COMPARISON OF CYLINDER PRESSURE DATA OF A GASOLINE ENGINE FOR IDEAL OTTO AND REAL CYCLES

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Abstract- In this study, cylinder pressure changings of a 4 stroke gasoline engine were formulated as a function of crankshaft angle. Cylinder pressure – crank angle graphs were obtained for ideal Otto cycle by using obtained equations. In the followings section, the 4 stroke engine was modeled by using 1-D numerical analysis program and pressure data acquired. The graph obtained by theoretical calculations and the other one obtained by the 1-D model were compared. The deviations of the cylinder pressure data determined by ideal system assumptions from the actual data were determined and illustrated.

Keywords- Cylinder pressure, Ideal Otto Cycle, 1-D Engine Model

I. INTRODUCTION

During the operation of the engine, the source of the obtained net work is cylinder pressures. The pressure becomes the gas force on the piston and it causes the rotation of the crankshaft. Determining the cylinder pressure is quite difficult. Except for experimental studies, it can be detected the approximate values using ideal Otto cycle and engine simulations. [1]-[2]
In a study by Chan and Zhu [3], thermodynamic analysis and modeling for high ignition advance has been made in a carbureted gasoline engine. It was investigated the exhaust gas temperature changings according to cylinder pressure and valve positions. It was evaluated that the effect of the ignition advance change on cylinder pressure and indicator diagram.
Choi et al [4], have studied on a model for stratified combustion in direct - injection spark ignition engines. The 3-D simulation was applied in the direct injection spark ignition engine geometry by STAR-CD program. The simulation results have provided important data to understand the combustion process in the engine.
Hooper, P. R. et al. [5], have simulated an engine by using Ricardo –Wave software. Fueling methods and core engine parameters have been modeled and compared, for multi-fuel operation.
Yontar, A. A. et al. [6] have numerically and experimentally investigated performance and exhaust emissions of Honda L13A4 motor at %75 throttle opening rate with respect to engine speed. The complete test engine was modeled by using Ricardo-Wave 1-D numerical analysis program. Experimental and model data have been compared. Effects of throttle opening rate on the performance and emissions have been presented.
In another study, Yontar, A. A. et al. [7] have modeled the combustion chamber of a four cylinder spark ignited engine with CFD software. They have investigated the effects of the ignition advance angle variation on performance and emissions of the engine fueled with isooctane. Optimum ignition advance time has been determined for constant speed, compression ratio and the air-fuel mixture ratio

II. DETERMINATION OF POSITION OF THE PISTON

Theoretically, piston's movements and positions should be analyzed for calculating the cylinder pressure. It is impossible to think the movement of piston independent from connecting rod and crank. In crank-connecting rod-piston mechanism; while piston moves linear, the motion of crank is circular, connecting rod is not only linear but also circular. These different movement types should be defined by one parameter.
In the study, all movements were defined as a function of crankshaft angle θ. In all equations, it was assumed that reference point of the piston's movement is TDC (Top dead center) and the crank rotates clockwise direction.
Any position of the piston was examined for intake or power stroke in figure 1, the obtained geometric and trigonometric equations has been a reference for other strokes.

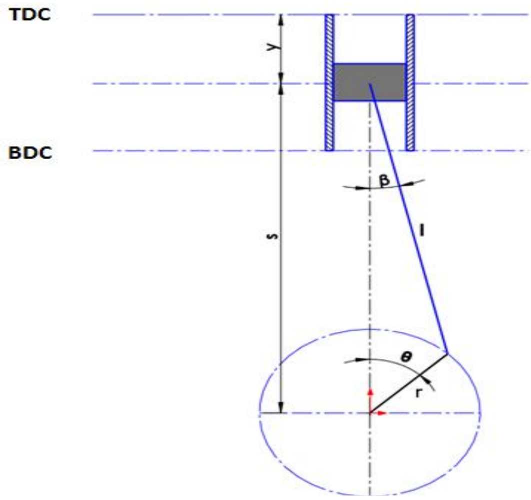

Fig.1. Positions of Crank and Piston

$$y + s = l + r \Rightarrow y = l + r - s \quad (1)$$

$$(s - r.\cos\theta)^2 = l^2 - r^2.\sin^2\theta \quad (2)$$

$$s = \sqrt{l^2 - r^2.\sin^2\theta} + r.\cos\theta \quad (3)$$

Equation 3 has been replaced with s term in eq.1 and thus, the piston position can be formulated as a function of crank angle.

