

Thermal Modeling of Power Steering System Performance

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ABSTRACT

Power steering systems provide significant design challenges. They are detrimental to fuel economy since most require the continuous operation of a hydraulic pump. This generates heat that must be dissipated by fluid lines and heat exchangers. This paper presents a simple one-dimensional transient model for power steering components. The model accounts for the pump power, heat dissipation from fluid lines, the power steering cooler, and the influence of radiation heat from exhaust system components. The paper also shows how to use a transient thermal model of the entire system to simulate the temperatures during cyclic operation of the system. The implications to design, drive cycle simulation, and selection of components are highlighted.

INTRODUCTION

Recent changes in Federal test procedures for emissions and fuel economy have focused attention on the energy consumed by automotive systems previously neglected due to the cost of alternative configurations. Now we need models of many minor systems in order to predict fuel economy and support design efforts. One such system that has received little attention is the power steering. Existing analyses have dealt primarily with the mechanical or hydraulic aspects of the system [1,2,3]. A few have described alternative designs to reduce energy consumption [4,5], but none have dealt with the thermal modeling and the effects of various configurations on component temperatures.

A thermal model can be a valuable tool in at least three ways. First, thermal information can assist in the selection of a power steering cooler and in the evaluation of hydraulic line locations. If, for example, lines can be located so as to minimize exposure to hot exhaust components and maximize exposure to areas of high airflow, a power steering cooler may be eliminated or reduced in size.

Secondly, a thermal analysis can be used to show the temperature effects of an electric powered pump or a

variable displacement pump or a speed limiting clutch design. If these result in less heat dissipation, then the cost of a more sophisticated pump may be offset by the elimination of a heat exchanger. Finally, a transient analysis can show how thermal inertia of the components influences the temperatures.

The model described here is modular and is organized such that components and configurations can be changed easily. We also discuss areas where additional information is required in order to support the model. In particular, local air flows and air temperatures are not items generally available.

COMPONENTS

For this analysis, we consider the power steering system to consist of the pump, steering gear, heat exchanger, and return fluid reservoir. These are connected with either a plain steel high-pressure line or rubber hose. The rubber hose may be plain or covered with either a simple braided anti-abrasion sleeve or a reflective covered fiberglass sleeve. There are several different types of hose used in various combinations in a typical system

For purposes of this thermal analysis, we do not consider the piston/cylinder assembly. This is because this unit does not provide significant cooling even when in operation. When considering the "worst case" thermal design condition, we must disregard any cooling by the piston/cylinder. Thus we do not include it in the thermal circuit.

COMPONENT MODELS

There are 3 basic component models and one heat exchanger model. Stringing these elements together creates a power steering system model.

For each element, we write a lumped transient energy balance in which the temperature of the solid material in contact with the hydraulic fluid is at the same temperature as the fluid. This is because the thermal resistance due to convection between the oil and the

bounding solid is much less than that between the solid and the surrounding air.

Figure (1) shows that the convection coefficient inside a 1.9 cm diameter tube flowing power steering fluid. Even at low temperatures and flow rates, the inside convection coefficient is 10 times higher than that typical of airflow over the outside. Thus the major thermal resistance is not between the oil and the tube wall.

