

Estimation of braking capability for two distinct auxiliary engine brake systems paired with an exhaust brake

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Abstract Nowadays vehicles achieved an important increase in energy efficiency. Though highly desirable, in the case of heavy transport vehicles, this leads to a pronounced deficiency in their native deceleration capacity. This deficiency is more pronounced when traveling down slopes with important inclination, or when the traveling mode is with multiple starts and stops, as in the case of city travel. In such operating conditions, using only the conventional braking system can induce important thermal overloads, reducing braking efficiency, or even rendering the system useless. In order to limit this deficiency, auxiliary braking systems are often provided for heavy transport vehicles. Such systems serve to obtain a negative torque at the engine's crankshaft thus actively slowing the vehicle. The present paper aims to simulate the braking capacity obtained by using a combination of two distinct engine brake systems: the Jake brake and the Bleeder brake. The obtained results provide information regarding the evolution of thermodynamic parameters over the engine working cycle, with applications to optimize the deceleration capacity of vehicles that use diesel engines. Based on the presented data, it can be determined which of the analyzed auxiliary braking systems may be best suited, for implementation on particular road vehicles.

1. Introduction

By making use of the latest discoveries in the automotive industry, with regards to: injection systems, supercharging technologies, vehicle aerodynamics, new materials used in the construction of internal combustion engines and of vehicle bodies respectively, an increased vehicle efficiency was reached by reducing friction losses and by increasing engine power. In the case of heavy transport vehicles a lower curb weight is thus attained, leading to a higher carrying capacity. Although the aspects listed above represent vehicles advantages, in the case of heavy-duty vehicles there remains an important deficiency in the reduction of travel speed, especially when descending slopes with a high degree of inclination or when traveling through towns. In the case of frequent stopping maneuvers, said action can be regarded as a continuous and lengthy operation of the classic braking system. Since the classic braking system is a mechanical one based on direct contact between two elements, the friction surfaces are dimensionally limited due to the necessity of heat dissipation on the one hand and wheel dimensions on the other hand. For this reason, auxiliary braking systems such as the engine brake are often employed in heavy transport vehicles. These include various assemblies mounted on the engine at the level of the valve actuation system. The auxiliary engine brake systems dealt with in this article are the Jake brake and the Bleeder Brake.

The advantage of these two auxiliary systems consists in a high braking efficiency, a relatively low production price, and an easy implementation, even for vehicles not designed for this purpose, according to [1]. With these types of auxiliary systems, the sequence and the duration of the processes taking place during a motor cycle are modified with the intent of extracting as much energy as possible from the kinetic energy of the vehicle.

2. Model setup

In order to accomplish the proposed study, a computational program consisting of two distinct parts was developed. The first part deals with the evolution of thermo-gas-dynamic parameters for each process of the engine cycle, while the second part represents a dynamic engine model. The computational program is developed in the Mathcad environment and was validated in [2]. This program consists of a series of fixed pitch iterative loops that use differential equations characteristic for each process.

The engine braking process is characterized in the computation program by a gas exchange process. In this case, in addition to the gas state equation, the differential equation of temperature, mechanical work, heat exchanged with the walls, and others, a supplemental series of equations describing the flow through pipes are used. By means of several variables implemented in the calculation code, or by using the conditioning functions, the regime and direction of the gas flow are estimated. Depending on the momentary values of these variables, the calculation code automatically determines whether critical or subcritical regime equations found in [3], must be used.

At the end of each iteration step, the computational program stores the instantaneous values of the thermo-gas-dynamic parameters of the process within a matrix. These values are used as input data for the next process. The computational program allows the process evolution to be customized by imposing the characteristic values for every studied case. Thus, for the implementation of the exhaust brake regime, the value of $dcol_{ev}$ parameter that characterized the exhaust gas pipe diameter will be set equal to 5 mm, different from 50 mm in case of operation without the action of exhaust manifold butterfly valve.

This study is carried out by introducing in the computational model, the catalog data corresponding to a Lombardini 6LD400 mono-cylinder, summarized in Table 1.

Table 1. Constructive parameters for the engine.

Cylinder diameter	86 mm
Stroke	68 mm
Engine displacement	395 cm ³
Maximum power speed	3600 rpm
Engine power	8 HP
Compression ratio	18
Rod length	112 mm

For engine operation in Jake or Bleeder braking mode, it is necessary to impose a motion law for exhaust valve lifting within the calculation code. This is implemented by using a cubic interpolation function, for which it is necessary to indicate the maximum lifting height, the angle values of the opening and closing of the exhaust valve, in order to achieve braking. The value of the gap between the exhaust valve and the valve seat is considered to be 0.4 mm for the Bleeder brake action.

The exhaust valve first opens at a crank angle of 5 degrees ahead of the top dead center firing (TDCF), when the engine is running in the Jake brake mode. This value was adopted for this study, based on previous research performed by the authors in [4].