$$y = l + r - \sqrt{l^2 - r^2.\sin^2\theta} - r.\cos\theta \quad (4)$$

III. CALCULATING OF CYLINDER PRESSURE BY USING IDEAL OTTO CYCLE EQUATIONS

In the ideal Otto cycle, cylinder pressure of a 4 stroke engine refers to 4 different situations. The first one is intake pressure. In the intake stroke, suction valve opens and the air is started to take into the cylinder at about 1 atm. While air is sucked by vacuum effect of the piston, the piston moves downward. Theoretically, suction continues until crank angle $\theta = \pi$. Because of the open valves, cylinder pressure may be considered to be equal to atmospheric pressure in intake stroke

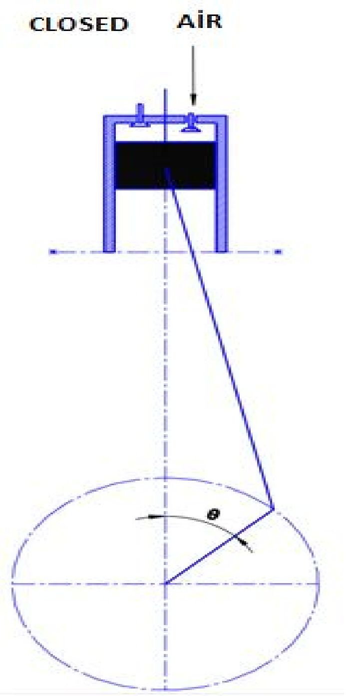

Fig.2. Crank-Connecting Rod - Piston Mechanism in Intake Stroke

The second situation is the pressure in the compression stroke. While compression, it is assumed that system is adiabatic and isentropic.
When piston is at any 'y' point between $\pi \leq \theta \leq 2\pi$, cylinder volume V_y;

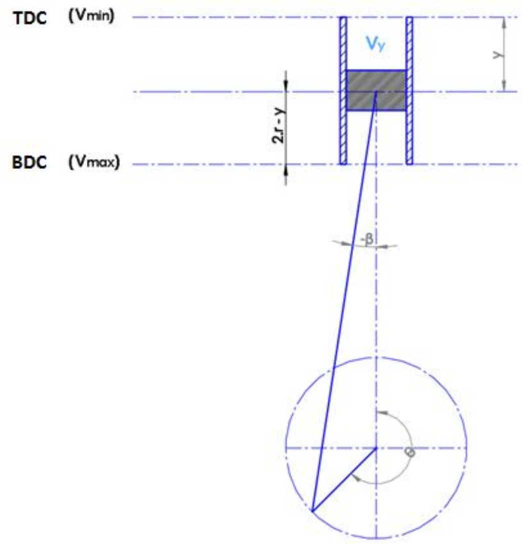

Fig.3. Crank-Connecting Rod - Piston Mechanism in Compression Stroke

$$V_y = V_{max} - (2r - y).\left(\frac{\pi.D^2}{4}\right) \quad (5)$$

Substituting equation 3 into equation 4 and instead of 'y', cylinder volume can be calculated in compression stroke as a function of crank angle.

$$V_y = V_{max} + \left(l - r - \sqrt{l^2 - r^2.\sin^2\theta} - r.\cos\theta\right).\left(\frac{\pi.D^2}{4}\right) \quad (6)$$

Cylinder pressure - volume graph is shown in figure 4. In the graph, during the movement of the piston from point 1 to 2, the temperature was assumed to increase from 69 °C to 243 °C. (Based on 1-D model results). From Table A-2E (Ideal-gas specific heats of various gases), specific heat ratio 'k=1,394' was chosen at 156 °C average temperature for air. [1]

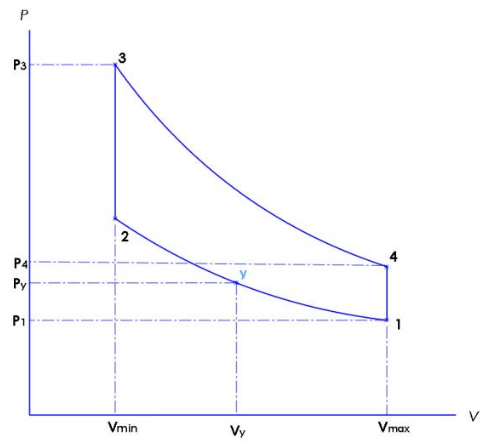

Fig.4. P-V Graph for an Instant in Compression Stroke

At any time in compression stroke, cylinder pressure;

$$P_y = P_1.\left(\frac{V_1}{V_y}\right)^k \quad (7)$$

If V_y replaces with equation 6, cylinder pressure can be determined as a function of θ in the compression stroke.

$$P_y = P_{min} \cdot \left(\frac{V_{max}}{V_{max} + \left(\frac{\pi . D^2}{4}\right) . \left(l - r - \sqrt{l^2 - r^2 . \sin^2\theta} - r . \cos\theta\right)} \right)^{k=1,389}$$

(8)

The third situation is pressure in the power stroke. The stroke is assumed adiabatic and isentropic too.

