Internal Combustion Engine

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Abstract

For this experiment, our lab group utilized a four-stroke internal combustion engine based on a theoretical Otto cycle to evaluate engine performance and calculate engine parameters. A dynamometer was connected to the four-stroke engine and its components were used to measure characteristics of the engine while the engine was operating at a range of 2000-3200 rpm. These values were then used to calculate engine parameters such as the brake mean effective pressure. Estimations on engine parameters were then made using data given, and the most desireable engine speed was chosen based on different criteria. The procedure and data collected during this lab allowed us to successfully evaluate engine performance and allowed us to select the correct engine for a specific application.

Introduction

Internal combustion engines are widely used in engineering applications that are common in our daily lives. In this lab, our group analyzed the characteristics of a four-stroke internal combustion engine based on the theoretical Otto Cycle at different speeds in order to determine various engine parameters. These parameters allow us to find the best possible engine speed for a specific application. The Otto cycle is a thermodynamic cycle that describes a typical spark ignition piston engine and relates a gas to changes in pressure and volume as well as to heat additions and removals. Our experimental setup consisted of a small four-stroke 5.5 hp Honda GX160 engine connected to a dynamometer. The dynamometer includes an oil pump and a flow control load valve to control and measure oil pressure using a pressure gauge. An oil flow meter is used to measure oil volumetric flow rate and two temperature indicators measure cylinder head temperature and hydraulic oil temperature. Our procedure consisted of starting the engine after performing the necessary checks, and the RPM was then set to 2000 by adjusting the load on the engine while at full throttle. Once the engine was at 2000 rpm, the oil pressure and flow rate was recorded. The fuel weight before and after a 30 second period was also recorded, and this data collection was repeated at 2300, 2600, 2900, and 3200 rpm. Data collection continued at ¾ and ½ throttle at 2600 rpm, and data was lastly collected at ¼ throttle at 2000, 2300, 2600, 2900, and 3200 rpm. Using these values, the brake power, torque, fuel consumption, brake specific fuel consumption, cycle efficiency, and brake mean effective pressure was calculated at each engine setting. The predicted efficiency of the engine was calculated, and the maximum piston speed, number of times the spark plug fired, and the approximate tensile stress induced on a connecting rod was found. These calculations allowed us to determine the most desirable engine speed for maximum power output, maximum engine torque, and maximum engine efficiency.

Results and Discussion

When analyzing the brake power with respect to RPM, the throttle position has a large effect on the result. The more open the throttle, the higher the brake power. Also, the brake power increases almost steadily with increasing RPM at full throttle with a peaks at 2900 RPM with an output of 4.266 HP. When on One-Quarter throttle, the brake power decreases with increasing RPM.

Along with brake power. The throttle opening also directly increases the torque, fuel consumption,cycle efficiency and brake mean effective pressure. It is only the brake specific fuel consumption that decreases when the throttle is opened. The increase in RPM increases the output for brake power (at open throttle), fuel consumption, and brake specific fuel consumption. Conversely, the increase in RPM reduces the torque, brake mean effective pressure and efficiency of the engine.

Brake power is the only output recorded from the dynamometer that has a different trend with respect to RPM in accordance to the throttle setting.

The maximum torque and efficiency are recorded at the minimum RPM of 2000 as .0156 ft-lbf and 28% respectively.

For an engine running at 2900 RPM, the maximum piston speed can be found by multiplying the stroke by pi/12, and multiplying the result by the running RPM. When the engine in this lab runs at 2900 RPM, the piston moves at 46.99 m/s.

For a 4-stroke engine, the spark plug fires once for every 2 Revolutions. If the engine runs at 2900 RPM, this would give 1450 fires/min or 24.17 fires/s.

