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Mathematical Investigation and Modeling of Pressure and Temperature Variation Inside a Si Engine

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Abstract

Studying various parameters of an engine through experimentation consumes lot of time and funds. By devising ways to simulate the engine and virtually test the performance of the output parameters leads to resource saving. In this work a four stroke SI engine has been modelled on grounds of various established mathematical theories and by referring previous research. The paper investigates the pressure and temperature variation inside an SI engine at compression and combustion phases with respect to the crack rotation at a constant speed, considering the variation of properties with temperature, all this done to proximate the real processes.

Keywords: *Combustion Process, Modeling, Simulation, SI Engine, Crank Rotation*

1. Introduction

The objective of this paper is to develop a mathematical model combining the physical formulae and empirical formulae. Simulation process has come to develop and use the appropriate combinations of assumptions and equations that permit critical features of the process to be analysed. As of now two basic models have been developed, they can be categorized as thermodynamic and fluid dynamic. The concern is laid upon the thermodynamic or the energy conservation approach with emphasis on combustion physics and chemistry, heat transfer and friction processes relevant to spark-ignition engines with simplified assumptions. Engine geometries, such as bore, stroke, and compression ratio are calculated to obtain physical information such as displacement volume, area and volume variation as function of crank angle [1].

$$V(\theta) = \frac{V_d}{r-1} + \frac{V_d}{2}[\frac{l}{a} + 1 - \cos\theta - \left\{\left(\frac{l}{a}\right)^2 - (\sin\theta)^2\right\}]^{\frac{1}{2}} \quad (1)$$

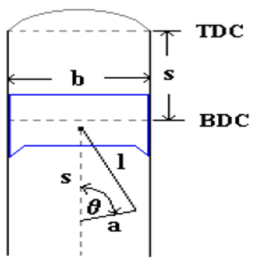

Fig.1: Volume Variation

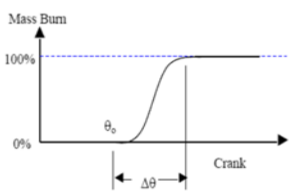

Fig.2: Wiebe Function

For comparison, engines are assumed to work on ideal air standard closed cycles. This deviates from idealism as an engine actually works on an open cycle with a gas exchange process in each rotation of the crank for a four stroke engine, and thus leading to finite loses. In an actual engine heat addition process is not instantaneous as assumed in ideal Otto cycle instead but it takes finite time for the heat addition process. Then the cylinder pressure prediction is done by integrating it with the factor of heat addition. Heat energy needs data from amount of flow in mass and burn characteristic which is described by Wiebe function. Predicted pressure is used to determine temperature inside cylinder and heat transfer from cylinder to wall chamber. Rate of heat loss will be fed back to the pressure prediction function. Resulted pressure will be converted to indicate mean effective pressure subtracted by mean friction, then work and power will be known finally [2]. The Wiebe Function: The Wiebe function (f) is widely used in engine simulations to represent the mass fraction burn profile as a function of crankshaft position [4]. Wiebe function model fits the experimental mass fraction burn profiles.

$$f(\theta) = 1 - exp\left[-a\left(\frac{\theta-\theta_o}{\Delta\theta}\right)^{m+1}\right] \quad (2)$$

To account for the large temperature difference seen in the air standard Otto cycle constant average values of specific heat are used. Specific heat is expressed as a polynomial function of temperature with differential set of constants for different range of temperatures. Heat is lost from the system due to the presence of a thermal

