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EXPERIMENTAL STUDY ON DIESEL ENGINE FITTED WITH VISCO FAN DRIVE

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Abstract: *The paper studies the performance increase of a heavy duty diesel engine when the cooling fan is driven discontinuously. A viscous fan was initially investigated on a dedicated fan bench in terms of air flow rates versus pressure loss, consumed power and efficiency. The viscous fan was tested further, being mounted on a turbocharged diesel engine with two types of coolant heat exchangers. The thermal behavior was analyzed using as indicator the engine thermal constant. The experiments confirmed the requirements for controlled drive of cooling fan in heavy duty vehicles.*

Key words: *diesel engine, cooling fan, variable speed drive.*

1. Introduction

The demand for energy efficiency and lower emissions in the transportation sector imposed to internal combustion engines power savings from their auxiliary systems.

As the cooling system is conventionally dimensioned based on the heat dissipation required at rated power, the direct-drive engine mounted fan systems consume an excess power which is not proportional to the heat flow rate required to be released, but to the engine speed.

For heavy duty vehicles, the drive of the cooling systems, mainly of the low pressure axial fans, could be substantially improved through the use of intermittent or variable-speed drives. These drives are decoupling the fan speed from the engine speed, the control of the fan drive being operated by the cooling fluid temperature. As a main result, the power consumed by the fan is considerably lowered [1], [2], [4]. The main gain can be expressed in fuel economy due to low thermal loads of the engine when it doesn't require the operation of the cooling fan - especially in mild operation modes such as starting, warming-up or partial loads - leading to fuel savings of up to 5% [2], or even 6-10% [1]. Other advantages are shorter periods of fan operation, which lead to lower noise and higher reliability.

The present paper describes the research work performed on a 5.5 liter diesel engine to fit a variable speed fan, in terms of fan and fan-drive performances. A prediction of energy saving along the engine lifespan is formulated, having as reference the direct-drive engine mounted fan solution.

2. Testing Procedures

The tested engine was a 798-05 type heavy duty, four-stroke, direct injection diesel engine, manufactured by Roman Truck Company, having in-line, vertical, six cylinder configuration, with its main parameters described in Table 1 [9].

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Two types of tests were performed on the facilities of Road Vehicle Institute (INAR Braşov) in order to find out the individual characteristics of the fan (section 2.1) and its behavior in the engine assembly (section 2.2).

Engine characteristics Table 1

Engine type	Diesel
Bore x Stroke [mm]	102 x112
Total displacement [l]	5.5
Compression ratio	17:1
Rated power [kW]	113
Rated speed [rpm]	2800
Maximum torque [N·m]	510
Maximum torque speed [rpm]	1800

2.1. Tested Fan Characteristics

The fan type was Eaton SNM 0461-3122396 with an outer diameter of 530 mm and 7 blades, 112 mm thick.

The coupling of the fan was visco type SNM 0679EV 17876 and it was mounted on the crankshaft pulley.

The fan drive contains silicone oil which has a variable capacity to transmit torque.

The control of the quantity of silicon oil entering the drive is done by a bi-metallic sensor which actuates a piston in function of the air temperature behind coolant radiator.

The visco fan was tested on a dedicated bench, being measured air speed, driven power, fan speed and pressure loss on the cooling heat exchanger.

The variation of air speed at different constant fan speeds (fan speed is equal to engine speed in direct drive) was done using in the air admission diffuser several obturator rings with different inner diameters.

The following tests were performed on the fan test bench [6]:

a) Air flow rate versus pressure loss, at constant speed;

b) Fan consumed power versus speed;

c) Fan efficiency.

The fan without drive was mounted on the fan test bench which has a variable speed d.c. motor, illustrated in Figure 1; two thirds of the fan width was introduced in the fan diffuser.

There were measured, based on section variation: the fan speed (with the bench tachometer), the air speed in a reference section of the diffuser (with anemometer and Pitot - Prandtl tube), the pressure loss (with the differential manometer), driving torque (with the bench dynamometer).

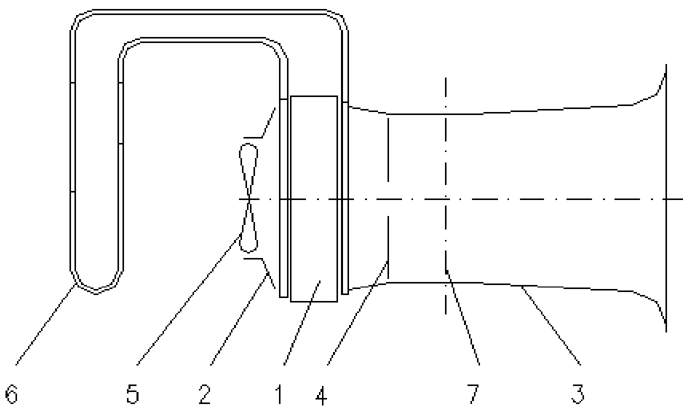

Fig. 1. *Fan bench layout: 1 - water radiator; 2 - fan diffuser; 3 - air admission diffuser; 4 – obturator; 5 - fan; 6 - differential manometer; 7 - air speed measuring section*

The data were processed, being calculated:

A. Fan air flow rate:

$$Q_{air} = S \cdot v_{air} \ \text{[m}^3\text{/s]}, \quad (1)$$

with v_{air} - mean air speed [m/s] and S - the section of the diffuser [m^2] where it was measured the mean air speed.