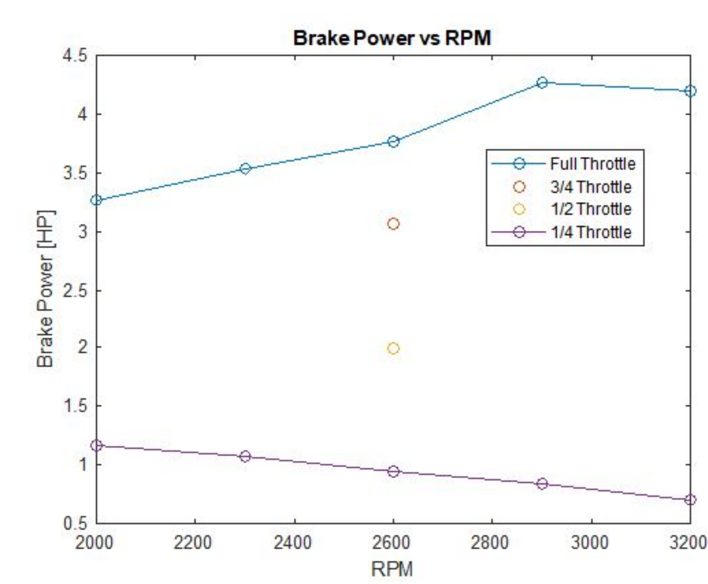
To find the tensile stress in the connecting rod during each Cycle. The deceleration was found using delta(V)/delta(t) As -9086.66m/s^2 (using the time for a quarter stroke). The Force was then found from F=ma, and the tensile stress is Just this divided by the cross sectional area of the connectin Rod. This gave 5.887GPa.

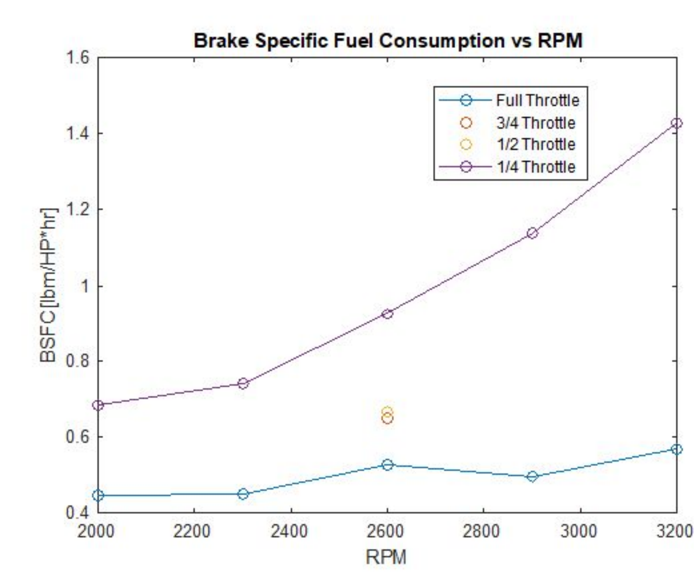
At 2900 RPM and full throttle, torque, cycle efficiency, and the brake mean effective pressure have a local maximum. The brake specific fuel consumption has a local minimum at this same RPM and full throttle. Also, this is where the Brake power has an absolute maximum horsepower, so at maximum horsepower, it could be implied that 2900 RPM is an optimally efficient speed for operating the engine.

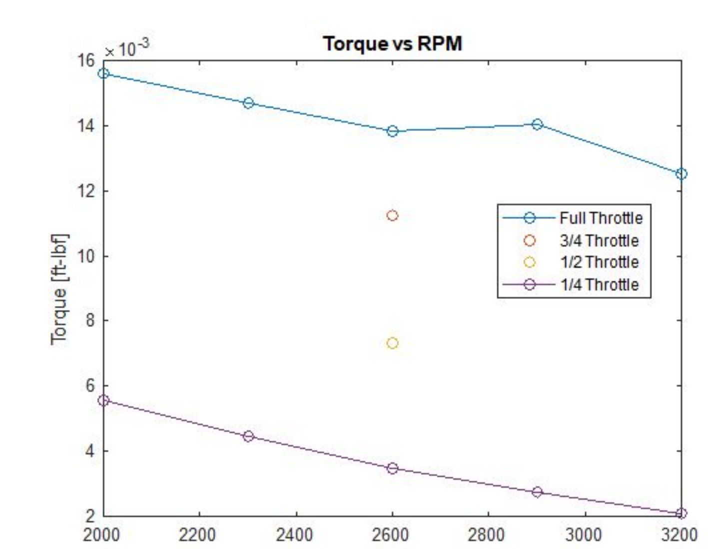
Generally, the cycle efficiency decreases as speed increases, but it increases at 2900 RPM on full throttle.