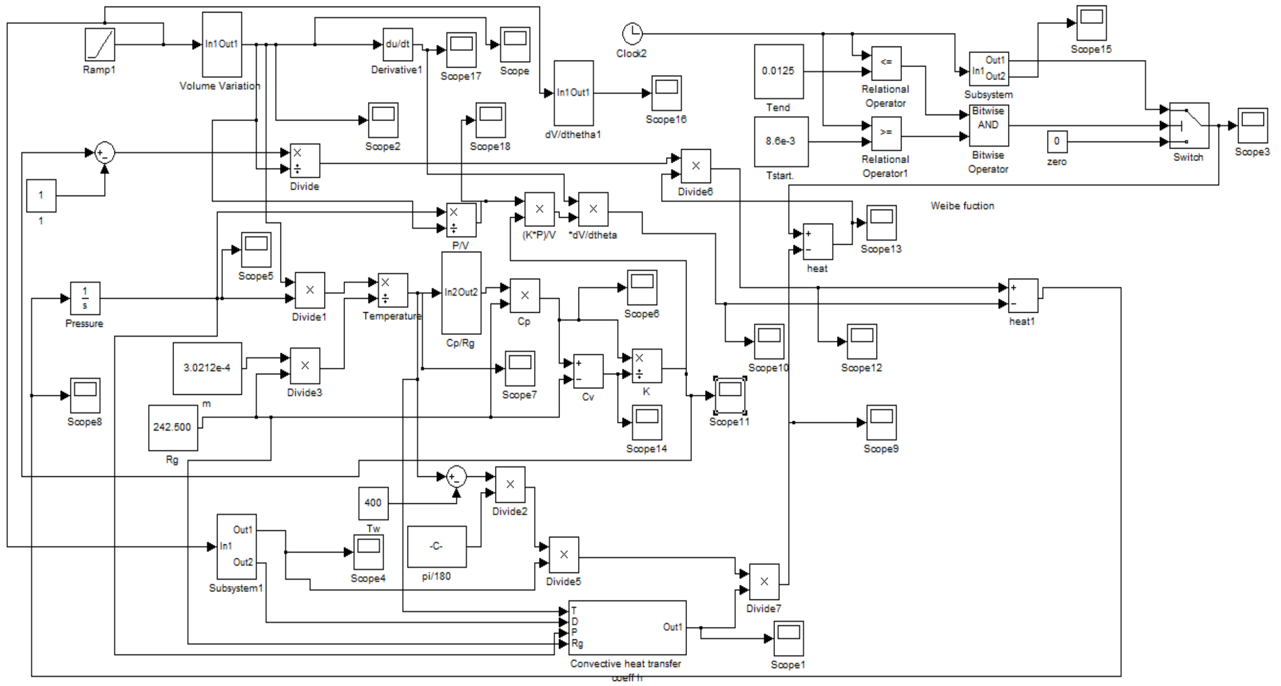

Fig 3: Full model

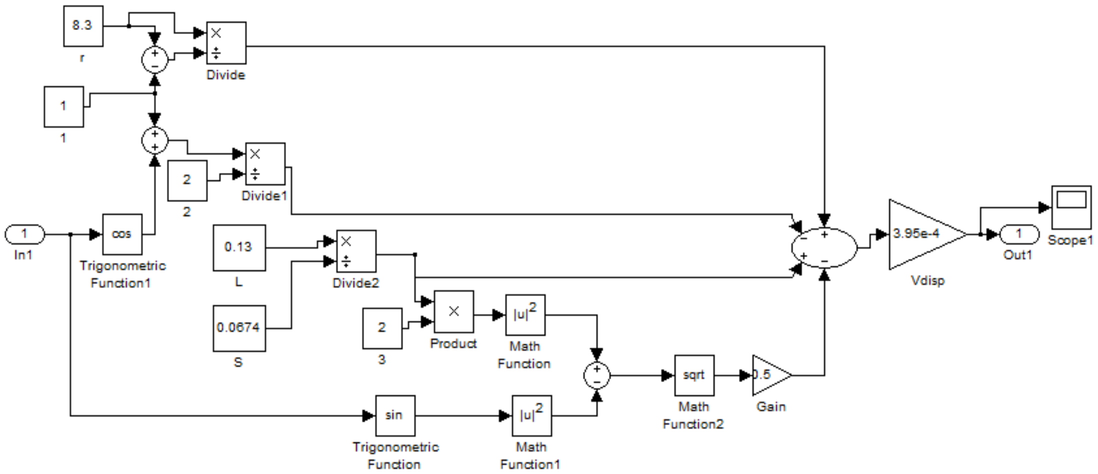

Fig4: Volume Variation

gradient. Heat loss commonly takes place by convection and radiation processes, the major one being convection. For generic results various heat transfer coefficient models were studied such as Annands, Hohenberg's and Woschni's models. The coefficient for the convective heat transfer is taken from the Woschni model expressed as a function of temperature, pressure, and the velocity of the burned gas.

