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Use of Electronic Viscous Drive to decrease Fan duty cycle

Dhiraj Ramdas, S.P.Pachpute

Department Of Mechanical Engineering, D Y Patil College Of Engineering, Akurdi, Savitribai Phule Pune University,Pune-411041.

Abstract

The Viscous Fan drive is part of the primary cooling module in commercial vehicle. Recently with many studies and researches on mechanically actuated viscous fan drives has led for the cooling optimization. However, there is very limited research on the electronically actuated viscous fan drive to achieve constant temperature of cooling. Standard ROA test along with Vector Tool is used to understand the effect of electronically operated viscous fan drive. This study demonstrates that with use of electronic Viscous Fan Drive the fan duty cycle changes with change in control of coolant temperature. With Physical trail the most optimized control points are derived and analyzed for saving in fan duty cycle.

Keywords: *Fan Duty Cycle, Electronic Viscous Fan Drive.*

1. Introduction

A torque limited fan clutch/drive is based on the principle of torque transmitter wherein the torque from driver to the driven is transmitted with help of viscous fluids. The two type of actuation currently available are air temperature sensing and coolant temperature sensing. In air temperature sensing fan drives (mechanical), a bimetallic plate in front of fan drive senses the air temperature exiting the radiator and opens a control port inside the fan clutch. In coolant temperature sensing fan drive(electronic), the bi-metallic strip is replaced by either a solenoid actuated valve. We are trying to find the benefit of electronic fan drives in terms of fan energy consumption, with help of a feedback sensor/logic resulting in varying fan output speed as per the cooling required.

The ever tightening emission limits and constant pressure for increasing engine power are resulting in increased engine operating temperature. This coupled with continuous drive for fuel economy improvement because of the stiff competition are forcing OEMs to explore alternative cooling solutions resulting in less power take off and quick response as cooling requirement shoots up.

The fan drives or fan clutches are present in market since last few decades. Mechanically driven radiator cooling fan, generally located between radiator and engine and is driven by a belt and pulley connected to the engine's crankshaft. When the engine is cool or even at normal operating temperature, the fan clutch partially disengages the fan drive from engine. This saves power, since the engine does not have to fully drive the fan. However, if engine temperature rises above the clutch's engagement temperature setting, the fan becomes fully engaged, thus drawing a higher volume of ambient air through the vehicle's radiator, which in turn serves to maintain or lower the engine coolant temperature to an acceptable level. Mechanical fans are most common in trucks and suv, and some rwd cars. This is easier to accomplish because the engine is mounted longitudinally, with the belt accessory components mounted facing the radiator. The fan is mounted on the crankshaft pulley or one of the accessory pulleys (e.g. the water pump pulley) and will spin in between the radiator and the engine, drawing air back through the radiator and blowing it over the engine. Even though the air has been heated by passing through the radiator, it is still much less hot than the engine surface, so the airflow over the engine helps with cooling.

2. Working Principle

The basic components of fan clutches are shown in below Fig.1 rotor fixed to the input shaft of the device, sits inside the chamber within the housing, which rotates on bearings around the input shaft. The chamber is filled with silicone fluid/viscous fluid, which transmits torque from the rotor to the housing, onto which the fan is bolted.

In air temperature sensing fan drives, a bimetallic plate in front of fan drive senses the air temperature exiting the radiator and opens a control port inside the fan clutch. Fluid flows from the reservoir into the drive chamber thus increasing the fan speed.

The pictorial representation of the mechanical fan drive is explained in Fig.2. The oil couples the housing and the primary disk and thus rotating the fan with respect to input shaft speed.

In coolant temperature sensing fan drive, the bi-metallic strip is replaced by either a solenoid actuated valve or a proportional valve.

