

Internal Combustion Engine Design: a Practical Computational Methodology

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ABSTRACT

Internal combustion engine design is a complex operation in which a large quantity of variables must be considered. In industrial field, a new internal combustion engine project starts from the development of well-established solution and from the designer experience. The aim of this research is the development of a series of procedures to design and to verify all main engine components starting from a deep bibliographic research. Every engine component (crankshaft, piston, piston pin, connecting rod, engine block, engine head, bearings and valvetrain) has its own interface for the design and the check. First of all, a deep bibliographic analysis was performed in order to find the best design procedures and a series of geometrical and thermodynamic data for a generic internal combustion engine. All these data are used as calculation input data. A large number of input data are in common for all the components and they are implemented in an input interface while other information, such as components material or typical geometric dimension, are requested in the specific component interface.

INTRODUCTION

In industrial field, a new internal combustion engine project starts from the development of well-established solution and from the designer experience. In academic field, students who approach for the first time the engine design have few instruments to understand the procedure for designing an engine and how the components dimensions can be defined. The aim of this research is to provide engine designers and students with an easy instrument that allows them to evaluate different engine conception, component design and a first attempt layout of the engine. The presented procedure does not want to substitute engineers

experience and specialists knowledge, but it has the intent to suggest a whole engine layout, considering interactions between each main component, that can be used as draft for the design of a new engine. In order to reach this goal, a series of procedures to design and to verify all main engine components starting from a deep bibliographic research are implemented in MATLAB[®] language by means of graphical user interfaces (GUI). MATLAB[®] choice is due to the possibility to perform an independent interface in which every component design can be executed after the introduction of some characteristic parameters of the new internal combustion engine. A simple tool is then obtained and it is called "Engine Development Code".

ENGINE DEVELOPMENT CODE

The code basic philosophy is to insert the minimum number of parameters for evaluating engine layout, so the common inputs (thermodynamic data and engine type) are introduced in the first panel for starting the procedure. For every engine component, a tailored interface is developed, that after the input of characteristic data, allows user to design and dimensionally validate the component. This philosophy is supported by means of a wide bibliographic analysis performed in order to find the best design procedures and a series of geometrical and thermodynamic data for a generic internal combustion engine.

The first computational step is the crank study that is implemented to calculate the total force acting on the engine components. This force considers inertia forces due to reciprocating mass (piston, rings, piston pin, connecting rod, and crank) and combustion forces due to the chamber pressure. In order to obtain the total force, the user has to define two series of parameters: geometrical/topological and thermodynamic parameters. Engine Development Code proposes the analyses of

crankshaft, piston, piston pin, connecting rod, engine block, engine head, bearings and valvetrain. In Figure 1 the code front-page is shown. The code is really user friendly: in few clicks, the user can choose a component, then insert the requested data and finally obtain the new design.

Geometrical/Typological parameters such as cylinder bore, cylinder number, reciprocating mass weight, engine architecture, are required to calculate the inertia forces:

$$F_a = -m_a \omega^2 r (\cos \theta + \lambda \cos 2\theta), \quad (1)$$

where m_a is the reciprocating mass weight, r the crank radius, ω the engine angular velocity, θ the crank angle, and $\lambda = r/l$ the elongation ratio (l : crank length).

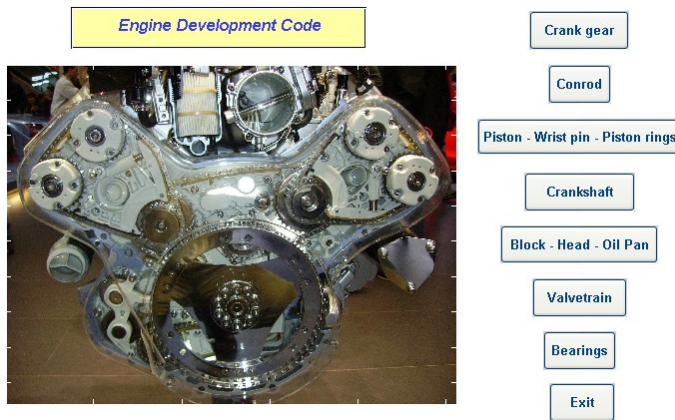


Figure 1 – Engine Development Code: front-page.

Figure 2 – Geometrical/typological parameters interface.

Figure 2 shows the geometrical/typological parameters interface where the user can fill all blank form and save the data. Thermodynamic parameters are required to define the thermodynamic cycle and to calculate chamber pressure and combustion forces:

$$F_g = (p_g - p_0) \frac{\pi D^2}{4}, \quad (2)$$

where p_g , p_0 and D are respectively the chamber pressure, the counterpressure, and the cylinder bore. The combination of Equations (1) and (2) gives the total acting force:

$$F = -m_a \omega^2 r (\cos \theta + \lambda \cos 2\theta) + (p_g - p_0) \frac{\pi D^2}{4}. \quad (3)$$

Figure 3 shows the thermodynamic parameter interface where the user has to fill all blank form and choose “Refresh graphs” in order to visualize theoretical cycle and chamber pressure. User can insert parameters for spark ignition engine, compression ignition engine or he can load an external file with experimentally acquired data. These two interfaces (Figures 2 and 3) are common to all components because they define engine type and load condition. If a component requires other parameters for its design or validation, those parameters are required in its own interface.

