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PERFORMANCE IMPROVEMENT OF AN INTERNAL COMBUSTION ENGINE

M.G. Rasul[*] and R. Glasgow

School of Advanced Technologies and Processes, James Goldston Faculty of Engineering and Physical Systems,
Central Queensland University, Rockhampton
Queensland 4702, Australia.
* m.rasul@cqu.edu.au

ABSTRACT

A method of increasing the performance of an internal combustion (IC) engine without any major investment or mechanical parts which requires additional energy to operate is investigated. A convergent-divergent induction nozzle is tested in order to increase the air flow into the engine which in tern may increase the overall performance. The induction system was applied to the air before the throttle body of a four-cylinder, four-stroke diesel engine connected to an engine dynamometer with airflow and pressure drop measurement facilities. The measurement was done at an engine speed of about 3500 rpm. The results are compared against the performance characteristics of a plain (without nozzle) induction system. Investigations were also done to find out the most suitable material for the nozzle itself taking into consideration the factors influencing its conditions such as vibrations and temperature variations. The results of test show an increase in air flow into the engine, an increase in brake power as well as in mechanical efficiency which demonstrate that the nozzle type induction can improve the performance of an IC engine.

Keywords: IC engine, Tests, Brake power, Torque, Efficiency.

1. INTRODUCTION

It is found in the literature that the increase in airflow into an IC engine may increase the brake power as well as mechanical efficiency of the engine [1, 2]. The standard procedure to increase airflow in IC engines is to force feed the air with a compressor. There are two methods of doing this, the first being a turbocharger [3]. Energy attained from the exhaust gases is provided into the turbocharger, which runs through an impeller creating momentum. Connecting a compressor with a shaft to the spinning impeller then uses that momentum to force feed the air to the engine. However the downfall with this method is that the impellers' internal inertia puts a backpressure on the exhaust working the engine harder, hence requires more fuel. In addition, the air charged by the compressor gets heated, firstly from the exhaust heat and secondly, from compressing the air necessitating an intercooler using more drive power. The second method is to supercharge the engine, which runs a belt driven compressor off the crankshaft again loading the motor and heating the air [1]. Therefore it is obvious that a high flow design needs to be incorporated into the air intake of the IC engine which requires a substantial investment.

In this study a convergent-divergent induction nozzle is tested in order to increase the air flow into the engine to investigate whether this test will show an increase in performance or not. The experiment was done at an engine speed of about 3500 rpm. The results are compared and discussed against the performance characteristics of a plain without nozzle) induction systems.

2. LITERATURE AND THEORETICAL CONSIDERATION

The purpose of an IC engine is to convert heat energy into mechanical energy by burning fuel in the cylinder and utilizing the resultant pressure of combustion to drive automobiles [4-7]. A reciprocating IC engine comprises of a piston which moves in a cylinder and forms a moveable gas-tight plug, a connecting rod and a crankshaft [1]. If the engine has more than one cylinder than the cylinders, pistons, etc are identical and all con-rods are connected to a common crankshaft. The angular positions of crank pins are such that the cylinders contribute their power strokes in a selected and regular sequence, and to aid in engine balance. The reciprocating motion of the piston is converted to the circular motion of the crank through this procedure. All engines are suited for their purpose, where it can be low revving torque, high revving power, engine longevity, fuel consumption, capital or running cost.

The power that an engine is capable of producing is the most desired information when dealing with engine specifications. The indicated power is described as the rate of work done by the gas on the piston. In order to calculate this, the mean effective pressure (MEP) is required for the mathematical process. To determine MEP, a pressure versus displacement volume graph must be constructed with each of the cycles of processes. This can either be measured or sourced from the operating manual of the specific engine [1, 5].

The indicated power for 4-stroke engines can be determined by,

$$IP = \frac{MEP \times ALNn}{2} \tag{1}$$

where, A is the cross-sectional area of the cylinder (in m^2), L is the stroke length (in m), N is the speed of the engine (in rad/s) and n is the number of cylinder.

The brake power can be calculated by,

$$BP = 2\pi NT \tag{2}$$

where T (=WR) is the torque (in Nm), W is the net load (in Newton) and R is the radius from the axis of rotation (in m).

