THEORETICAL AND EXPERIMENTAL STUDY OF THE IMPROVEMENT OF THE INLET MANIFOLD OF INTERNAL COMBUSTION ENGINE

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RESUME
In internal combustion engines, the inlet manifold is of immense importance for the engine operation. This is basically due to its influence on the power supplied by the engine and on the emission of contaminant gases. We here describe an experimental and theoretical study of the inlet manifold of the engine, operating in a stationary regime. Firstly, the mass flow through the inlet manifold was measured for fixed pressure differences between the engine's inlet and exhaust. The results are in good agreement with the values calculated by numerical simulation. Secondly, based on the numerical analysis, a modification of the inlet manifold's geometry was proposed in order to increase the mass flow rate, and its effectiveness was verified experimentally.

1. INTRODUCTION
In the process of loading of an ignition-by-compression engine, air and fuel are introduced into a cylinder. The air is pulled in through the inlet manifold by the negative pressure difference caused by displacement of the piston, while the fuel is injected directly just before combustion begins. The loading process is controlled by varying the amount of fuel that is injected in each cycle, while the air mass flow is practically invariant for a given rotatory speed.
The mass flow rate through the inlet manifold has a considerable influence on the engine's power and yield, and on the emission of contaminant gases. In particular, the engine's power output is approximately directly proportional to the mass flow (Garro, 1992). To evaluate the dependence of the latter quantity on the geometry of the inlet manifold, one considers, as a first approximation, operation under a stationary regime (Genta, 2000). In this approximation, air flows through the system for a fixed valve aperture, the piston closing the cylinder is eliminated, and suction is produced by a fan located in its place, which generates a pressure difference ΔP between the entrance of the inlet manifold and the bottom of the cylinder. With this approximation, one straightforwardly obtains the dependence of the air mass flow m_a on the valve aperture for a fixed ΔP. The stationary approximation neglects, however, both the dynamic effects and the influence of combustion.
The present work is an experimental and theoretical study of the stationary regime dependence of m_a on the valve aperture for the inlet manifold of the D909 engine manufactured by Deutz-Diter. This is an air-cooled diesel single-cylinder, four-stroke engine with natural air intake and

direct injection. It has a 0.709 l cylinder volume, develops 11 kW maximum power at 3000 rpm, and 38.5 N•m maximum torque at 2000 rpm. Section 2 presents the comparison between the experimental and the numerical results, with good agreement, thus validiting of the simulation method. A proposed modification of the inlet manifold, based on the predictions provided by the simulations, is presented in Sec. 3, together with the experimental confirmation of the improvement represented by the proposal. The principal conclusions are presented in Sec. 4.

2. VALIDATION OF THE NUMERICAL METHOD

2.1 Experimental

Figure 1 shows some of the details of the cylinder and the inlet manifold. The latter comprises a tube, a conduit, eight rings, and a valve. As can be observed, the inlet manifold conduit is shaped to encourage the appearance of vortices in the flow, thereby improving the mixing with the fuel. Due to its influence on the mass flow, the connection of the inlet manifold conduit to the cylinder plays a crucial role in the loading process. The eight rings making up the connection have the following dimensions:

- Cylindrical, height 0.6858 mm.
- Toroidal, height 4.4592 mm.
- Toroidal, height 0.1274 mm.
- Cylindrical, height 0.4525 mm.
- Tronconical at 45o where the valve is seated, height 1.275 mm.
- Cylindrical, height 0.7 mm.
- Tronconical at 45°, height 1.775 mm.

The experiment was conducted on a test bench on which was placed the engine block containing the inlet manifold and the cylinder. A pressure difference ΔP was established between the inlet manifold tube and the bottom of the cylinder by means of a variable speed fan. The pressures at the mouth of the inlet manifold tube (atmospheric pressure) and at the bottom of the cylinder were determined using static pressure meters. A stagnation deposit was placed between the fan and the cylinder to ensure uniform flow. For a given valve lift, the mass flow m_a through the system was measured using a calibrated nozzle equipped with differential pressure meters. The measurements were made for 10 values of the valve lift in the 1–10 mm range.

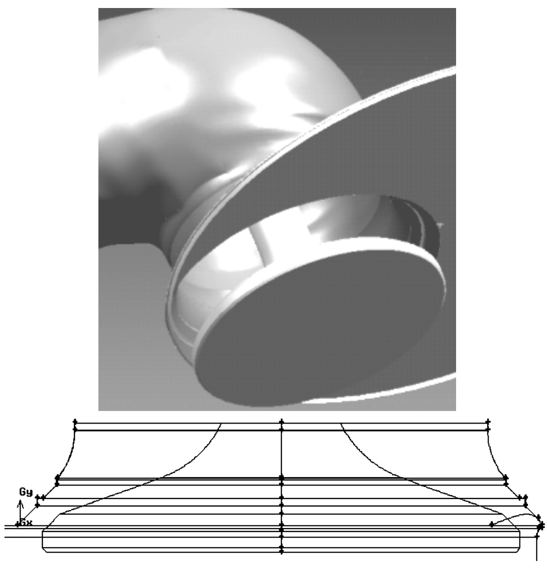

Figure 1. Details of the cylinder and the inlet manifold of the D909 engine.