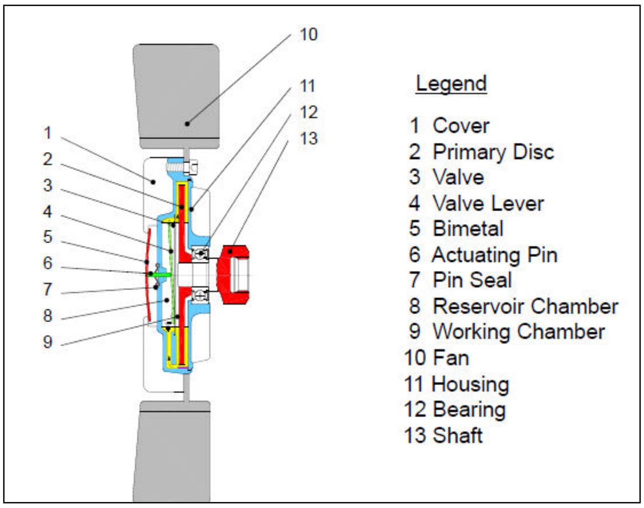

Fig.1 Mechanically actuated fan – disengaged

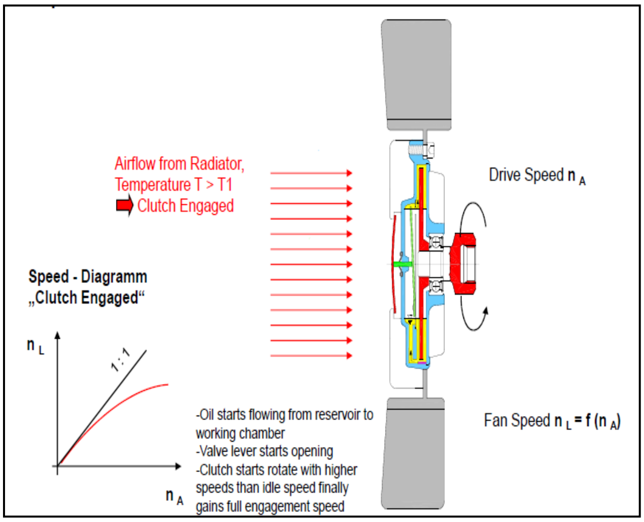

Fig.2 Mechanically actuated fan – engaged

3. Problem Statement

It air sensing fan drives could not fully control the fan speed in proportional behavior according to engine operating temperature. This results in excess fan power consumption and inconsistent rate of heat transfer from coolant. To answer to this problem, Electronic actuators are required in fan drive systems, which can sense the coolant temperature directly and control the Fan speed.

4. Literature Review

de Souza Filho[1], describes that the embedded electronic has been used to add intelligence to a purely mechanical systems to aide reduction of fuel consumption which is one of the major concerns of automotive engineering. Few factors affecting FE identified are type of engine used, quality of fuel, vehicle load, gear shifting, driver's usage of vehicle and the cooling system technology available. The current definition of fan in cooling system utilizes portion of engine power to run, thus, influencing the fuel consumption and contributing to NVH level of vehicle, which is critical to passengers' comfort. Another alternative suggested is the use of electric fans that can so as to increase the heat exchange in defined areas of radiator, along with reduction in noise and run time. Study based on comparison between electrically operated fans and mechanical viscous fan clutch shows the benefits on FE and fan power consumption of electrically controlled system over mechanical ones.

Xu.Z, Johnson.J[2], based on computer aided cooling system in automotive cites that a set of control functions for computer controlled diesel cooling system, using the vehicle engine cooling system code. Engine operating conditions such as the engine load, engine speed, and ambient temperature are considered as the controlling variables in the control systems. Comparison simulation tests between the conventional cooling system and the computer controlled cooling system on a defined commercial vehicle and cooling system, using the vehicle-engine-cooling control system model under different ambient and route conditions show that the computer controlled cooling system would offers increase of coolant, oil and engine body temperature at low ambient temperature, and with light load conditions helps in increasing engine thermal efficiency. It helps in keeping higher oil temperature at low ambient temperature. Thus during cold start, engine inner parts temperature rises faster resulting in reduced engine wear. The varying oil temperature under variable load conditions reduces the thermal stresses in the engine wall. Faster fan engagement at higher ambient temperature and heavier load conditions reduces energy consumed by the fan. The validation of these simulation results with a computer controlled engine cooling system is discussed in detailed in their published papers by researchers.

