# The Effect of Spark Plug Position on Spark Ignition Combustion

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**SUMMARY**

The way in which position of spark plug affects combustion in spark ignition engine was studied by using the developed quasi-dimensional cycle simulation (using two-zone burning model) program. The purpose of this paper is to model the geometric interaction between the propagating flame and the general cylindrical combustion chamber. Eight different cases were recognized. Appropriate equations to calculate the flame area $(A_f)$, the burned and the unburned volume ($V_b$ & $V_u$) and the heat transfer areas related to the burned and unburned regions were derived and presented for each case. Predicted results for the Paykan, 1600 cc engine are presented and compared qualitatively with the predicted results of the reference [1].

## INTRODUCTION

In recent years the combined effects of environmental legislation and the energy saving demands have led to a major expansion of research and development work in order to make a better fuel combustion, and reduce noise and pollutant emissions. In this context many codes were developed to simulate internal combustion engines, such as quasi-dimensional models [2-4] and two or three, dimensional codes, which classified as CFD codes [5-7]. Although the CFD codes (like KIVA) permit to simulate very well the physical phenomena involved in engines, but the long time needed for calculation is one of their shortages. In opposition the quasi-dimensional models (like SAPENG used in this research) are fast execution models, which can be used extensively by automotive industry in order to develop engine design and filling and emptying operation very fast. The purpose of this work is to determine the effect of spark plug position on the burning process of disc combustion chamber geometry in SI engines by introducing some algebraic correlations. The approach taken is to use the developed engine cycle simulation to perform illustrative calculations aimed to show the feasibility of using the given correlations in quasi-dimensional cycle simulations.

## SI ENGINE CYCLE SIMULATION

The SI engine cycle is treated as a sequence of four continues process: intake, compression, combustion (including expansion), and exhaust. The combustion process is simulated as a two zone quasi-dimensional model. The combustion chamber is divided into two volumes: the unburned zone (subindex u) composed by air, fuel and residuals and burned zone (subindex b) composed by combustion products. The energy equation for each zone is applied to open system. The Annand correlation is used to calculate the rate of heat transfer from engine. The numerical method for solving differential equations in this work is Range-Kutta fourth order. The detailed of the program is given in Ref. [8].

## GEOMETRIC INTRACTIONS

If spark plug is located at the center of the disk shape combustion chamber four different cases as shown in Figure1 can be distinguished as follows [9].

$$r_f \le B/2 \; ; \; r_f \le h_{gap} \qquad \text{(Case 1)} \qquad (1\text{-a})$$
$$r_f \le B/2 \; ; \; r_f > h_{gap} \qquad \text{(Case 2)} \qquad (1\text{-b})$$
$$r_f > B/2 \; ; \; r_f \le h_{gap} \qquad \text{(Case 3)} \qquad (1\text{-c})$$
$$r_f > B/2 \; ; \; r_f > h_{gap} \qquad \text{(Case 4)} \qquad (1\text{-d})$$

Where $r_f$ is the flame radius, B is the cylindrical bore and $h_{gap}$ is the height of combustion chamber. If the spark plug is not located at the center, eight possible cases can be distinguished due to different values of eccentricity (e), cylinder bore (B) and combustion chamber height ($h_{gap}$). These cases showed by the following relations corresponds to the figures 2 (a) to (h).

