THE INFLUENCE OF THE EXHAUST PIPE LENGTH OVER THE BRAKING TORQUE PRODUCED BY A DIESEL ENGINE

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Abstract: *With the implementation of new technologies in the automotive industry, a significant decrease on their deceleration capacity was found, particularly in the case of heavy vehicles. A solution for the attenuation of this shortcoming is to use various auxiliary braking systems. Of these, the exhaust brake system is discussed in this article. The purpose of this paper is to analyze the braking torque obtained by changing the dimension of the primary exhaust manifold, between the body of the brake flap and the outlet port of a single-cylinder diesel engine. The study is performed by using a calculation code, previously developed by the authors in Mathcad environment [Manolache-Rusu, 2014]. The carried out simulations aim to optimize the efficiency of the exhaust brake process, in order to achieve a maximum braking torque to the drive shaft. From these simulations it was found that the value of mean braking torque per cycle is influenced by the length of the primary exhaust pipe and at the same time by the operating speed of the engine.*

Keywords: *exhaust brake, brake flap, mean braking torque, exhaust pipe length, deceleration capacity*

1. Introduction

The technical progress of the last period has led to an increase in the performance of road vehicles. On the other hand, their deceleration capacity considerable decreased, becoming necessary implementation of different auxiliary braking systems, especially at the heavy vehicles.

The design of the mechanical components of internal combustion engines is based on a series of functional parameters that improve the operating performance. By using auxiliary braking systems, it is intended to consume an important amount of displacement kinetic energy of the vehicle, as a result of obtaining a significant negative torque at the engine shaft. This qualitative parameter of internal combustion engines is influenced according to [Manolache-Rusu, 2018], [Aradhye, 2017], [Bawage, 2016] by the valve timing, exhaust valve head size, engine displacement, engine speed and last but not least the size of the exhaust manifold.

For normal combustion engine operation, the optimum dimensions of the primary exhaust pipe in order to achieve the maximum performance may be calculated with Eq. (1,2) from [Graham, 2006].

$$P = \left(850 \cdot \frac{180^{\circ} + \gamma}{n_p} - 3 \right) \quad [in] \qquad (1)$$

$$ID = \left[2.1 \cdot \sqrt{\frac{0.785 \cdot cc}{(P+3) \cdot 25}} \right] \quad [in] \qquad (2)$$

Where:

P – Length of the exhaust primary pipe;

γ – Number of engine rotational degrees at which the outlet valve opens after BDC;

n_p – Engine speed corresponding to maximum power;

cc – Engine displacement;

ID – Inside diameter of the exhaust pipe;

Constructive and functional sizes of the Lombardini 6LD400 diesel single cylinder engine, which was chosen for this study, are in accordance with the catalog data [Lombardini, 2019], and shown in Table 1.

Table 1: *Lombardini 6LD400 constructive and functional sizes*

Number of cylinders (N)	1
Bore (B)	86[mm]
Stroke (S)	68[mm]
Engine displacement (cc)	395[cm^3]
Maximum power speed (n_p)	3600 [rpm]
Compression ratio	18:1
Exhaust valve seat diameter	31[mm]
Exhaust valve angle	45[deg]
Connecting rod length	112[mm]
Advance of the exhaust valve opening (γ)	21[deg]
Delay of the exhaust valve closing	3[deg]
Injection advance	25[deg]
Engine power	8[HP]

The use of the exhaust brake system can have important advantages, especially when it is combined with other engine brake systems. Under these conditions, a maximum braking torque value of up to 1.7 times much higher than engine torque that is obtain at full normal operation can be achieved and also reducing the mechanical stresses from the engine mechanism [Manolache-Rusu, 2019].

2. Methodology

Since the manufacturer of the used engine does not specify the constructive dimensions of the exhaust manifold, they are theoretically determined by means of Eq. (1,2). The calculated values are summarized in Table 2 and used as reference data in this study.

Table 2: *Calculated sizes of the primary exhaust pipe*

length of the pipe (P)	diameter of the pipe (DI)
1129[mm]	30[mm]

As it is shown in Fig. 1, the exhaust system is divided into a several sections.

