?

• Fan system is not producing useful work (parasitic loss)
• Saving power on cooling leaves more power for useful work
• Saving power on cooling saves fuel and reduces operating cost
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Power and Energy Savings

- 200 hp machine
- 30 hp fan (15% of Engine Power)
- Fuel Cost: $3.50/gal
- Specific fuel consumption .3518 lb./hp-hr
- 7.3 lb/gal of diesel fuel
- Operating days/year: 180 days/year
- Operating hours/day: 8 hours/day
- 10% decrease in average fan speed (33.1% power savings)
- 9.93 hp saved on average

\[
\frac{.3518 \text{ lb}}{\text{hp-hr}} \times \frac{9.93 \text{ hp}}{1} \times \frac{8 \text{ hr}}{\text{day}} \times \frac{180 \text{ day}}{\text{year}} \times \frac{\text{gal}}{7.3 \text{ lb}} \times \frac{$3.50}{\text{gal}} = $2412 / \text{yr}
\]
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Fan Power as a Function of Temperature

\[
\frac{T_{\text{Coolant}} - T_{\text{ActualAmb}}}{T_{\text{Coolant}} - T_{\text{MaxAmbient}}} = \text{Cooling Effectiveness}
\]

\[
P_{\text{Fan}} = \frac{P_{\text{Fan}_{\text{max}}}}{(\text{Cooling Effectiveness})^3}
\]

Fan Power as a Function of Ambient Temperature

@ Vehicle Maximum Heat Rejection

105°F (42°C) takes 60% of Full Power
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Fan Noise vs. Fan Speed

\[ L_{w_c} = L_{w_b} + (50) \log_{10} \left( \frac{N_c}{N_b} \right) \]

15% Increase in Fan Speed

\[ L_{w_c} = L_{w_b} + (50) \log_{10} \left( \frac{1.15}{1} \right) \]

\[ L_{w_c} = L_{w_b} + 3dB \]

3dB Increase in Fan Noise doubles the noise level to the human ear

European Noise Legislation:

DIRECTIVE 2000/14/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 8 May 2000
of 14 December 2005
amending Directive 2000/14/EC on the approximation of the laws of the Member States relating to the
to the noise emission in the environment by equipment for use outdoors

(c) Fan drive with continuous variable speed

If the fan can work at continuous variable speed, the test shall be carried out either according to 2.1(b) or
with the fan speed set by the manufacturer at no less than 70% of the maximum speed.
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Noise Legislation

OSHA Noise Exposure Limits:

<table>
<thead>
<tr>
<th>Sound Level (dBA)</th>
<th>Exposure Limit (hours/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>8</td>
</tr>
<tr>
<td>92</td>
<td>6</td>
</tr>
<tr>
<td>95</td>
<td>4</td>
</tr>
<tr>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
</tr>
</tbody>
</table>

* Employee notifications are required for environments with sound levels greater than 85 dBA
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Noise Legislation

![Graph: Sound Power Level Change as a Function of Fan Speed Change](image-url)

- Change in Fan Speed, (%)
- Change in Sound Power Level, (%)
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Proportional Fan Drive Types

• Mechanical Continuously Variable Transmissions
• Viscous Clutch Drives
• Electric Generator/Motor Drives
• Variable Pitch Fan Blades

• Hydraulic Fan Drive Systems
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Hydraulic System Advantages

- Compliments other hydraulic machine functions
  - Propel
  - Work function
- Flexible connections allow for optimal cooler location
- Reversing is an option
- Fan off function
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Basic Hydraulic Fan Drive System
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Speed to Pressure Relationship

- Follows the fan torque curve
  - Motor pressure differential increases with the square of fan speed (ideal)
  - By controlling pressure difference across the motor, fan speed can be controlled

![Ideal Motor Pressure vs. Fan Speed](chart.png)

(for a fan designed at 3000 rpm and 2500psi)
What happens when the control system fails?
The system must default to a full fan speed state.
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Fixed Pump Fixed Motor System

Up to 35 hp
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Variable Pump Fixed Motor System

10 to 50 hp
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Over Center Pump Fixed Motor System

30 hp and up
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Reversing Function

• **Why would I use a reversing fan?**
  - Agricultural, Construction, Forestry
  - Removes contamination to operate cooler at highest efficiency
  - Reduce manual blowout frequency
  - Remove washout water from radiator without getting into machine
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Fixed Pump Fixed Motor Reversing System
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Variable Pump Fixed Motor Reversing System
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Distributed Cooling

Engine Coolant
EGR

Hydraulics
Transmission

A/C
CAC
Power Electronics

Divide and Conquer!!
• Benefits:
  - Locate coolers closer to their heat sources
  - Smaller coolers can fit in tighter places
  - Each cooler can be cooled according to its need
    • Prevents overcooling of individual cooling systems
    • Better thermal control of individual systems
# Hydraulic Distributed Cooling Systems

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>CAC</td>
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<tr>
<td>Radiator</td>
<td>Radiator</td>
<td>Radiator</td>
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<tr>
<td>Oil Cooler</td>
<td>Oil Cooler</td>
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<tr>
<td><strong>Dimensions</strong></td>
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<tr>
<td>43”</td>
<td>50”</td>
<td>30”</td>
<td>16”</td>
</tr>
<tr>
<td>27”</td>
<td>27”</td>
<td>30”</td>
<td></td>
</tr>
<tr>
<td>21 cc</td>
<td>14 cc</td>
<td>11 cc</td>
<td>8 cc</td>
</tr>
<tr>
<td>Fan Power</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>12.5 HP Max</td>
<td>23 HP Max</td>
<td>9.6 HP Max</td>
<td>1.3 HP Max</td>
</tr>
<tr>
<td>3.4 HP Avg</td>
<td>6.3 HP Avg</td>
<td>2.6 HP Avg</td>
<td>0.3 HP Avg</td>
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<tr>
<td>Power From engine</td>
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<td></td>
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</tr>
<tr>
<td>22 HP Max</td>
<td>42 HP Max</td>
<td>17.5 HP Max</td>
<td>2.5 HP Max</td>
</tr>
<tr>
<td>8.1 HP Avg.</td>
<td>15.9 HP Avg</td>
<td>6.8 HP Avg</td>
<td>1.0 HP Avg</td>
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<tr>
<td></td>
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<td>delta 22 HP</td>
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<td>20 HP</td>
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<td>delta 8.1 HP</td>
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<tr>
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<td>7.8 HP</td>
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Thank You

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