In order to evaluate the breaking capacity, the dynamic engine model developed in Mathcad was used. This calculation uses the values of the thermo-dynamic parameters within the matrices as input data in order to determine the instantaneous engine torque. The evolution of the engine torque is imposed

by the values of the tangential force component of the crank mechanism, denoted by F_t , at every step. According to [3], this force is directly influenced by the in cylinder gas pressure p_{cil} , as.

$$F_t = \left[(P_{cil} - P_a) \cdot A_p + F_j \right] \cdot \frac{\sin(\alpha + \beta)}{\cos(\beta)} \quad (1)$$

where, P_a - atmospheric pressure, A_p - area of the piston head, F_j - inertia forces of the masses in translation, α - crank shaft angle, β - angular displacement of the connecting rod.

Engine operation in braking mode is achieved by suppressing fuel injection for all study cases. For this reason, in the computational code the combustion process is completely replaced by a gas exchange process. Also, when using the exhaust brake, the release process will be replaced by a compression one due to the high pressure set at the exhaust valve gate as a result of decreasing gas passage section at the level of the exhaust manifold. Other studies on auxiliary braking systems are made by the authors in [5, 6, 7], but these do not treat the influence of the Bleeder braking system on the vehicle's deceleration capacity.

3. Results

This paper aimed to evaluate the braking torque evolution obtained at the Lombardini 6LD400 engine shaft when it is used in different engine brake modes. The results obtained are related to the evolution of the in cylinder pressure, with applications to optimize the deceleration capacity of vehicles equipped with diesel engines.

Five cases were studied, aiming to evaluate the braking performance of the mono-cylinder engine during operation in three distinct auxiliary braking modes: Jake brake, Bleeder brake and exhaust brake. In all of these situations, the fuel injection is suppressed. It is also desirable to evaluate the braking capacity for combining each type of engine brake with the exhaust brake. Actuation of the exhaust brake assumes complete closure of the exhaust butterfly valve for all study cases. The study is performed by imposing a constant engine speed, considered at 3600 rpm. The braking power can be evaluated based on simulated results of the average torque obtained at the crankshaft.

Figure 2 shows the evolution of in cylinder pressure for all five study cases.

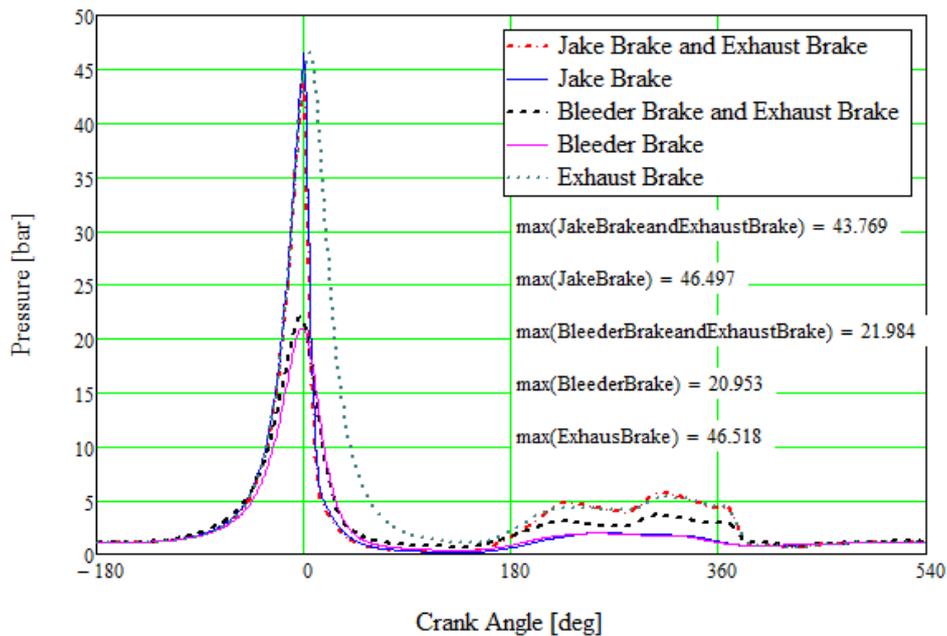


Figure 2. In cylinder pressure evolution.

The graph shows that the in cylinder pressure records high values when the engine is used in Jake Brake and Exhaust Brake modes. A maximum value of 46.518 bars is reached in the case of Exhaust Brake. Also, the use of the engine in this brake mode leads to an increase in cylinder pressure during the forced evacuation process. During the discussed process case in cylinder pressure value exceeded 5. On the other hand when the engine is running in the Bleeder Brake mode, the maximum cylinder pressure is around half from the peak pressures reached in the previously discussed cases.

In Jake braking mode, a sudden drop in cylinder pressure near the TDCF is observed, as a result of lifting the exhaust valve from its seat. When combining the action of the engine brake system with the exhaust brake, it is observed that the characteristic pressure evolutions for the two distinct braking modes are preserved.

Using the proposed dynamic engine model, which uses the cylinder pressure matrix, it is possible to evaluate the engine torque. The evolution of the engine torque and its average values per cycle are illustrated in Figure 3.

The lowest mean retarding torque value of -8.9 Nm is obtained in the case of the exclusive exhaust brake action, although the in cylinder pressure value in this operation case records a maximum value.