B. Fan absorbed power (from the d.c. motor):

$$P_{abs} = \frac{M \cdot n_f}{9550} \ \text{[kW]}, \quad (2)$$

with M - the torque [N·m] required for fan driving, and n_f - fan speed [rpm].

C. Useful power (released to the air by the fan):

$$P_u = \frac{Q_{air} \cdot \gamma \cdot h}{1000} \ \text{[kW]}, \quad (3)$$

with γ - specific weight of the fluid [N/m^3] and h - differential head.

D. Fan efficiency:

$$\eta = \frac{P_u}{P_{abs}}. \quad (4)$$

The fan characteristic is illustrated in Figure 2 - there were calculated and represented the curves of equal efficiency. The efficiency, η, is plotted in percentages and the speed, *n*, in rotations per minute.

The highest efficiency was 60%, being situated in the range of mean air flow rates (2-3 m^3/s) corresponding to moderate engine speeds (1500-2300 rpm) which have the highest operation frequency in the whole engine life span. The power consumed for the fan driving was

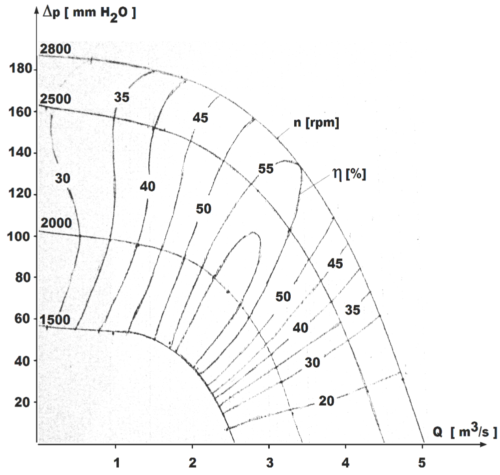

Fig. 2. *Curves of constant efficiency on visco fan characteristic* $h - Q_{air}$

measured on the fan test bench, at different speeds of the d. c. motor, being illustrated in Figure 3.

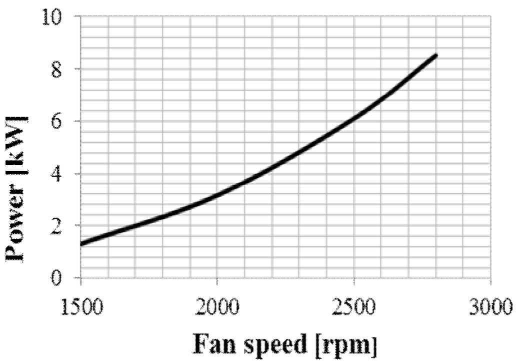

Fig. 3. *Fan drive power versus speed*

It has been noticed that the power consumed for driving the fan, *P*, varies with the fan speed, n_f, being numerically very close to the third power of fan speed, according to similarity laws of the turbo-machinery.

The power type regression applied to Figure 3 generated the Equation (5):

$$P = 4 \cdot 10^{-10} \cdot n_f^{\,2.9881}, \quad (5)$$

with *P* expressed in kW and n_f in rpm.

The correlation coefficient expressed through the R-squared value was 0.9999.

2.2. Fan-Radiator-Engine Assembly

Being known the fan performances, it is necessary to find out if the fan and its drive are suitable in the cooling system of the 798-05 engine. The engine has the fan mounted directly on the crankshaft, being fitted with two types of coolant heat exchangers, manufactured at the company Romradiatoare Braşov, with their main characteristics described in Table 2 [10].

Heat exchanger parameters Table 2

Heat exchanger	Type 732	Type 710
Thickness [mm]	50	82
Frontal area [m^2]	0.310	0.392
Total area [m^2]	20.7	34.8
Number of tubes	153	260
Number of tube rows	3	3
Capacity [l]	8.6	8.8
Mass [kg]	25.2	35.4

The accordance between fan-engine-radiator and the environment can be checked with a metric called engine thermal constant [5]. By definition, the thermal constant of a cooling system is the difference between coolant temperature at the outlet from the engine, $t_{w,o}$, and the mean air temperature at the inlet in the heat exchanger, $t_{a,i}$, according to the Equation:

$$K = t_{w,o} - t_{a,i} \, . \tag{6}$$

The 798-05 engine standard [9] stipulates that at stabilized rated load operation mode, the rate of heat released in coolant system must be of 0.82 kW for each kW of engine effective power; the coolant temperature should be maximum 85 °C. As a consequence, the thermal constant must be maximum 55 °C for temperate climate and maximum 40 °C for tropical climate.