The difference between IP and BP is known as friction power (FP). The mechanical efficiency of the engine is given by [2],

$$\eta_M = \frac{BP}{IP} \tag{3}$$

The power output of an IC engine depends on the amount of charge which can be induced into the cylinder. This can quantitatively be expressed by volumetric efficiency as given below,

$$\eta_V = \frac{V}{V_S} \tag{4}$$

Where, V is the volume of air induced measured at free air conditions and V_S is the swept volume of the cylinder. The specific fuel consumption (sfc) is the mass flow rate of the fuel consumed per unit power output which is a criterion of economical power production. The sfc of an engine can be given by,

$$sfc = \frac{\dot{m}_f}{BP} \tag{5}$$

where, $\dot{m}_f$ is the mass of the fuel consumed per unit time.

A duct of smoothly varying cross sectional area in which a steadily flowing fluid can be made to accelerate by pressure drop along the duct is defined as nozzle [1]. When the fluid is decelerated in a duct, causing a rise in pressure along the stream, the duct is defined as diffuser, which is used in centrifugal compressors and ramjets. A nozzle begins at the inlet, contracts abruptly to the throat and then gradually expands through to the outlet in order to avoid high frictional losses between the fluid and the nozzle as shown in Figure 1.

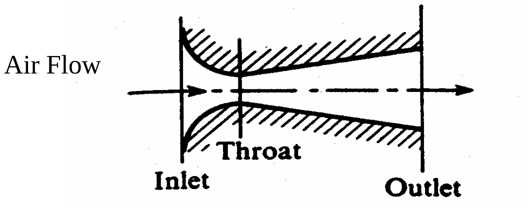

Fig 1. A typical convergent-divergent nozzle[1]

A nozzle operating at design pressure ratio will have a fluid velocity equal to the speed of sound (sonic velocity), making the flow up to the throat subsonic and the flow after the throat supersonic. The ratio of the pressure at the section where sonic velocity is attained (P_c) to the inlet pressure (P_1) of a nozzle is called critical pressure ratio. The relationship between critical pressure and inlet pressure can be given by [1],

$$\frac{P_c}{P_1} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{(\gamma-1)}} \tag{6}$$

where, γ is the specific heat ratio. For air $\gamma = 1.4$, therefore the critical pressure ratio is 0.528. Similarly, the ratio of the temperature at the section of the nozzle where the velocity is sonic (T_c) to the inlet temperature (T_1) is known as critical temperature ratio and can be given by,

$$\frac{T_c}{T_1} = \left(\frac{P_c}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}} = \frac{2}{\gamma+1} \tag{7}$$

Therefore for air, the critical temperature ratio is 0.833. The velocity at the throat of a correctly designed convergent-divergent nozzle is called critical velocity (V_c) and can be given by,

$$V_c = (\gamma R T_c)^{1/2} \tag{8}$$

In most practical applications the velocity at inlet is negligibly small in comparison with the exit velocity and often ignored. To avoid excessive losses between the fluid and nozzle, the angle of the divergent duct is kept below about 20^o to prevent breakaway of the fluid from the sidewall. For a given pressure, the divergent portion of the nozzle is comparatively longer than the convergent portion. The majority of the friction losses occur after the throat in the diverging section due to the increasing velocity and wall expansion. Since the majority of losses are in this section, it is approximated that all of the friction losses occur in the diverging region.

3. EXPERIMENTAL

The size of the induction nozzle depends on the intake size of the throttle body and engine’s swept volume. The nozzle exit area was considered same as the throttle body intake. The nozzles were fabricated to be self-supportive, with the weight of the air box hose requiring support to hold rigid for consistency in testing. The nozzle used in the experiment is shown in Figure 2. The outside diameter of the intake of the engine was 66 mm and the nozzle was made to suit that. The critical diameter (i.e throat diameter) of the nozzle was 25 mm. The material chosen for the nozzle was an epoxy resin and woven fibres of glass matting for strength and vibration. During experimenting, the nozzle showed no signs of fatigue or failure indicating that the fibre glass was a suitable material for nozzle construction. It is to be noted that the plastic material was not suitable to withstand constant vibration and temperature variations.

The diesel engine used for testing is shown in Figure 3 with nozzle mounted on the throttle body of the engine. The engine was an Isuzu 4 cylinder, 4-stroke with a bore and stroke of 84 mm. The engine power was determined by a Heenan dynamic dynamometer type GVAL, Mark I-IV. The data acquisition was done through a Labview software together with proximity sensor and PCB quartz press transducer type 112A sensitivity 17.11 pC/bar. The engine was fully serviced before experiments were carried out to maintain consistent results output from the engine. The service included replacing the oil and filter, and a general engine tune-up.