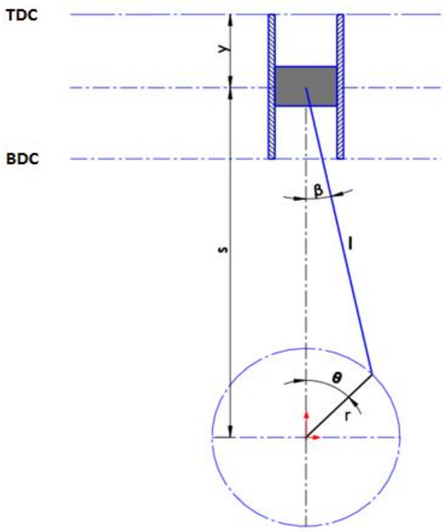

Fig.5. Crank-Connecting Rod - Piston Mechanism in Power Stroke

At any 'y' point between $2\pi \le \theta \le 3\pi$, cylinder volume V_y;

$$V_y = V_{min} + y . \left(\frac{\pi . D^2}{4}\right) \quad (9)$$

$$V_y = V_{min} + \left(l + r - \sqrt{l^2 - r^2 . \sin^2\theta} - r . \cos\theta\right) . \left(\frac{\pi . D^2}{4}\right) \quad (10)$$

P-V graph should be examined in order to associate volume and pressure. Cylinder pressure - volume graph is shown in figure 6.

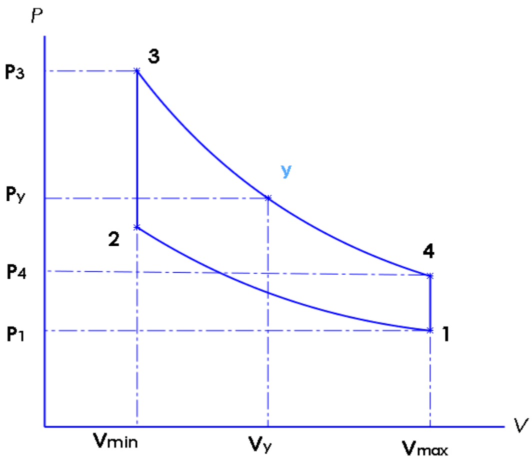

Fig.6. P-V Graph for an Instant in Power Stroke

During the movement of the piston from point 3 to 4, the temperature was assumed to decrease from 1600 °C to 600 °C. (Based on 1-D model results). From Table A-2E (Ideal-gas specific heats of various gases table) specific heat ratio 'k=1,312' was chosen at 1100°C average temperature for air [1]. Cylinder pressure at point 'y';

$$P_y = P_3 . \left(\frac{V_3}{V_y}\right)^k \quad (11)$$

Instead of V_y, equation 10 can be used for calculating pressure in power stroke;

$$P_y = P_{max} \cdot \left(\frac{V_{min}}{V_{min} + \left(\frac{\pi . D^2}{4}\right) . \left(l + r - \sqrt{l^2 - r^2 . \sin^2\theta} - r . \cos\theta\right)} \right)^{1,312}$$

(12)

The fourth case is the exhaust pressure. In the exhaust stroke, the exhaust valve opens and cylinder pressure becomes approximately 1 atm. Theoretically, exhaust continues until $\theta = 4\pi$. Because of the open exhaust valves, cylinder pressure may be considered to be equal to atmospheric pressure.

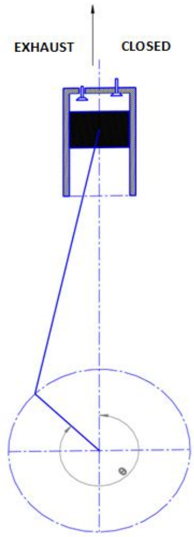

Fig.7. Crank-Connecting Rod - Piston Mechanism in Exhaust Stroke

4 stroke engines complete a cycle at 720°. For 4 situation identified above, pressure – crank angle graph in 0° – 720° range is shown in figure 8.

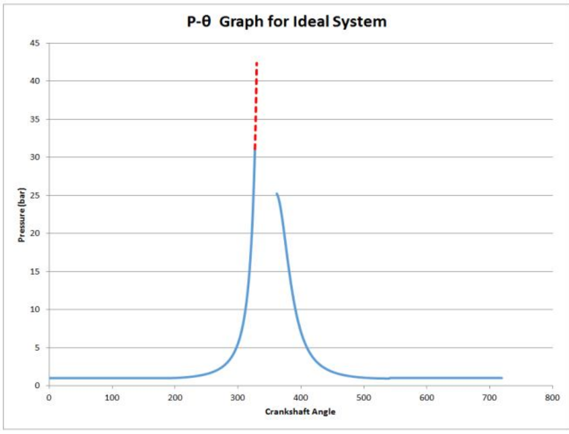

Fig.8. Crankshaft Angle - Pressure Graph

1-D MODELING

In the numerical part of the study, a 4 stroke spark ignited engine was modeled by a modeling program with all components. Geometric and physical features of the components of the engine used in the study were determined. Each element constituting the motor was modeled and all elements from intake line to exhaust line were connected to each other.