2. Mathematical Model

The model is beginning from the combustion process. The volume variation in the engine for the charge is given by eq. (1) in terms of geometrical variation of the combustion space. From the first law of thermodynamics, we know that energy within the system remains conserved. Based on ideal gas model and other fundamental theories, the relation of pressure with respect to crank angle is given by:

$$\frac{dP}{d\theta} = \frac{k-1}{V}\left(Q_{in}\frac{\partial f}{d\theta} - Q_{loss}\right) - k\frac{P}{V}\frac{dV}{d\theta} \quad (3)$$

In the above equation Q_{in} ∂f/dθ is the heat energy released from the combustion which is modelled with the help of weibe function incorporating variable mass burn rate for the fuel [8]. The combustion process is considered to be progressive. The adjustable parameter values are found to be a=5 and m=0. The right hand side term of eq. (1) deals with the pressure variation as a result of the combustion process and the second term deals with the variation due to geometric variation [5, 7].

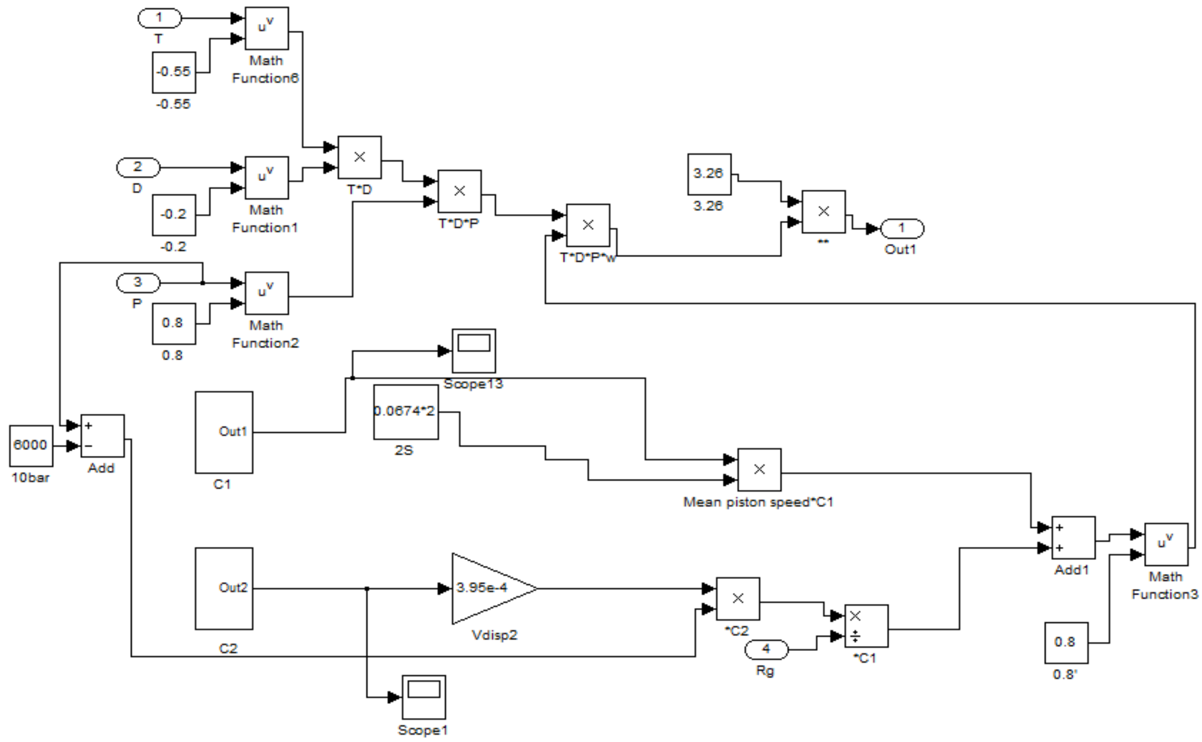

Fig.5: Heat loss model

The specific heat relations can be given as [3]:

For 200<T<1000K (4)

$$\frac{C_p}{R_g} = 3.56839 - 6.788729 \times 10^{-4}T + 1.5537 \times 10^{-6}T^2 - 3.29937 \times 10^{-12}T^3 - 466.395 \times 10^{-15}T^4$$

For 1000<T<6000K (5)

$$\frac{C_p}{R_g} = 3.08793 - 12.4597 \times 10^{-4}T - 0.42372 \times 10^{-6}T^2 - 67.4775 \times 10^{-12}T^3 - 3.97077 \times 10^{-15}T^4$$

The convective heat transfer coefficient taken from the Woschni model is as follows:

$$h_{cg} = 3.26D^{-0.2}P^{0.8}T^{-0.55}w^{0.8} \quad (6)$$

In this work an SI engine with the following parameters was considered. [3].