The 798-05 engine was mounted on the eddy-current dynamometer and the visco fan was fixed with the coupling on the crankshaft pulley.

The measured parameters were air temperature at the inlet in the heat exchanger, $t_{a,i}$, air temperature at the outlet from the heat exchanger, $t_{a,o}$, coolant temperature at the outlet from the engine, $t_{w,o}$, engine speed, n_e and fan speed, n_f. The engine was adjusted for two ratings: at the rated power 113 kW / 2800 rpm and at 88 kW / 2500 rpm, using for each rating both types of heat exchanger. The results of the tests are summarized in Table 3 [7], [8].

The first tests at 113 kW / 2800 rpm indicated that the engine fitted with visco fan and type 732 heat exchanger with thermal constant 63 °C may operate only in relatively cold environments, with the maximum air temperature of 22 °C.

By replacing the 732 type heat exchanger with the 710 type which has a larger total area, the thermal constant reached the value of 50 °C, meaning that it can be operated in environments with the maximum ambient temperatures of 35 °C, being suited for temperate climate.

For the second power adjustment, 88 kW / 2500 rpm, similar calculations indicated that the maximum environmental temperature could be 30 °C when the type 732 heat exchanger was used and of 40 °C when the engine was cooled with the type 710 heat exchanger, thus indicating that both solutions are convenient for operation in temperate climate.

During the heating and cooling periods there were measured the air temperature downstream heat exchanger (using a bimetallic sensor mounted in the air flow) and the correspondent fan speed. The tests for heating and cooling were triplicated and the mean values were illustrated in Figure 4.

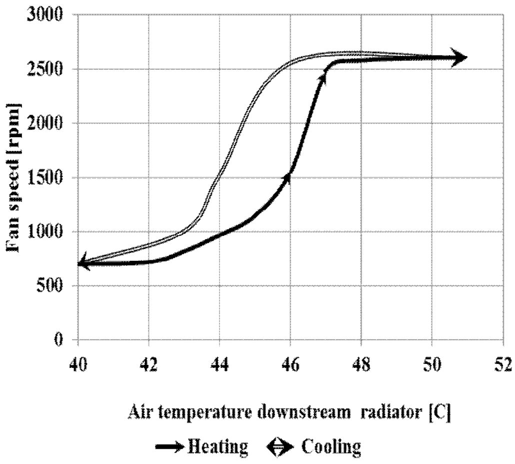

Fig. 4. *Fan speed versus air temperature*

The hydrostatic fan drive has a specific transmission law meaning the dependency between fan speed and cooling air temperature at the rated engine speed.

There is a temperature hysteresis in the heating mode compared to cooling mode due to thermal inertia of the engine, which can be appreciated to maximum 2 °C.

3. Energy Saving Potential

According to product standards, for each engine component is required a duty cycle and an expected life within the system which must include some relations between technical parameters and time shares from the lifespan.

For visco fans and drives that data are cooling power, fan speed, engine speed and percentages of time in operation at different load conditions [3].

In the case of 798-05 engine, the life span in the operation modes as starting, warming-up and warming up in cold weather, are evaluated at 5% [9]; the air temperatures at radiator outlet are low and the fan speed is 700 rpm.

That differentiated speed leads to significant power savings - as similarity fan laws say - due to power-speed law, which is a third power exponential.

When the fan idles at 700 rpm, 25% of the rated speed, it will only consume 1.56% from the rated fan power.

Numerical application is based on Figure 3; the highest consumed power was 8.53 kW and the correspondent consumed power at the speed of 700 rpm is just 0.133 kW, thus motivating around 5% power saving and fuel economy.

4. Conclusions

As a result of the tests performed with the visco fan - 7 blade, Ø530 - there may be concluded the following statements:

Comparing to actual series fan mounted on the truck engine, the visco fan has a speed independent of the engine speed, being controlled by the cooling requirements of the engine.

By fitting the appropriate radiator, the thermal constant meets the requirements of the engine, having a fair thermal operation mode in temperate climate.

The power savings are evaluated to be close to the literature values of 5% fuel and power economy.

Engine cooling test results Table 3

Engine power [kW]	n_e [rpm]	n_f [rpm]	$t_{w,o}$ [°C]	$t_{a,i}$ [°C]	$t_{a,o}$ [°C]	K [°C]	Heat exchanger
113	2800	2610	91	28	51	63	732
113	2800	2630	85	35	59	50	710
88	2500	2410	88	33	51	55	732
88	2500	2420	83	38	58	45	710

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