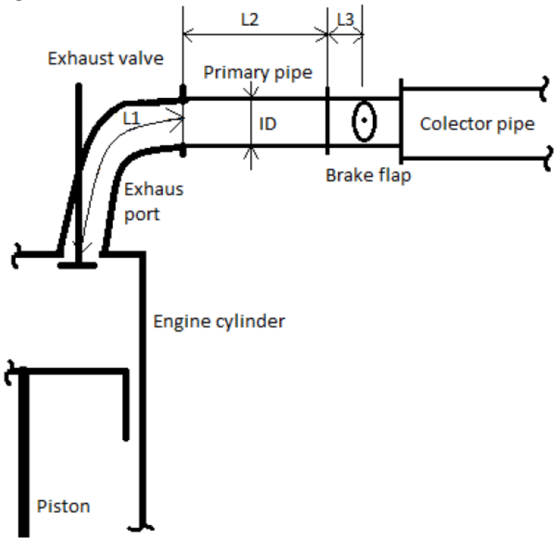

Figure 1: *Sections of the exhaust manifold*

The lengths of the sections of interest are marked with L1, L2 and L3 respectively. The L1 parameter characterizes the length of the exhaust port, which it was imposed by the manufacturer of the cylinder head through a constructive value. For this study we will consider this length to have the value of 50 mm. The L3 represents half of the brake flap body length which has also an imposed value. This value we will consider it equal to the half of theoretically calculated diameter of the primary exhaust pipe. Thus, in this theoretical study, the change of the length of the exhaust pipe upstream of the flap refers at the change of the L2 parameter value of the physical model. To do this, the computing program developed in Mathcad uses the L_{colev} parameter, which refers to the total size of the exhaust manifold. Since the chosen engine is a single cylinder with one exhaust valve, the value of the L_{colev} parameter is the one calculated by Eq. (3).

$$L_{colev} = L1 + L2 + 2 \cdot L3 \quad [mm] \quad (3)$$

In those circumstances, according to the above mentioned assumptions, the minimum L_{colev} parameter value for this study is 80 mm, while the maximum value will not exceed the theoretical value calculated by Eq. (1).

The cross section area provided for exhaust gases by the butterfly throttle position of the brake flap is imposed in the calculation code through D_{colev} parameter. Thus, the value of the cross section area at the restriction will be 0.785 mm^2 in the case of the fully closed flap, and 660.5 mm^2 for the case of the fully open flap.

The simulations will be carried out for two impose speeds, one equal to the speed of maximum power, and another below to it. According to [Bawage, 2016], in the case of normal operation with combustion, each speed corresponds to a certain optimum size of the exhaust pipe in order to achieve maximum performance.

The calculation code developed in Mathcad generates the in cylinder pressure matrix based on the input data entered. The in cylinder pressure matrix is processed to determine the values of the instantaneous engine torque for each rotation degree of the crankshaft. In this way the evolution chart of the engine torque are generated and by using the *[mean]* command of the Mathcad, the value of the average engine torque per cycle is specified.

In Table 3 are specified the 10 study cases for which simulations were performed.

Table 3: *Study cases*

Parameter name	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
D_{colev} [mm]	29	1	1	1	1	1	1	1	1	1
L_{colev} [mm]	1129	1129	1129	800	500	300	250	200	100	80
Engine speed [rpm]	3600	2000	3600	3600	3600	3600	3600	3600	3600	3600

3. Results

The evolution chart of the torque at the engine shaft, for the first three study cases is presented in Fig. 2. From the evolution of the instantaneous engine torque related to the first case, when the brake flap is fully open, the average engine torque value registers a rather small negative value, of only -9Nm.