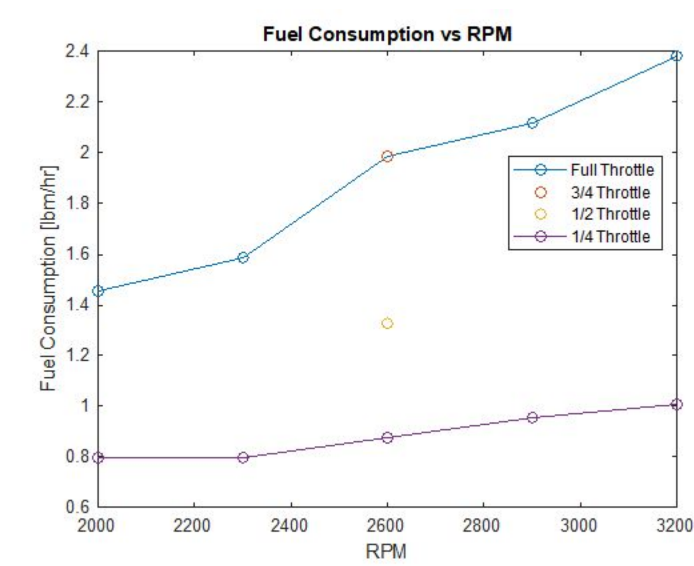
More fuel is consumed per brake power as shown in the Brake Specific Fuel Consumption plot. Possible causes might include a growing need for fuel injection as the air-fuel mixture must account for more combustion with the increasing speed while air friction plays a role as well.

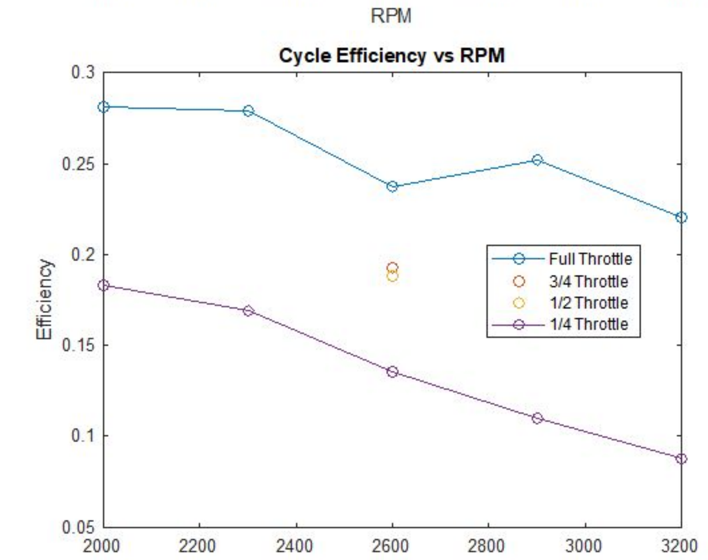
Throttle	RPM	Brake Power (HP)	Torque (ft-lbf)	Fuel Consumption (lbm/hour)	BSFC (lbm/hr*HP)	Cycle Efficiency	BMEP
Full	2000	3.27013	0.01561	1.455110322	0.4449704	0.2812	0.01561
	2300	3.53778	0.01469	1.587393078	0.4486979	0.27886	0.01468
	2600	3.76896	0.01384	1.984241348	0.526469	0.23767	0.01384
	2900	4.26634	0.01405	2.116524104	0.4960988	0.25222	0.01404
	3200	4.2007	0.01254	2.381089617	0.5668316	0.22074	0.01253
3/4	2600	3.06301	0.01125	1.984241348	0.6478076	0.19315	0.01124
1/2	2600	1.99096	0.00731	1.322827565	0.664418	0.18832	0.00731
1/4	2000	1.16321	0.00555	0.793696539	0.6823302	0.18338	0.00555
	2300	1.07351	0.00446	0.793696539	0.7393456	0.16924	0.00445
	2600	0.94516	0.00347	0.873066193	0.9237256	0.13546	0.00347
	2900	0.83722	0.00276	0.952435847	1.1376133	0.10999	0.00276
	3200	0.70449	0.0021	1.00534895	1.4270543	0.08768	0.0021