$$r_f \le h_{gap} \; ; \; r_f \le B/2 - e \qquad \text{(Case 1)} \qquad (2\text{-a})$$
$$r_f > h_{gap} \; ; \; r_f \le B/2 - e \qquad \text{(Case 2)} \qquad (2\text{-b})$$
$$r_f \le h_{gap} \; ; \; r_f > B/2 - e \; ; \; r_f \le B/2 + e \qquad \text{(Case 3)} \qquad (2\text{-c})$$
$$r_f \le h_{gap} \; ; \; r_f > B/2 + e \qquad \text{(Case 4)} \qquad (2\text{-d})$$
$$r_f > h_{gap} \; ; \; r_f > B/2 - e \; ; \; r_f \le B/2 + e$$
$$r_f \le \sqrt{( h_{gap}^2 + (B/2 - e)^2)} \qquad \text{(Case 5)} \qquad (2\text{-e})$$
$$r_f > B/2 - e \; , \; r_f \le B/2 + e$$
$$r_f > \sqrt{( h_{gap}^2 + (B/2 - e)^2)} \qquad \text{(Case 6)} \qquad (2\text{-f})$$
$$r_f > h_{gap} \; , \; r_f > B/2 + e$$
$$r_f \le \sqrt{( h_{gap}^2 + (B/2 - e)^2)} \qquad \text{(Case 7)} \qquad (2\text{-g})$$
$$r_f > B/2 + e \; , \; r_f > \sqrt{( h_{gap}^2 + ( B/2 - e)^2)} \qquad \text{(Case 8)} \qquad (2\text{-h})$$

Eccentricity (e) is the distance between the location of spark plug and the center of disc combustion chamber.

## CALCULATION OF ENFLAME VOLUME, FLAME FRONT AREA AND WALL AREAS

Chen and co workers [9] presented the following equation for calculating the enflame volume of burned region.

$$V_b = (\pi/8)\, B^3 \{[1/3\, (2r_f/B)^3\, [\alpha^3 - \beta^3 - 3(\alpha - \beta)] - (2r_f/B)\, \alpha\} \qquad (3)$$

Where α and β can be obtained from following equations in regard to the four cases shown by equation 1.

$$\alpha = 0 \qquad (r_f \le B/2) \qquad (4\text{-a})$$
$$\alpha = \sqrt{[\, 1 - [( (B/2)/ r_f )^2\, ]} \qquad (r_f > B/2) \qquad (4\text{-b})$$
$$\beta = 1 \qquad (r_f \le h_{gap}) \qquad (4\text{-c})$$
$$\beta = h_{gap} / r_f \qquad (r_f > h_{gap}) \qquad (4\text{-d})$$

The volume of unburned is obtained after estimation of burned volume

$$V_u = V - V_b \qquad (5)$$

Chen [9] presented the following equation for calculating the flame front area

$$A_f = (\pi/4)\, B^2 \,[2(2r_f/B)^2 (\alpha - \beta)] \qquad (6)$$

The equation for calculating the heat transfer area of the burned region is given by [9]:

$$A_b = \pi r_f^2 \,[\,2 + B\alpha / r_f - (\alpha^2 - \beta^2)] \qquad (7)$$

The heat transfer area of the unburned region is therefore can be calculated:

$$A_u = A_t - A_b \qquad (8)$$

The percentage of eccentricity ($E_{per}$) is determined by the following relation:

$$E_{per} = (2e/B) * 100 \qquad (9)$$

Now, if the location of spark plug changes from the center, eight different cases of interaction of the flame with the surface of piston or cylinder wall may be created, therefore eight different equations for calculating the enflame volume, the flame front area, and the wall areas related to the burned and the unburned regions can be obtained. The details of these equations are given in reference [8].

## RESULTS & DISCUSSIONS

The results obtained in this work are based on Paykan 1600c.c. engine. These data correspond to the 3000 rpm condition. The spherical flame maps of the combustion chambers considered in this study are shown in Figs. 3-6. The acceptable way to compare the flame propagation properties of general combustion chamber is to evaluate the non-dimensional surface-to-volume ratio of the flame ($A_f / V_b^{2/3}$) as a function of volume fraction entrained ($V_b / V(\theta)$) or of flame radius ($r_f / B$). Results obtained for the disc combustion chamber with side and center ignition are plotted in Fig. 3 which shows flame front area versus flame radius for selected crank angles from top dead center. The radius at which the flame area is first affected by crank angle equals the distance from the spark plug electrodes to the nearest piston surface. Usually this distance is shorter for chambers with side ignition than for chambers with more centered ignition. Note also that as the spark plug location nears the center of chamber the flame radius required for the flame to propagate through the entire chamber decreases. Fig. 4 shows the flame area versus the flame radius and crank angle for different percentage of eccentricity. It can be seen as the percentage of eccentricity increases the shape of curves in Fig. 3-b (center ignition) closes to the shape of curves in Fig. 3-a (side ignition). Fig. 5 shows the rate of burning versus crank angle for different ignition angle and different percentage of eccentricity. Fig. 6 shows the corresponding cylinder pressures of the cases presented in Fig. 5 which we could have been expected.