The engine was connected to the mechanical dynamometer to record the brake power of the engines. All of the other measurements such as the mean effective pressures, temperatures and other quantitative values were recorded and displayed on the software called Lab View. To measure the airflow at the intake of the throttle body, an airflow meter (calibrated in advance) was incorporated into the system.

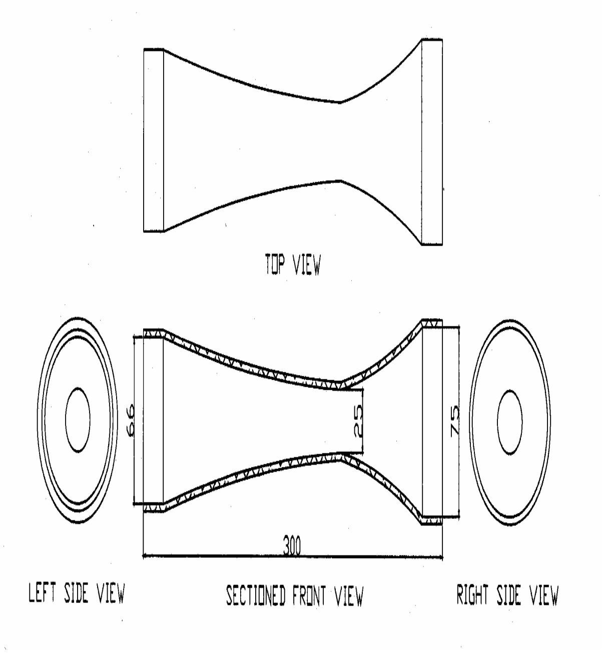

Fig 2. Schematic diagram of the nozzle used in the experiment

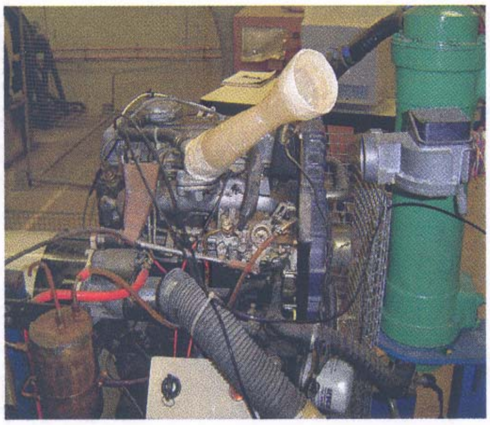

Fig 3. Diesel engine with nozzle mounted on the throttle body

The constant current hot-wire anemometer was used to measure the airflow velocity. A hot-wire anemometer measures both mean and instantaneous velocities. The element of the anemometer is either a thin wire or metal film laid over a glass support and coated to protect the film [8, 9]. In a constant current hot-wire, an electrical circuit is formed using the element. As the air passes over the element it is cooled reducing the resistance causing variation in the output voltage where once calibrated can calculate the instantaneous airflow velocity through the nozzle.

The power transferred from a wire sensor can be expressed as [8, 9]

$$P = I^{2} R_{sensor} = \left(a + b\sqrt{\rho U^{/}} \right) \times \left(T_{sensor} - T_{fluid} \right) \qquad (9)$$

Where, I is the current through the sensor, R is the resistance, ρ is the density of the fluid (in kg/m^3), $U^{/}$ is the instantaneous velocity of fluid (in m/s), T is the temperature (in ^{o}K), and a and b are the constants. For a constant temperature system, R_{sensor} and T_{sensor} are constant, so $V^2 \propto I^2$. Thus provided T_{fluid} is constant,

$$V^{2} = \left(A + B\sqrt{\rho U^{/}} \right) \qquad (10)$$

where V is the bridge output voltage.

4. RESULTS AND DISCUSSION

Incorporation of the induction nozzle onto an IC engine may have little or no effect on the output power, however there may be an unforseen factor that the airflow may have actually increased but not enough to impact on the final performance result of the engine. The expected outcome of the experiment was mainly to increase the brake power. In achieving this, the volumetric efficiency and possibly the mechanical efficiency will increase. The engines will also run smoother with a cleaner combustion due to the increase in airflow into the cylinder.

The experiment without nozzle induction and with nozzle induction was carried out. The indicated mean effective pressure, maximum and minimum pressures, and air flow rate were measured at engine speed of about 3500 rpm under varying load condition. The indicated power, brake power, friction power and mechanical efficiency were determined. The results without nozzle and with nozzle are presented in Table 1 and 2 respectively.