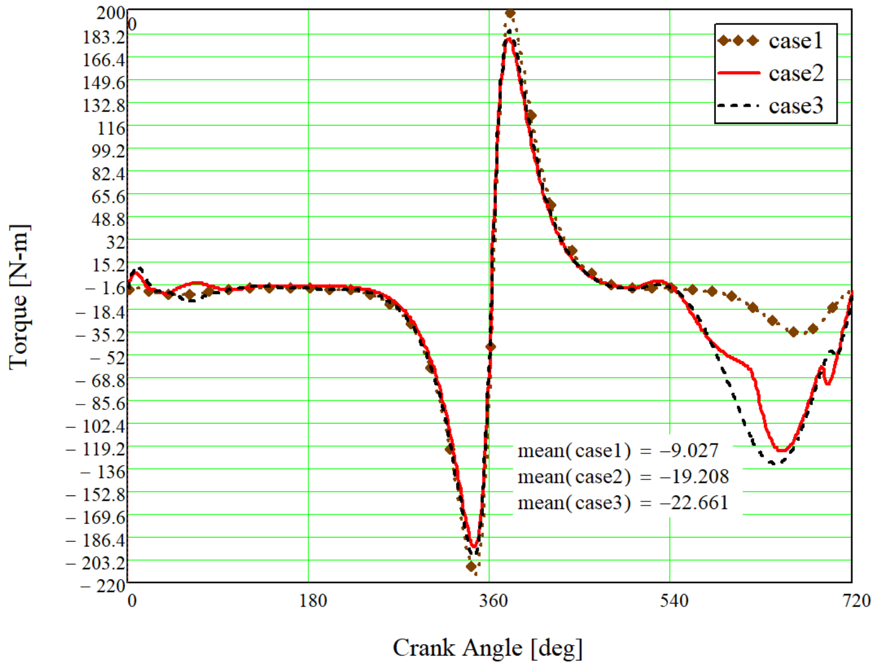

Figure 2: *Evolution of the engine torque corresponding to the optimum theoretical length of the exhaust pipe during normal operation*

This value is mainly due to the frictional and inertial losses. It should be noted that during the engine braking mode the fuel injection is suppressed.

For the same exhaust pipe length value, this time with the complete closed brake flap, at a lower speed than the maximum power speed, we note that the mean brake torque value registers an increase of approximately 10 Nm compared to the first studied case. The third simulation case is performed also with the brake flap completely closed, for the same length of the exhaust pipe, but at an increased speed corresponding to maximum power. In this case, an increase of the average brake torque, up to -22.661 Nm, is observed for the Lombardini 6LD400 engine.

The evolution of the instantaneous engine torque for other four simulation cases is illustrated in Fig. 3.

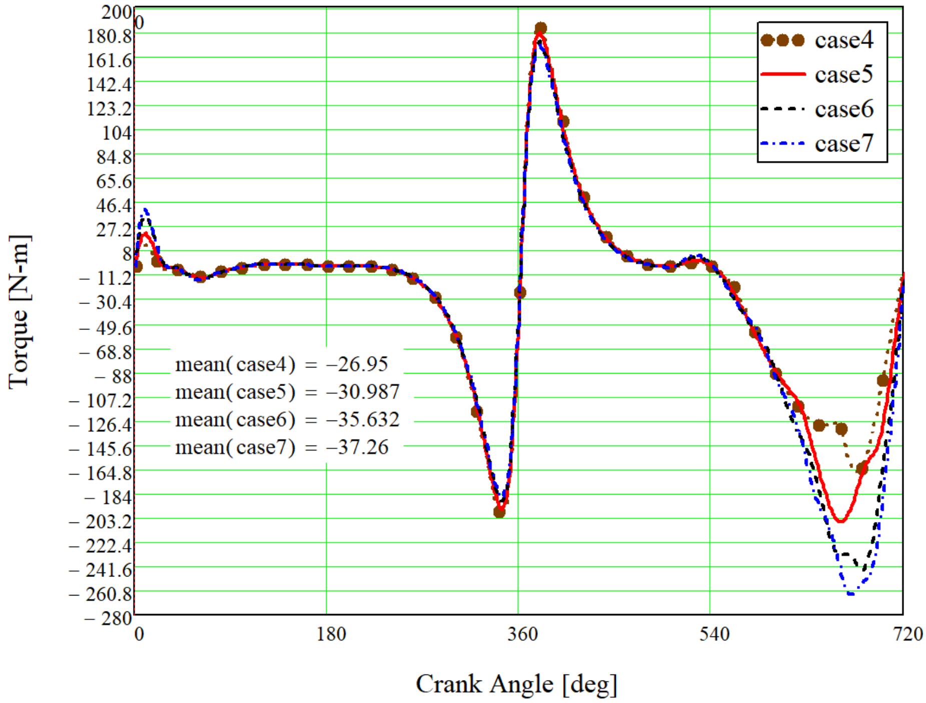

Figure 3: *Evolution of the engine torque corresponding to four different lengths of the exhaust manifold, between 800 mm and 250 mm*