Lee.K, Lee.J[3] and others discusses on viscous fan clutch with continuous variable speed function for engine cooling system resulting in reduced cooling fan noise and improving the overall fuel efficiency of the engine. It is a known fact that operation of the engine cooling fan is one of the major sources for noise and vibration and power consumption in engine. With help of a continuous speed control fan drive clutch providing the required cooling air flow rate proportional to engine cooling load, it can result into decreased fan driving horsepower along with improvement in fan noise and vibration. The study published shows viscous fluid fan clutch, for small and medium diesel engines (less than 3.5 ton class), having a linear variable speed control function corresponding to cooling load and low temperature hysteresis has been developed. The results obtained tell that the proposed viscous fluid fan clutch can decrease the engine fan operational noise and vibration as well as the cooling fan driving horsepower significantly.

Blair.E[4] reiterate the desire for regulation of noise levels and power saving thus proposing to make fan drive mandatory for heavy truck applications. Their paper evaluates the reduction of power drain and fan noise for two types of fan drives generally available today: the on-off air-activated clutch and the modulated viscous drive. In addition, the principles of operation, life, and application considerations are discussed in depth in their paper.

Gangwar.H, Sharma.A, Pathak, S, Dwivedi, V[5] have analyzed the relative benefits of incorporating a new cooling fan drive system concept over conventional viscous fan driven cooling system with step-less variable speed control independent of engine speed variation. The hydraulic fan drive system controls fan rpm based on the fluid temperature as compared to air temperature in conventional viscous coupling fan drive system. HFD system results in prompt response when increase in coolant temperature is observed. HFD system provides more control on fan rpm. In this paper we are discussing about optimization of HFD system to achieve enhanced cooling system performance and also to increase fuel economy comparison

Kanefsky.P, Nelson.V, and Ranger.M[6]discusses the designing of engine cooling system based on fundamentals of system engineering from a systems engineering perspective. The researchers explain how the task of designing a complex system can be made easier by the application of systems engineering principles. Systems engineering provides three key benefits: It facilitates batter communication. Requirements define the problem thus allowing team members to see their own work in context. Key information is standardized and made easier to visualize and verify. An auditing is performed to ensure that important information is documented for making important decisions. They translate requirements into design. All requirements are specified in common terms and are consistent and linked from the customer to the vehicle all the way down to components. Also, the manufacturing and service issues are addressed up-front in the design process.

5. Objective

To decrease the fan duty cycle in viscous fan drives by use of electronic actuators (Solenoid).
To integrate this program in ECU of cooling system so as to ensure required cooling of power train.
The methodology to achieve this objective is to replace the bimetal with solenoid coil as shown in Fig.3 which is operated by the ECU. The ECU checks the current coolant temperature and the current fan speed which it receives from fan speed sensor in built in the fan drive itself. These values are then compared with the logic chart value and the correction value is then sent by the ECU in terms of voltage modulation to the solenoid valve. The solenoid valve then regulates the quantity of the viscous fluid to be present inside the working chamber for the desired fan speed. The corrected value is again cross-verified by the ECU by the feedback loop as shown in Fig.4 and again the cycle repeat still the coolant temperature stabilizes.