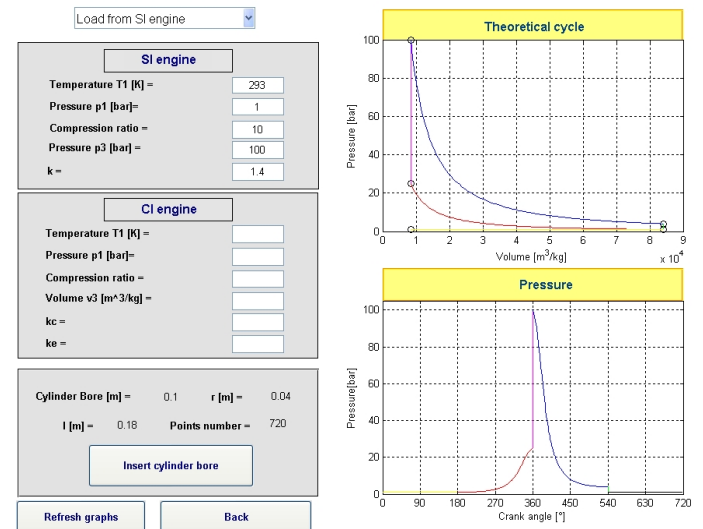


Figure 3 – Thermodynamic parameters.

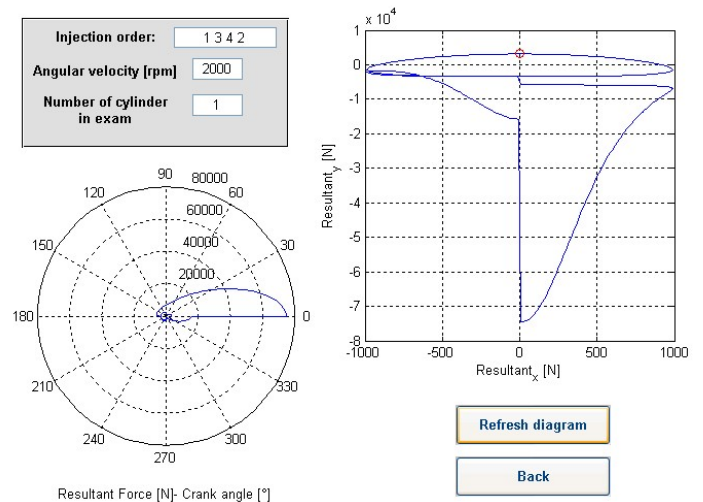


Figure 4 – Polar diagram interface.

In the “Crank Study” section of the code, the calculation of polar diagram is also implemented. In Figure 4 the “Polar diagram interface” is shown; here the user fills the blank forms with ignition order, angular velocity and cylinder number then clicks on “Refresh diagram” and the code returns the computed polar diagram. The

procedures for designing the main engine components are described in the following.

PISTON PROCEDURE

There are two methods to design piston: one analytical and the other empirical. Figure 5 shows the “First piston design method” interface. Some data required for the design, such as cylinder bore and maximum total acting force, come from the input data interface. User has to fill all blank forms with piston parameters then choose “Calculate” for designing the component.

Figure 5 – First piston design method interface.

Equation (3) can be used to calculate the normal force between piston skirt and cylinder wall:

$$F_n = F \tan \beta, \quad (4)$$

where β is the angle between connecting rod and cylinder axis.

Imposing an allowable contact pressure (p_{adm}) between piston skirt and cylinder wall, the piston skirt height is:

$$L = \frac{F_n}{p_{adm} D}. \quad (5)$$

In order to obtain a uniform pressure distribution on the piston dome, the piston pin must be positioned at the middle of the piston height. The distance between piston dome and piston pin center has to be:

$$H_c = \frac{L}{2}. \quad (6)$$

Piston dome geometry is conditioned by the chamber geometry but it can be approximated as a circular plate and its thickness calculated as:

$$s = \frac{D}{2} \sqrt{\frac{p_{max}}{\sigma_{adm}}}, \quad (7)$$

where p_{max} is the maximum chamber pressure, and σ_{adm} the allowable material stress.

Compression stress on piston skirt can be evaluated as:

$$\sigma = \frac{p_{max} D^2}{D_c^2 - D_i^2}, \quad (8)$$

where D_c and D_i are respectively the piston ring and the internal piston diameter.

Figure 6 shows the “Second piston design method” interface. The method calculates the piston dimensions in function of the cylinder bore by using appropriated multiplicative coefficients [2]. User has to fill blank form with the cylinder bore and choose “Calculate” in order to obtain the piston dimensions.

Figure 6 – Second piston design method interface.

PISTON PIN PROCEDURE

Figure 7 shows the “Piston pin” interface. Some data required for the design, such as cylinder bore and maximum force, come from the input data interface. User has to fill all blank forms with the piston pin parameters then choose “Calculate” for calculating the component.

For the piston pin design, Equation (3) can be used in order to calculate the bending stress at the middle of the piston pin:

$$\sigma_f = \frac{4FL_s}{\pi \frac{D_s^4 - d_s^4}{D_s}}, \quad (9)$$

where L_s is the piston pin length (approximately 95% of cylinder bore), D_s and d_s the external and internal piston pin diameter.