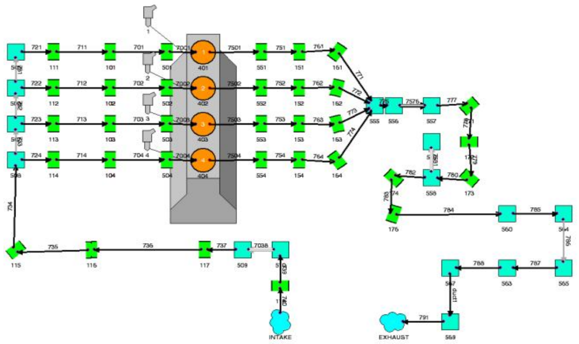

Fig.9. 1D Modelling of The System

The engine was modeled with all parts and simulated after defining the initial and boundary conditions (excess air factor, piston temperature, cylinder temperature, valve temperatures, engine block temperature, throttle opening rate, crank speed etc.). It was defined that convergence criteria is 0.01, the number of cycles is 300 and time step size is 0.5.

As a result of the analysis, cylinder pressure values obtained by the numerical model were examined. The results acquired from the motor model were evaluated in the following section as compared with the theoretical calculation results.

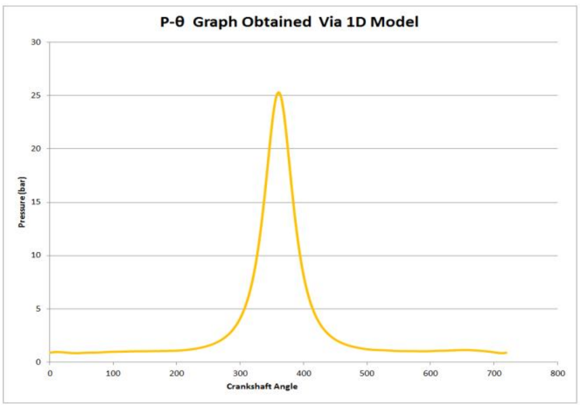

Fig.10. Crankshaft Angle - Pressure Graph

IV. COMPARISON OF RESULTS OF THE IDEAL SYSTEM AND 1D MODEL

The graphs obtained by the ideal system and 1-D model have been given above. The graphics are shown in figure 11 as overlapped to observe more clearly the difference between two systems.

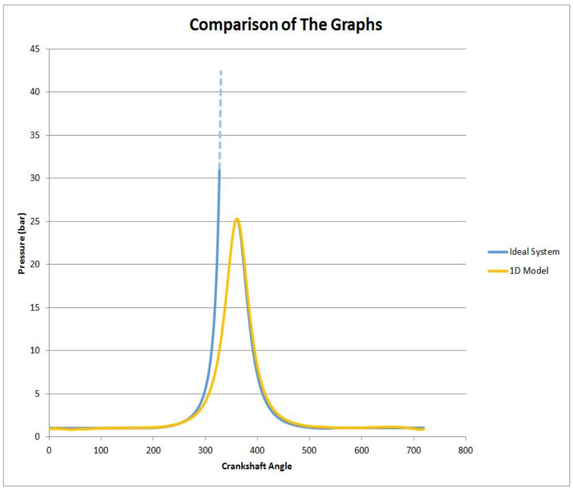

Fig.11. Comparison of the Systems

Serious differences are seen in compression region of the graph. It is observed that the ideal system pressure values are increasing abnormally after 255^{o} crank angle. The pressure value reaches 12000 bar at 345^{o}. After 345^{o}, pressure data doesn't make any sense. Because they are in complex numbers.
As for the other sections of the graph, it confirms that the pressure values are consistent for the ideal system and the model.

CONCLUSIONS

It is observed that significant differences between two systems on a portion of the graph. The main reason for the differences is ideal system assumptions. These are;
- The cycle executes in a closed system
- Air is used as a fuel (Standard air assumptions)
- Intake air pressure is 1 Atm
- All strokes take 180^{o} degree (0-180: Intake stroke, 180-360 : Compression Stroke, 360-540: Power Stroke, 540-720: Exhaust Stroke)
- Compression and power strokes are adiabatic and isentropic
- Cylinder pressure equal to atmospheric pressure in exhaust stroke
- Advance angle is '0' in combustion
- Cylinder pressure is independent of crank speed

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