Table 1: Experimental results without nozzle induction

Load (N)	IMEP (bar)	Max Pressure (bar)	Min Pressure (bar)	IP (kW)
0.95	5.90	6.02	5.77	32.41
1.50	6.31	6.43	6.17	34.75
2.50	6.35	6.51	6.26	35.58
3.48	7.24	7.32	7.16	39.84
4.15	7.19	7.33	7.02	39.67

Table 1: continued

Load (N)	BP (kW)	FP (kW)	Air flow (mm H_2O)	Mech. Effi. (%)
0.95	6.21	26.2	55.5	19.16
1.50	9.93	24.82	57.5	28.58
2.50	16.54	19.04	57.0	46.49
3.48	23.00	16.85	55.0	57.73
4.15	27.52	12.15	54.5	69.37

Table 2: Experimental results with nozzle induction

Load (N)	IMEP (bar)	Max Pressure (bar)	Min Pressure (bar)	IP (kW)
0.95	5.66	5.79	5.48	31.13
1.50	5.94	6.14	5.62	32.65
2.50	6.46	6.68	5.97	35.54
3.48	6.85	7.09	6.44	37.81
4.15	7.22	7.35	7.07	39.36

Table 2: continued

Load (N)	BP (kW)	FP (kW)	Air flow (mm H_2O)	Mech. Effi. (sec)
0.95	6.29	24.84	59.5	20.21
1.50	9.91	22.74	59.5	30.63
2.50	16.54	19.00	58.5	46.54
3.48	23.23	14.58	57.0	61.44
4.15	27.49	12.27	55.5	69.84

The mechanical efficiency as a function of brake power is compared in Figure 4. It can be seen from Figure 4 that the mechanical efficiency with nozzle induction system is always slightly higher than that of the without nozzles at corresponding brake powers.

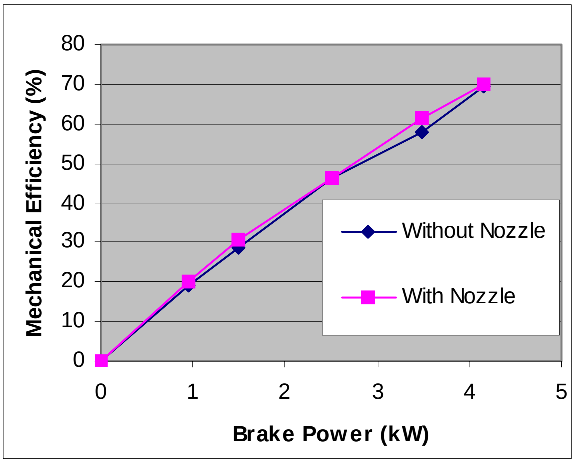

Fig 4. Mechanical efficiency as a function of brake power

The percentage increase or decrease in mechanical efficiency, brake power and air flow with nozzle induction system with respect to results obtained without nozzle induction system is calculated in Table 3. The values in Table 3 were calculated as difference in values between Table 2 and Table 1 times 100 divided by values in Table 1. A negligible (insignificant) reduction in brake power with nozzle induction system at engine load of 1.5 and 3.48 N can be seen from Table 3 compared to that of without nozzle induction system. This unexpected, although negligible, reduction may be due to the experimental errors such as fluctuating pressures and engine speed observed during experimentation. However, in general the results indicate that the brake power with nozzle induction system at different engine load increases or remain same compared to corresponding brake power without nozzle induction system. It can be noticed from Table 3 that the air flow increased up to 7.2%, the brake power increased up to 1.29% and the mechanical efficiency increased up to 3.71%. These data demonstrates that the convergent-divergent induction nozzle is superior to standard method (without nozzle induction) and an increase in overall performance could be achieved.

Table 3: Comparison of experimental results

Load (N)	% increase in mechanical efficiency	% increase in BP	% increase in air flow
0.95	1.05	1.29	7.2
1.50	2.05	-0.2	3.48
2.50	0.05	0	2.63
3.48	3.71	1.0	3.64
4.15	0.47	-0.1	1.83

5. CONCLUSIONS

The experimental results show an increase in overall performance of an IC engine. More specifically, the brake power increased up to 1.29%, the air flow increased up to 7.2% and the mechanical efficiency increased up to 3.71% which indicate that the induction system increases the overall performance of the engine. Although, a little increase in performance is evidenced from the results, however, further experiments are necessary to warrant any installation of any modification.

6. REFERENCES

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