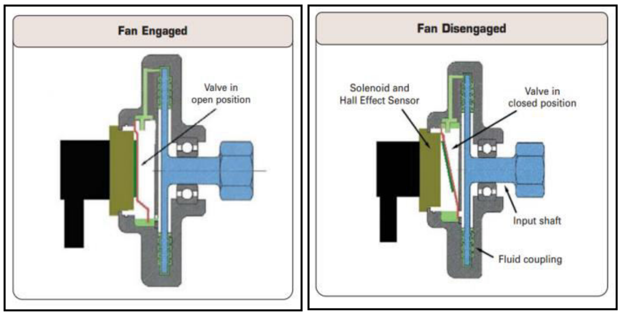

Fig.3 Experimental Setup – Electronic Fan Drive

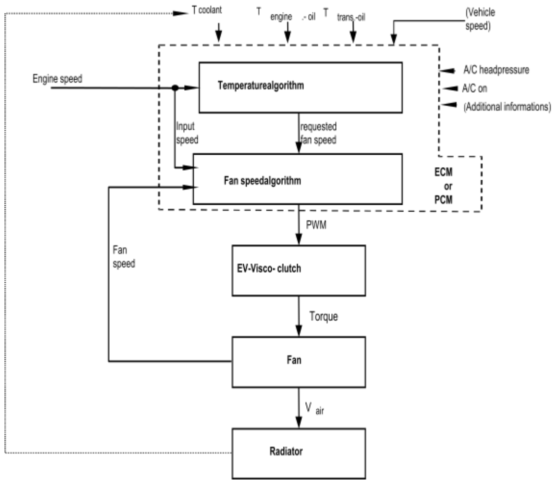

Fig.4 Experimental Setup – Control Logic

5.1 Governing Equations

1. Shaft Power = Power Consumption of the fan blade

   i. $P = M \times \omega$

   ii. $P = M \times 2 \times \pi \times n/60$

2. Aerodynamical power, $P = V \times \Delta Pstat$

3. Power , $P_2/P_1 = (n_2^3/n_1^3)$

   i.e, $Power \propto Fan\ RPM^3$

The values for fan power and mass flow rate are mainly derived from the fan curves plotted for various Fan RPMs in line with the defined cooling System.
A specific torque limit electronic viscous fan drive with fan of a specified diameter is primarily selected for the defined engine cooling system. The fan drive is selected based on the maximum fan torque generated at the max input shaft speed of the clutch. It should be duly noted that the fan drive should withstand the positive slip heat criteria resulted by the fan torque created. The inputs to the system as shown in the control logic are the coolant temperature measured by coolant sensor, engine rpm and fan rpm measured by hall effect sensor. The ECU of the vehicle reads the current measured temperature of c oolant and the engine and fan rpm. With increase in the loading condition of engine the engine rpm increases and the coolant temperature begins to rise. The increase in engine rpm invariably will accelerate the vehicle and there will be

increase in ram air through the front grill. The radiator thus exchanges heat with ambient at a faster rate. Thus, the scenario demands less Fan speed and the control logic sends bear minimum signals to the electronic viscous fan drive solenoid thus resulting in lower fan rpm. This saves he mechanical energy which otherwise would have spent. The logic takes a feedback signal and re-computes the fan speed required to fan speed actual and sends PWM signals to the solenoid of the fan.

The fan selected is determined through characteristic curves of its properties shown in Fig.5 at different running speed.