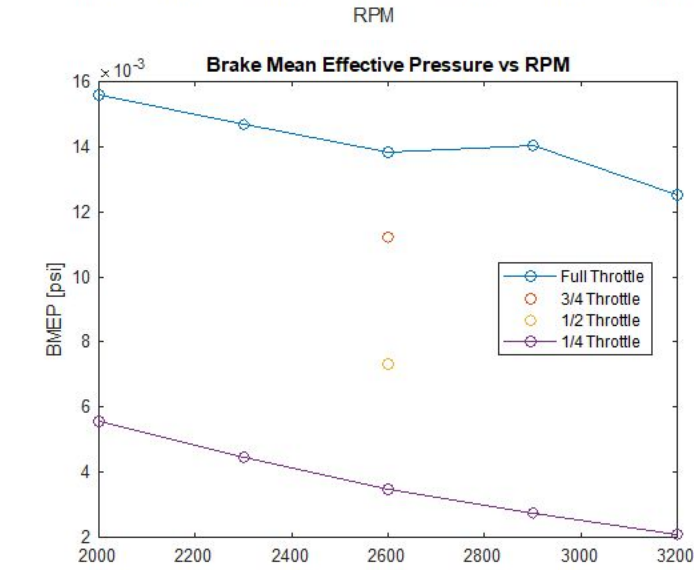












Error Analysis Discussion

There are several sources of error that may have caused errors in our results and final calculations. Sources can include incorrect timing of the 30 second window while measuring the initial and final weights of the fuel, unit conversion errors when calculating the engine parameters, and human error in reading the instrumentation that displayed the measurements such as for the pressure gauge. One error-prone step involves the incorrect reading of the instrumentation, as the measurements read can vary by an individual, leading to incorrect measurements and thus incorrect final calculations of the engine parameters. Another error-prone step involves the incorrect start up procedure of the engine, such as missing any leaks in the dynamometer or an insufficient motor oil level. Incorrectly starting up the engine can lead to widely inaccurate data as the required settings of the engine will be incorrect, greatly influencing the data collected and the following calculations. A new method of collecting data that would result in less error could include using a software program to record engine measurements such as the pressures and the temperatures. This would eliminate the possibility of human error as the software program would take a correct measurement of a value at the correct time.

Equations

Measured Brake power (W):

$$P_b = \frac{\dot{Q}\Delta p}{\eta_p} = \frac{(\text{dynamometer oil flow rate})(\text{dynamometer pressure})}{\text{pump efficiency}}$$

Brake specific fuel consumption (kg/Nm):

$$bsfc = \frac{\dot{m}_f}{P_b} = \frac{\text{fuel mass flow rate}}{\text{brake power}}$$

Brake mean effective pressure (N/m²):

$$bmep = \frac{W_b}{V_d} = \frac{P_b n_p}{V_d N} = \frac{(\text{brake power})(\text{revolutions per power stroke})}{(\text{displacement volume})(\text{rev/time})}$$

Brake Torque (Nm): $\tau = \frac{P_b}{2\pi N} = \frac{\text{brake power}}{2\pi \times (\text{rev/time})}$

Fuel/Air mass ratio $F/A = \frac{\dot{m}_f}{\dot{m}_a}$

$V_d = A_p L$

$\bar{S}_p = 2LN$

Volumetric Efficiency = $\eta_v = \frac{m_a}{\rho_{ai} V_d}$

Conversion Efficiency: $\eta_f = \frac{P_b}{\dot{m}_f H_{HV}} = \frac{1}{(bsfc) H_{HV}}$

Mechanical Efficiency: $\eta_m = \frac{P_b}{P_i}$

$$bmep = \eta_f \eta_v H_{HV} \rho_{ai} \left(\frac{F}{A}\right)$$

$$P_b = \eta_f \dot{m}_f H_{HV} = \eta_f \dot{m}_a (F/A) H_{HV}$$

$$P_b = \frac{\eta_f \eta_v \rho_{ai} V_d N (F/A) H_{HV}}{n_p} = \frac{(bmep) V_d N}{n_p} = \frac{(bmep) \bar{S}_p A_p}{2 n_p}$$

Conclusions

On full throttle, the engine has a relatively good torque, cycle efficiency, brake mean effective pressure, and brake specific fuel consumption, as well as a maximum absolute brake power, resulting from the engine speed of 2900 RPM.

At ¼ throttle, power, torque, brake mean effective pressure, and efficiency all simply decrease as the engine RPM increases, and the specific/absolute fuel consumption increases. The ½ and ¾ throttles at 2600 RPM show all results that lie between the highest and lowest throttle at 2600 RPM, as expected.

On full throttle at the desired engine speed of 2900 RPM, brake power is 4.266 HP, torque is .01405 ft-lbf, and efficiency is 25.22%. The absolute maximum torque of .01561 ft-lbf and absolute maximum efficiency of 44.50% occur at 2000 RPM, and the brake power is 3.270 HP.

References

[1] *Internal Combustion Engine Lab Manual, 650:435 Energy Systems Lab, Spring 2018*

[2] Pulkrabek, Willard W. Engineering Fundamentals of the Internal Combustion Engine. Pearson Prentice Hall, 2014.