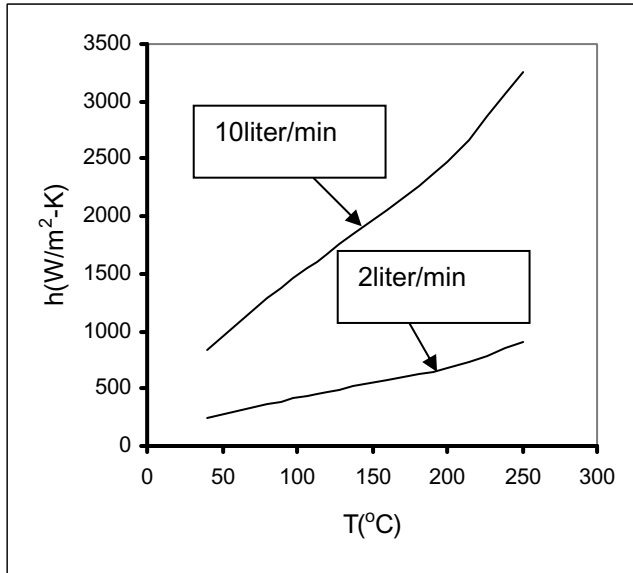


FIG. 1: Forced Convection Coefficient For Flow Inside a 1.9 cm Diameter Tube

This means that, for a length of steel pipe, the fluid plus the pipe may be treated as one lumped thermal mass with the fluid exiting at a temperature equal to that of the thermal mass.

The first basic element is a generalized lumped mass with fluid flowing through it. This element models the pump, steering gear, a length of bare steel pipe, and the reservoir. We treat the entire element and the fluid inside as being at the same temperature, T , at any instant of time.

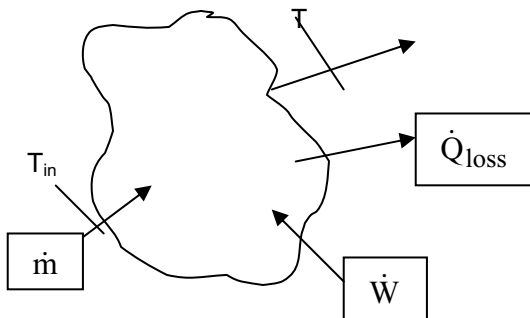


FIG. 2: Energy Flows for General Element

The transient thermal model for this element is:

$$C \frac{dT}{dt} = \dot{m} c_p [T_{in} - T] + \dot{W} - \dot{Q}_{loss} \quad (1)$$

where:

C is the thermal capacity of the element (mass times specific heat)

$\dot{m}$ is the rate of flow of oil through the element

c_p is the oil specific heat

T_{in} is the temperature of the oil entering the element (which is the temperature of the oil leaving the preceding element)

$\dot{W}$ is the energy input by shaft work (applicable to the pump only)

$\dot{Q}_{loss}$ is the heat loss from the element to the surroundings

The next element is a rubber hose or rubber hose with a cover. We model this using two nodes, the inner node being the fluid and part of the hose and the outer node being the rest of the hose plus cover.

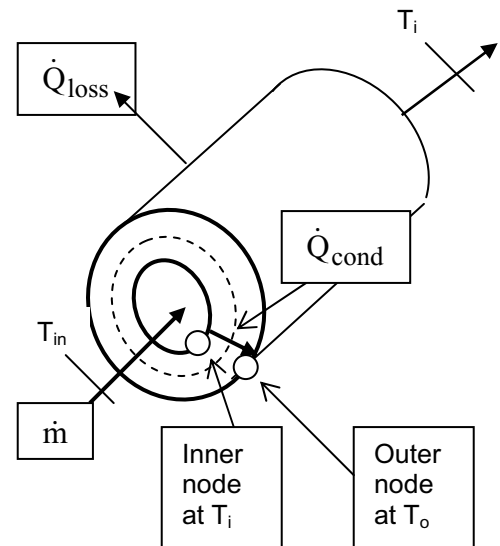


FIG. 3: Two-node Element for Hoses

For the inner node at T_i , conservation of energy is:

$$C_i \frac{dT_i}{dt} = \dot{m} c_p [T_{in} - T_i] - \dot{Q}_{cond} \quad (2)$$

And for the outer node:

$$C_o \frac{dT_o}{dt} = \dot{Q}_{cond} - \dot{Q}_{loss} \quad (3)$$

where C_i , C_o are the thermal capacities of the nodes

$\dot{Q}_{cond}$ is the radial heat flow by conduction

$\dot{Q}_{loss}$ is the heat loss from the outer node to the surroundings