Table 1 Experimental procedure parameters

Fuel	C8H18
Compression ratio	8.3
Cylinder bore (m)	0.0864
Stroke (m)	0.0674
Connecting rod length (m)	0.13
Crank radius (m)	0.0337
Clearance volume (m3)	5.41×10−5
Swept volume (m3)	3.95×10−4
Engine speed (rpm)	3000
Ignition timing	−25° BTDC
Duration of combustion	70°
Wall temperature (K)	400

Table 2 Nomenclature

a	Heat transfer area, m2
C_p	Specific heat at constant volume, m3
D	Cylinder bore, m
F	Wiebe function
k	Ratio of specific heat at constant pressure to specific heat at constant volume
l	Connecting rod length, m
m	Mass of cylinder contents, kg
P	Pressure inside cylinder, Pa
Q_{in}	Heat added from burning fuel, kJ
Q_{loss}	Heat energy getting dissipated from the engine via convection, kJ
r	Crank Radius, m
R_g	Universal gas constant
T	Temperature of the gas in cylinder, K
V	Cylinder Volume, m^3
V_d	Displacement Volume, m^3
w	Velocity of the burned gas, m/s
Δθ	Duration of combustion, degree
θ	Angle, degree
$θ_0$	Start of combustion or heat addition, degree

3. Simulink Model

The mathematical model was simulated on MATLAB/SIMULINK environment to find the various parameters in the combustion.

4. Results

Volume Variation with respect to time

The Volume is varying from 4. 5 x 10^{-6} m^3 to 0 m3 with the movement of piston.

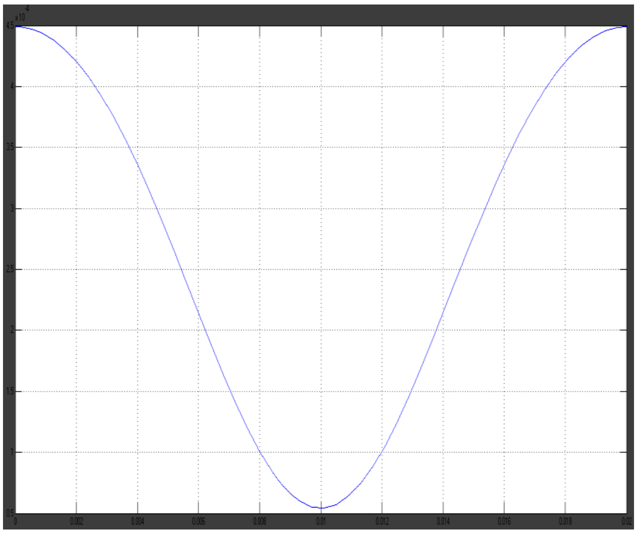

Fig.6: Simulink Graph showing Volume Variation

Variation of area available for heat transfer

The variation of area of the area available for heat transfer is varying from 0.025 m^2 to 0.0059 m^2

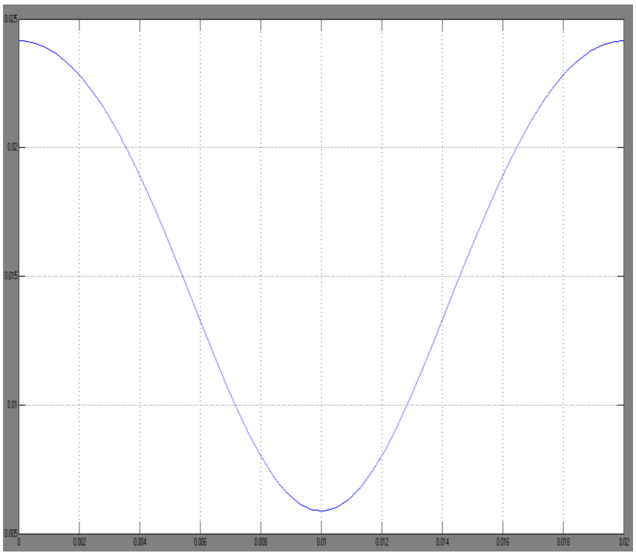

Fig.7: Simulink Graph showing Heat transfer Area variation

Variation of Polytrophic constant

K value is varying from 1.37 to 1.28 with the change of temperature during the working of the engine