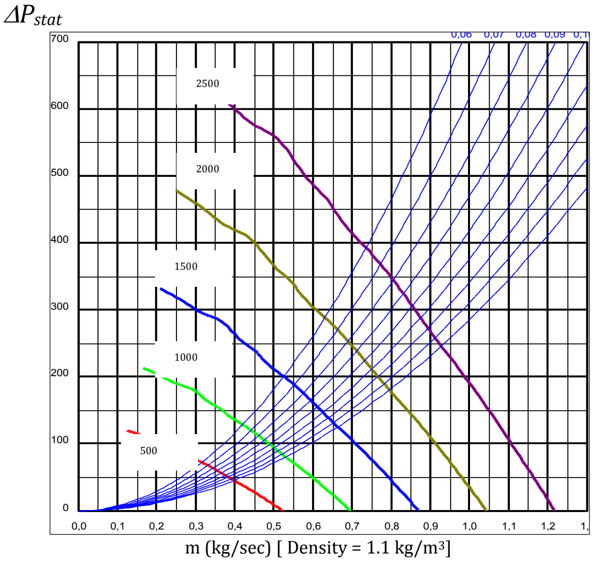

Fig.5 Fan Curves

6. Results

- On evaluating the behavior of the fan with respect to input signals, coolant temperature and drive speed it is duly noted that there is a drastic reduction in rpm of the fan with electronic viscous drive as compared to mechanical/bimetallic viscous drive. As shown in the Fig.7 the fan runs at lower rpm for most of the time and thus results in lesser consumption of fan energy.
- It is observed that the on doing back to back performance comparative study between mechanical viscous fan and electronic viscous fan, we see that in Fig.6 the coolant temperature is maintained between 86-92^{0}C in electronic viscous fan drive whereas in case of mechanical fan drive its 76-82^{0}C
- The fan runs in the rpm band of less than 1000 for more than 80% with electronic fan drive while in case of mechanical fan it runs between 1400-2000 rpm for more than 50% of time as described in Fig.7.
  - The time duration i.e. duty cycle of coolant running in temperature higher than 86^{0}C is about 60% in case of electronic while it is about 18% in mechanical.
  - Thus the energy consumed by fan for the entire run is computed as shown in Fig.8 and it is seen that there is 86% of reduction in fan power consumed with electronic fan drive with respect to mechanical fan drive.
- The data for fan duty cycle depict that the fan running is limited only during high cooling demand from the system. This reduces the fan power consumed by the power train

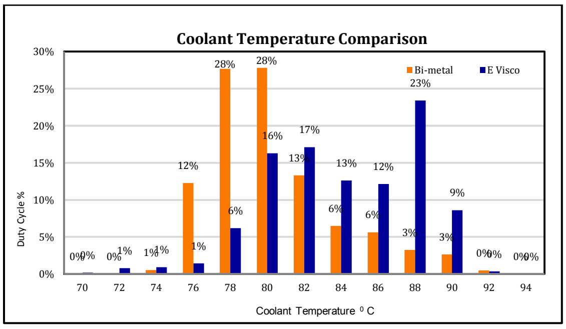

Fig.6 Coolant temperature comparison

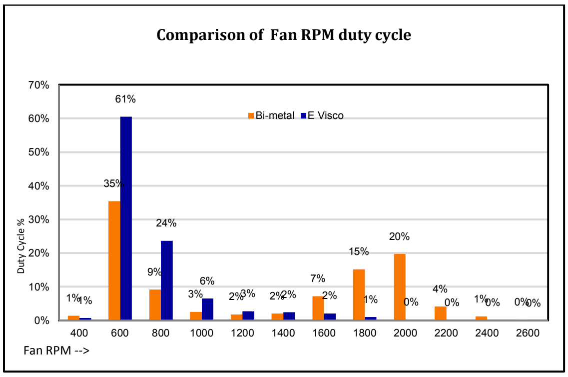

Fig.7 Fan Duty Cycle

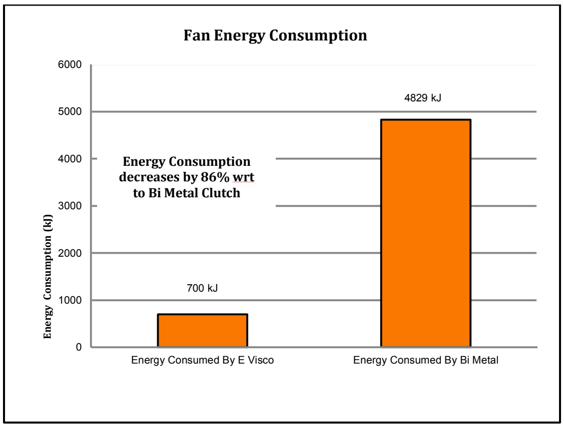

Fig.8 Fan Energy Consumption

7. Conclusions

The data shows the benefit of using the electronic viscous fan drive over mechanical/bimetal ones as it helps optimizing the fan speed. The resulting frugal running of fan so as to maintain the cooling load results in saving of fan power consumed. The fan runs only when there is demand from the ECU of the vehicle, i.e., when there is raise in coolant temperature. Based on these control points the fan drive is programmed to increase the fan rpm proportional to the rise in coolant temperature.

The control range defined should be the specified optimum range by the power train, and provision for immediate cooling during critical running conditions should be incorporated. Electronic viscous fan drive helps in maintaining the coolant temperature at desirable range as prescribed by the power train requirement. The continuously varying fan rpm helps maintain the coolant temperature and in return maintains the power train optimum running temperature. The configuration may be required to be tuned as per the combination of the Power Train to achieve maximum efficiency in fan power conservation.

8. References

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