## CONCLUSIONS

For cylindrical combustion chamber in which flame propagation occurs roughly spherically, the following conclusions can be drawn.

1. The effect of spark plug position on Spark Ignition Combustion investigated by using the quasi-dimensional SI engine cycle simulation (SAPENG).
2. Combustion chamber geometry and the position of spark plug have a strong effect on the burning time duration.
3. By increasing the percentage of eccentricity the flame area, rate of burning, turbulent flame velocity, maximum pressure, torque output will decrease.

4. The result obtained for the Peykan 1600c.c Motor qualitatively consistent with the results reported by the reference [1].


## ACKNOWLEDGMENT

The author gratefully acknowledges financial support by SAPCO Company and Ferdowsi University Research department. Also thanks to Mr. Amooshahi and Mr. Assadollahi for their collaboration in the development of the given algebraic correlations.


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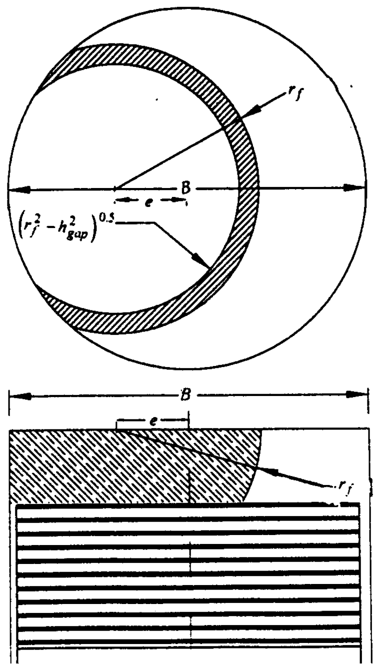


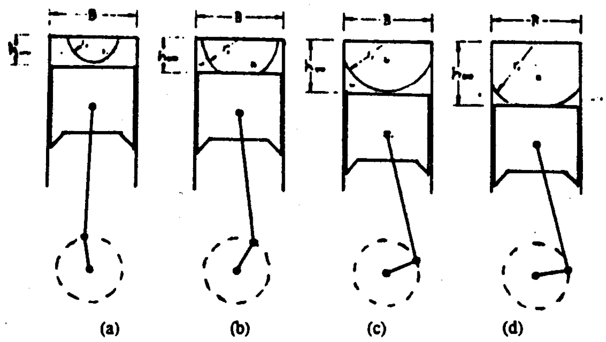




Fig. 1. Four different cases of geometric interaction between spherical flame and the combustion chamber walls and piston top surface when the position of the spark plug is centered.