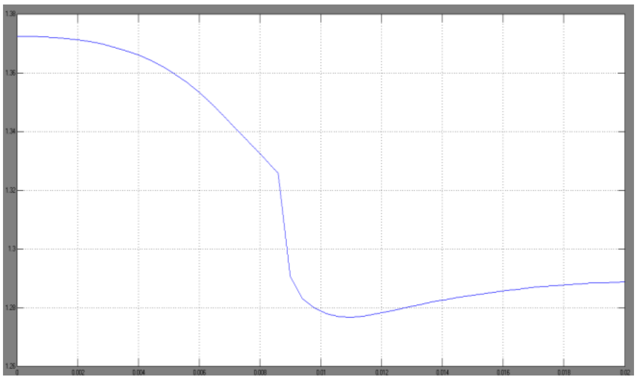

Fig.8: Simulink Graph showing Variation of k

Variation of temperature with repect to time

Peak Temperature of 2500k (approximately) is achieved

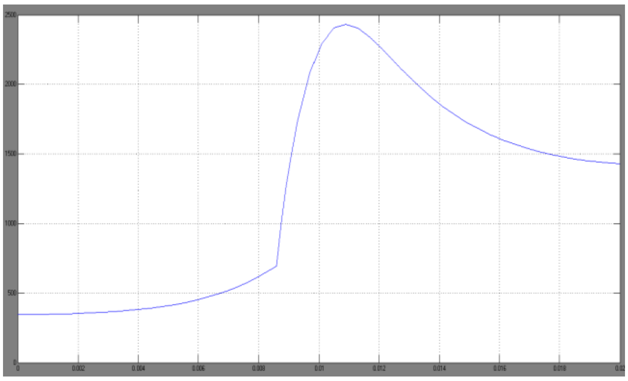

Fig.10: Simulink Graph showing Temperature variation inside the combustion chamber

Varation of pressure with respect to time

Peak pressure of 54 Bar is acchieved

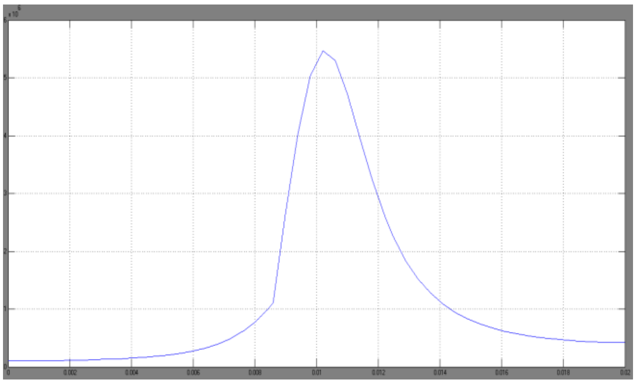

Fig.9: Simulink Graph showing Pressure variation during combustion in an engine

Variation of rate of change of pressure with respect to time

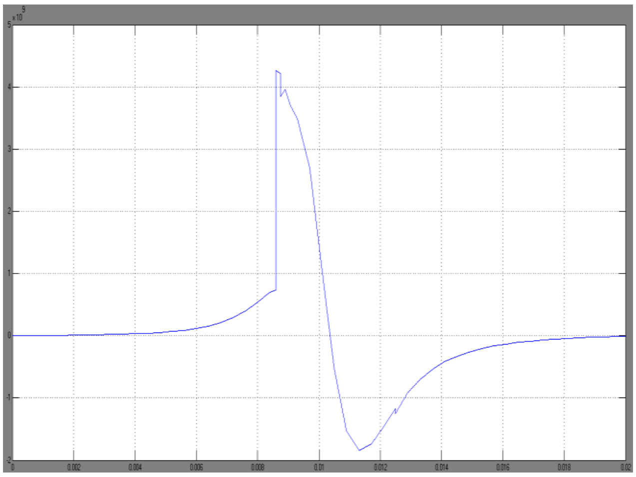

Fig.11: Simulink Graph showing Rate of change of pressure

Conclusion

The model simulated was quite consistent with the theoretical and previous works thus this model can be used as an iteration tool while designing a new engine. Thus it can save a lot of time and money. Further the model can be developed to incorporate even the gas exchange processes thus making it closer to the real case engine.

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