All cases illustrated by the Fig. 3 have been achieved with completely closed brake flap, at maximum power speed, with values of the exhaust pipe length imposed of 800mm, 500mm, 300mm and 250mm respectively. For these cases it is noted that with the decrease of the exhaust pipe length, an increase in the negative mean value of the engine torque at the shaft is recorded.

Fig. 4 also presents the evolution of the instantaneous engine torque for lengths of the exhaust pipe of 200mm, 100mm and 80mm respectively. The graph highlights that for the primary exhaust pipe length of 200 mm, the engine torque at the shaft reach a maximum negative value of -38.746Nm.

We also note from this graph that the maximum positive values of the instantaneous engine torque, related to these last three studied cases, has a very close value. Instead, the minimum negative value of the instantaneous engine torque is recorded for the eighth case of study.

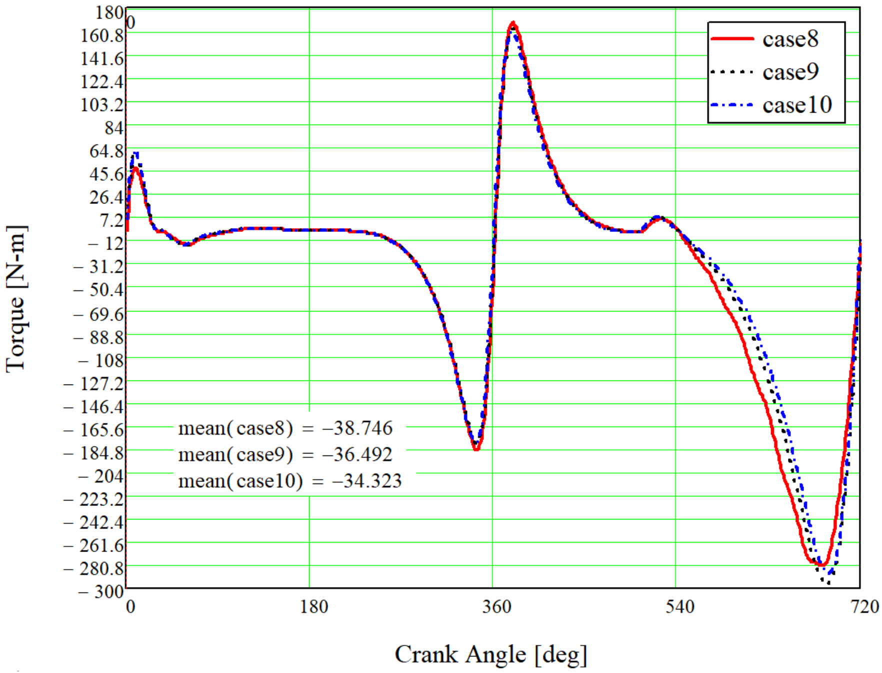

Figure 4: *Evolution of the engine torque corresponding to lengths of the exhaust manifold between 200 mm and 80 mm*

The lowest values of these positive and negative maximum, of the instantaneous engine torque at the shaft, lead to lower mechanical stresses of the engine mechanism components.

4. Conclusions

The implementation of an automatic exhaust pipe length adjustment system for standard vehicles shall not be justified across the increase contribution of the deceleration capacity. For this reason, accurately setting the optimum mounting distance of the brake flap body on the exhaust pipe, leads to an improvement in deceleration performance. For this configuration of Lombardini 6LD400 single cylinder engine, which operates at the maximum power speed, the optimum value for L_{colev} parameter was established to be 200mm.

So the brake torque at the engine shaft is substantially influenced by the length of the primary exhaust pipe when engine operate in braking mode. And the optimum value of this length varies for different values of engine speed.

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