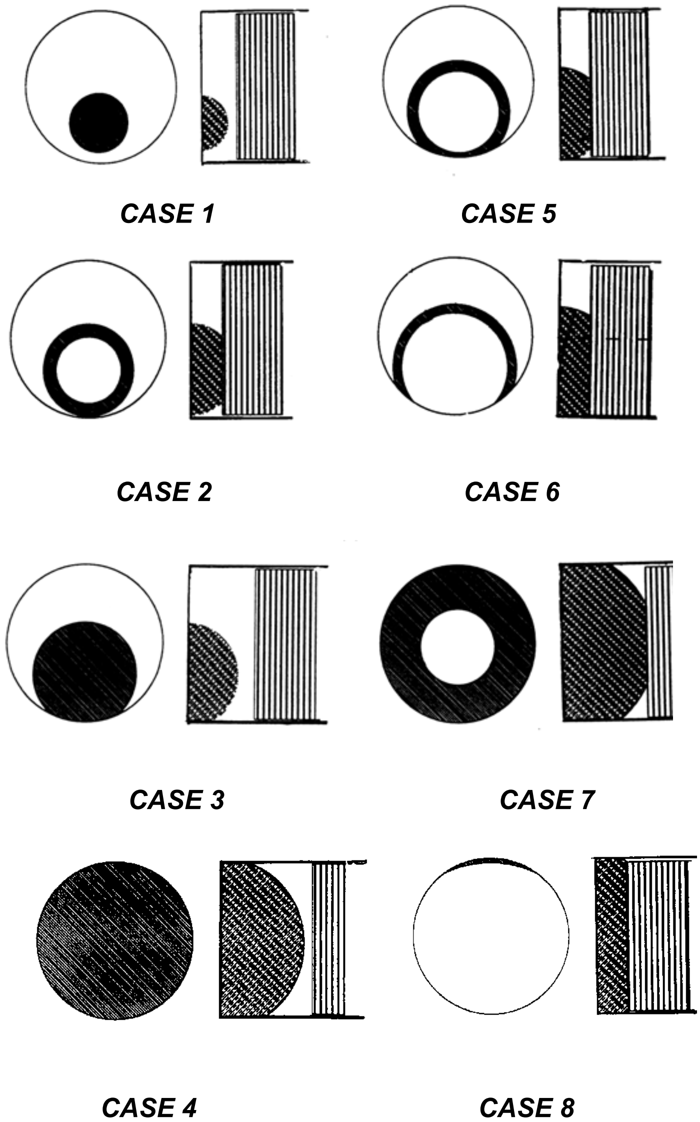



Fig.2. Eight different cases of geometric interaction between a spherical flame and the combustion chamber walls and piston top surface when the position of spark plug is not centered.

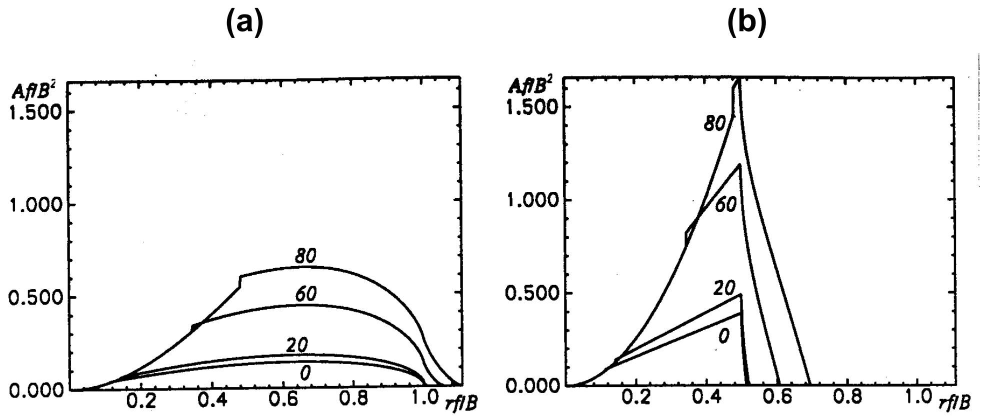
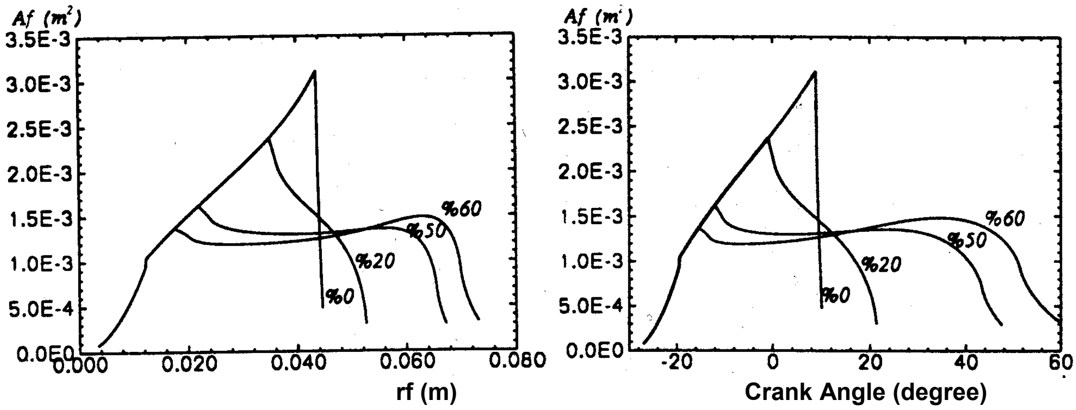
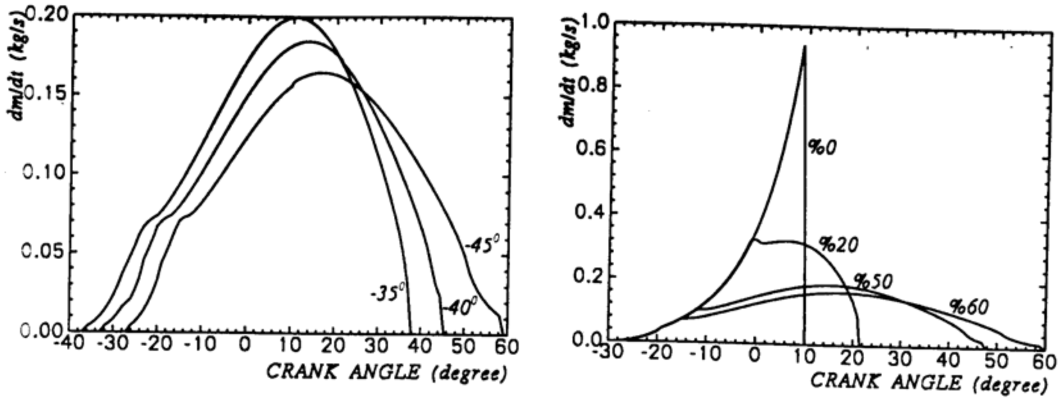