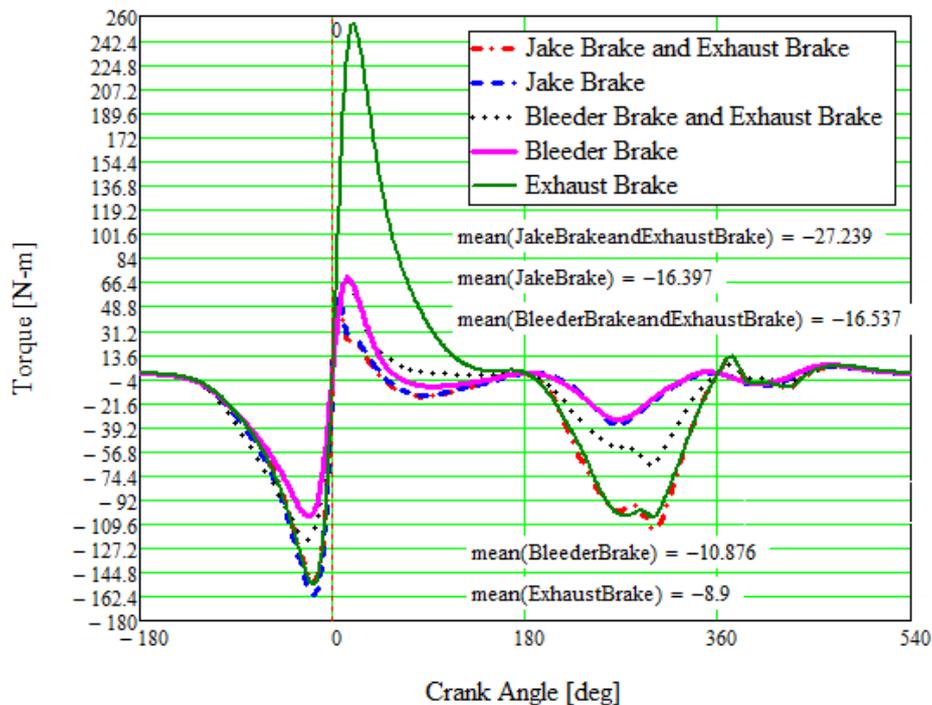


Figure 3. Instantaneous engine torque at the shaft.

Also in this operation mode the biggest difference between the minimum and maximum values of the instantaneous engine torque can be observed. This fact leads to major mechanical stress for the shaft. A higher average resistive torque value is obtained in the Bleeder mode, reaching -10,876 Nm and even higher in Jake brake mode for which the average value is -16,397Nm. This value is approaching the maximum generated engine power at 3600 rpm, but reversed. According to simulated torque values, it is obvious that the in Jake brake mode offers the best braking capacity. However, this system is more expensive and harder to implement than the others because synchronization with the distribution mechanism is required. Moreover, this braking system, according to [8], develops a strong noise during operation, this being the reason why its use was restricted in some countries.

The simulated results show that the simultaneous use of a Bleeder brake system with an exhaust restrictor lead to values of engine torque similar to those obtained in the case of Jake brake operation. This result shows that this constructive version can be used to replace the Jake brake system.

By attaching an exhaust brake system to the Jake brake system the mean value of the resistive engine torque is much higher, reaching -27,239 Nm. The braking power corresponding to this obtained value of the engine torque at the maximum power speed is -13,771hp, which is 1.7 times greater than the power that can be generated by the engine in case of normal operation. Table 2 summarizes the peak to peak values of engine torque expressed in Nm obtained for the five studied cases.

Table 2. Peak to peak engine torque values [Nm].

Jake Brake and Exhaust Brake	Jake Brake	Bleeder Brake and Exhaust Brake	Bleeder Brake	Exhaust Brake
203,466	217,009	188,819	173,848	407,841

It can be noticed that when using the engine in Bleeder mode, the peak to peak value is the lowest one. Use of the engine in this brake mode leads to minimal mechanical stress for the engine components while developing a braking power approximately equal to the one generated by the engine in combustion operation.

4. Conclusion

The results obtained in the present work can be summarized by several conclusions as further described. The Bleeder brake auxiliary system used in combination with an exhaust brake can easily replace the Jake Brake system as it would offer similar braking performance. In this way, the noise produced by the Jake system can be avoided.

In all studied cases, the mean engine torque value was found to be more important for the combined use of engine brake system and an exhaust restrictor than in the case of individual use.

The braking power developed by the Bleeder brake system in combination with an exhaust restrictor is approximately equal to the value delivered by the Lombardini 6LD400 single-cylinder engine operating normally at full throttle.

The use of the Bleeder brake system subjects the engine components to less mechanical stresses.

Although the maximum in cylinder pressure value when using the Bleeder braking mode is around half from the maximum pressure from the use of exhaust brake, the mean engine torque is significantly higher in the first case due to elimination of the spring effect of gases during the relaxation process.

Using an exhaust brake simultaneously with a Jake brake system in the case of Lombardini 6LD400 engine at maximum power speed it is achieving the brake power of -13,771hp, 1.7 times greater than the maximum engine output in normal operation under the same conditions.

5. References

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