2.2 Simulation

The numerical simulation of the problem was done using the computer program FLUENT (Fluent/Inc, 1997). Figure 2 shows the simulation domain. To simulate the intake of air from the atmosphere, a cylindrical deposit far larger than the inlet manifold conduit was added to the domain. The air stagnation pressure in the input section and at the side walls of this deposit were set equal to the atmospheric pressure. The air velocity at these surfaces was adjusted in the course of the simulations to fit the rest of the boundary conditions, which were established in the usual way taking into account the compressible and turbulent nature of the problem. The Reynolds stress equation model was used, together with wall functions for the solid boundaries. Second-order transformations were used to convert time and convection to discrete values (Gonzalez et al. 2002).

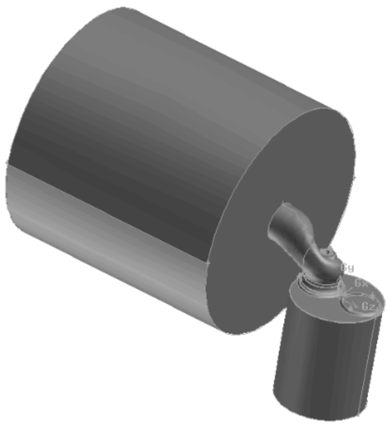

Figure 2. Simulation domain.

Figure 3 shows the error relative to the experimental value of the mass flow rate for a 3 mm valve lift and different grids. One observes that the error decreases as the number of cells increases. For 7.4 million cells, the discrepancy was approximately 3%. All the results presented here were obtained with this grid. Computations were performed using a cluster consisting of nine processing units in parallel. The server was equipped with a 3 Ghz Pentium-4 CPU and 2GB of RAM, and the other devices with a 2.8 Ghz Pentium-4 and 512 MB of RAM.

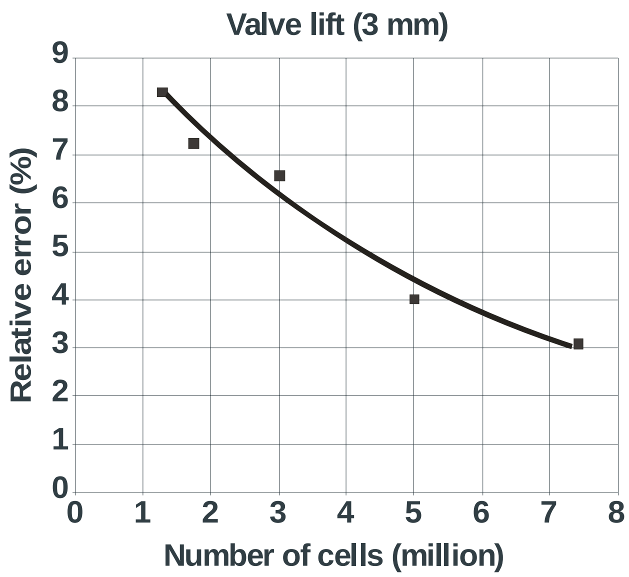

Figure 3. Error relative to the experimental value for a 3 mm valve lift.

2.3 Comparison

Figure 4 shows a comparison between the experimental data and the predictions of the simulation for a fixed pressure difference and different valve lifts. One observes that the mass flow increases with increasing valve lift. Figure 5 shows the relative errors of the simulation with respect to the experimental values of Figure 4. The errors were less than 5% for valve lifts within the range of reliability of the nozzle (3–10 mm), and less than 1% in several cases. For lifts less than 3 mm, the mass flow was less than the lower limit established for the use of the nozzle. These results showed that the accuracy of the numerical procedure was satisfactory.

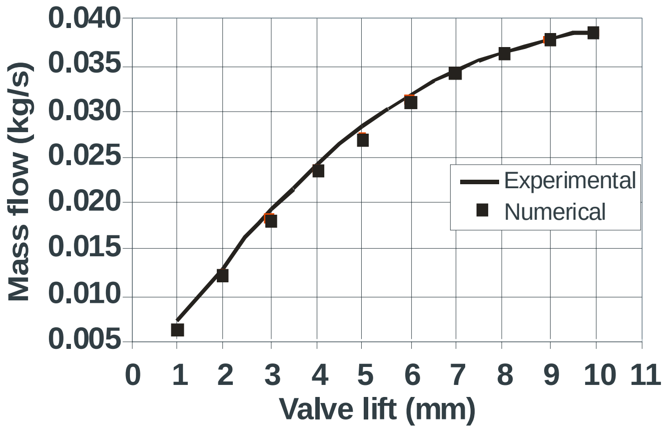

Figure 4. Comparison of experimental data and the predictions of the simulation for the mass flow obtained for a fixed pressure difference and different valve lifts.