Fig. 3. Flame area versus flame radius and crank angle from top dead center for
(a) disc chamber with side ignition.
(b) disc chamber with center ignition.



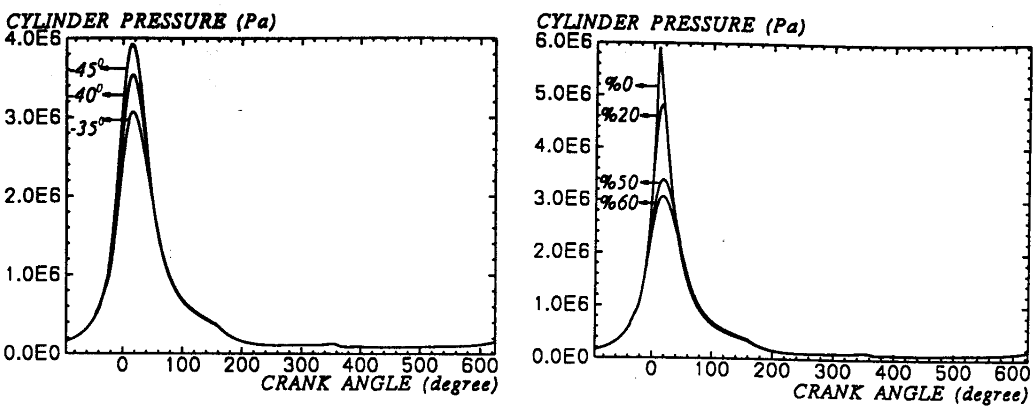

(a) (b)

Fig. 4. Flame area versus flame radius for the percent of eccentricity 0, 20%, 50% & 60% for high load Paykan engine. ($\eta_v$ = 92% & N = 3000rpm)
(a) flame area vs. flame radius (b) flame area vs. crank angle




(a) (b)

Fig. 5. Rate of burning versus crank angle for the Paykan engine ($\eta_v$ = 92% & N = 3000rpm).
(a) for 60% eccentricity of different ignition angles. (b) for different percentage of eccentricity.




(a) (b)

Fig. 6. Cylinder pressure versus crank angle for Paykan engine
(a) at 60% eccentricity for different ignition angle (b) for different percentage of eccentricity.

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