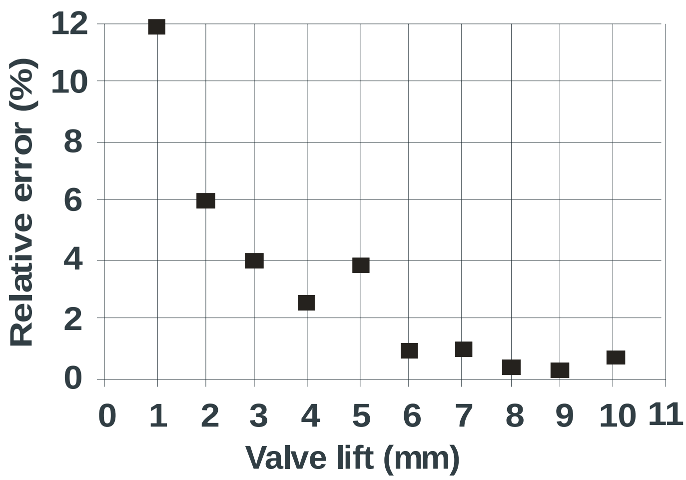

Figure 5. Relative errors of the simulation with respect to the experimental values of

3. THE PROPOSED IMPROVEMENT

3.1 Simulation

The main goal of the present work was to propose modifications to the original geometry of the inlet manifold that would increase the mass flow. From a practical standpoint, the proposed modifications have to be implemented by means of simple machining processes. We therefore restricted our analysis to modifications that only affect the inlet manifold ring and the valve.

Four possibilities were analyzed, calculating the corresponding mass flow for a valve lift of 3 mm. This value was chosen because it is within the range of reliability of the nozzle measurement, and the effect of the proposed modification on the mass flow would be more noticeable. Details of the original geometry and of the proposed modification are shown in Figure 6. This modification increases the cross section of the entrance to the cylinder, decreases the valve diameter, and maintains the seating angle. The Figure also shows the velocity modulus fields obtained for each case. One observes that the air flows more freely through the modified geometry. The increase attained in the mass flow is 11% (7.5% more than the experimental).

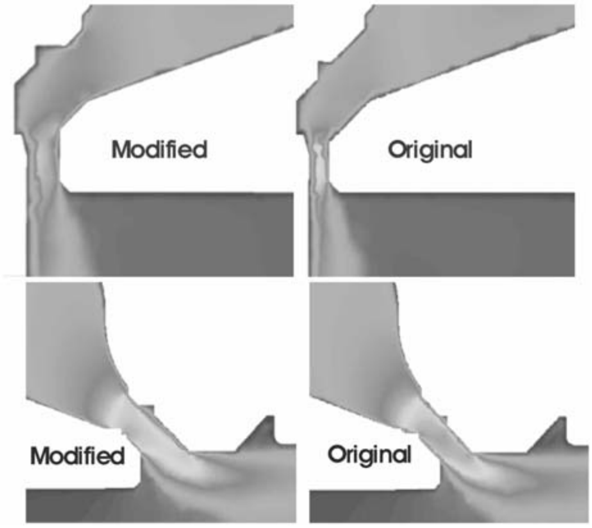

Figure 6**.** Velocity modulus fields obtained with the original geometry and the optimal modification.

3.2 Experimental validation

Finally, to check the simulation predictions, we constructed a prototype block incorporating the aforementioned modification. Figure 7 shows the increases in mass flow relative to the original geometry for different valve lifts. The improvement is significant. The numerical prediction obtained for a valve lift of 3 mm is also plotted.

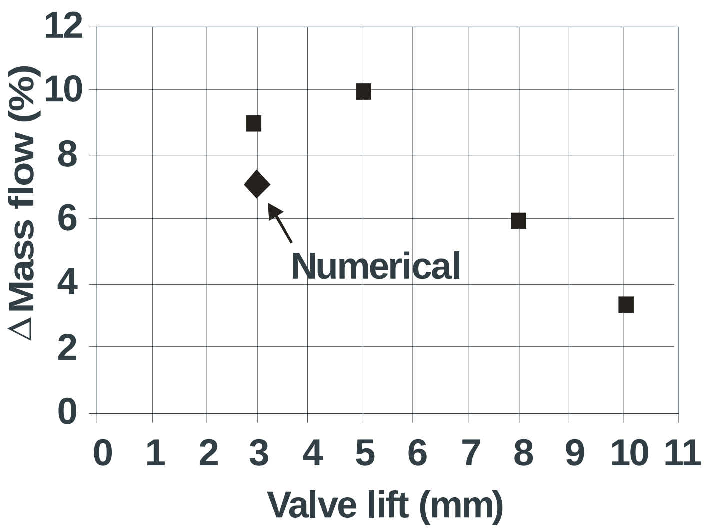

Figure 7. Mass flow increment attained for several valve lifts

4. CONCLUSION

The present results can be summarized as followos:

- Applying the program FLUENT to the present problem yielded accurate results that can be used in the design of future prototypes.
- Using this tool, a modification of the engine inlet manifold was proposed that led to significant increases in the mass flow in the stationary regime.

The study is currently being extended to the engine's real operating regime and the analysis of the effects of the proposed modification on the engine's performance.

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