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A Systematic Framework for Preliminary Dimensioning and Characterisation of Internal Combustion Engines

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Abstract

The design of an internal combustion engine is very complicated due to the number of physical, thermal and dynamic processes involved, which are interconnected. The structural design of an

engine requires the evaluation of loads, forces, and moments acting on its components, which are mainly generated by pressure and temperature changes during the operating cycle. This paper deals with the design of a structured approach to determining the preliminary dimensions of internal combustion engines. In this method, a generic engine construction is determined by geometric sizing, thermodynamic analysis and dynamic analysis. The proposed procedure allows to estimate the main dimensions of moving parts, the engine block and the cylinder head based on the limited data provided initially, including engine power, torque, rotational speed and operating conditions, and also taking into account the choice of material. In order to facilitate this process, a spreadsheet based computational tool has been developed to arrange the main engine parameters and calculation steps. The tool helps to select fuel, do a thermochemical analysis, to predict the emissions and to evaluate the real thermodynamic cycle by integrating the heat release behaviour. The calculated variations in cylinder pressure and temperature will then be used to calculate the forces generated by the gas pressure and the forces generated by the reciprocating component mass throughout the entire engine cycle. Moreover, this method enables the estimation of crankshaft torque, external speed characteristics and preliminary engine performance indicators..

Keywords

Characteristics; Dimensions; Forces; Design; Spreadsheet; Combustion Engine

Nomenclature and Abbreviations

CAE	Computer-Aided Engineering	
CAM	Computer-Aided Manufacturing	
CAD	Computer-Aided Design	
CFD	Computational Fluid Dynamics	
FEA	Finite Element Analysis	
GUI	Graphical User Interface	
ICE	Internal Combustion Engine	
A	Piston crown area	m^2
B	Cylinder bore	m
C_m	Mean piston speed	m/s
CR	Compression ratio	–
D	Diameter	m
F	Force	N
g	Acceleration due to gravity	m/s^2
IMEP	Indicated mean effective pressure	Pa
BMEP	Brake mean effective pressure	Pa

L	Stroke length	m
L_r	Connecting rod length	m
m	Mass	kg
$\dot{m}$	Mass flow rate	kg/s
m_j	Reciprocating mass	kg
N	Engine speed	rpm
ncyl	Number of cylinders	–
P	Power	W
p	Pressure	Pa
pmax	Maximum cylinder pressure	Pa
Q	Heat transfer	J
R	Gas constant	J/kg·K
r	Crank radius	m
T	Temperature	K
Tb	Brake torque	N·m
V	Volume	m^3
Vd	Displacement volume	m^3
Vc	Clearance volume	m^3
ω	Angular velocity	rad/s
ηb	Brake thermal efficiency	–
ηm	Mechanical efficiency	–
λ	Air–fuel equivalence ratio	–
σ	Stress	Pa
τ	Shear stress	Pa
gC	Mass fraction of carbon	–
gH	Mass fraction of hydrogen	–
gO	Mass fraction of oxygen	–
dU	Differential change in internal energy	J
δQ	Differential heat added to the system	J

1. Introduction

A combustion engine is a type of machine that generates mechanical energy at the output shaft by reacting fuel inside a closed volume or combustion chamber to produce chemical energy [1-4]. This machine is in constant evolution, with the latest numerical experimental tools incorporated into its modeling and simulation processes, as well as advances in scientific and technological knowledge [5-6]. The primary means of converting chemical energy into mechanical energy for the propulsion of most means of transportation in the world is the combustion engine. A variety of commercial engineering modeling and simulation tools (GT-Power®, Adams®, ANSYS®, among others) are included in engineering programs, and research groups and their members are able to benefit from these resources [7-9]. The preliminary definition of the dimensions of elements and machines must still be systematized, even though commercial programs are available. Accordingly, researchers construct predictive and diagnostic models for

engines based on traditional bibliographic information [10-14], which includes theoretical, experimental, and statistical information. The work of, Delprete [2], and Singh [14], among others, focuses on the pre-design of engine parts and the prediction of thermal and mechanical stresses. PET software for Ford to assist in the pre-design and calculation of combustion engine parts' critical geometry, as well as parametric assembly of solids [15-19]. The PET platform performs pre-design and calculation of critical geometry of combustion engine parts, as well as parametric assembly of solids. PET was developed to perform pre-design and calculation of critical geometry for combustion engine parts, as well as parametric solid assembly [20-24]. PET was designed to perform pre-design and critical geometry calculations for combustion engine parts as well as parametric solid assembly. The PET platform is designed to predict engine performance in various scenarios . A tool named "Engine Development Code," which has a graphical user interface (GUI) and is processed in MATLAB, uses expressions and models available in specialized literature to design and verify all the main components of a new internal combustion engine, was also developed by Delprete et al [2]. After entering some characteristic parameters of the new internal combustion engine, this tool allows the user to design each component. LS-DYNA was used to calculate the thermal and mechanical stresses on the components of a four-stroke diesel engine by Singh et al [14]. A major objective of this work is to demonstrate how to systematize the calculations necessary for the preliminary dimensioning of the main measurements of an internal combustion engine using Excel® program; the systematization is compatible with the work of the latter authors and is part of a larger systematization in our research group for CAE-CAM engine design [25-28]. It is assumed that the engine's initial parameters are known by the customer. The required information on speed, power, average effective pressure, and compression ratio is determined by the initial parameters defined by the customer [29-32]. The variables used to model the thermodynamic cycle with its intake, compression, combustion, expansion, and exhaust processes [33-37]. The results obtained will be used to generate curves for the complete thermodynamic cycle, which will be used to calculate and analyze the engine loads. This will be accomplished by systematizing the kinematic, static, and dynamic analysis until a clear understanding of the behavior of the loads generated at each element of the moving assembly is achieved [38-40]. The information on critical loads and geometric parameters obtained from pre-dimensioning is used to verify and calculate the strength of the parts. The recommendations of Romero [5] are followed in the process of systematization. A spreadsheet is developed as a result of the systematization process that can be used for thermochemical, thermodynamic, kinematic, and dynamic studies to determine engine frame dimensions [41-44]. However, spreadsheets can be created in engineering programs as a pedagogical tool that enhances solution analysis exercises in different subjects, particularly in design, as a pedagogical tool. The following sections of this

document provide a brief introduction to the thermochemical and dynamic fundamentals that underlie the initial calculations for the provisional design of engines.

2. Fundamentals of Engine Pre-Design

An internal combustion engine is pre-designed using construction and functional parameters, considering safety, stress distribution, deformations, dynamic characteristics, projected weight, and manufacturing costs [45-48]. It is essential that the designer has experience at this early stage in order to reach a successful solution quickly. Less experienced designers can use classical design methods and information based on experiments to facilitate the preliminary design of engine components using Excel® or Mat Lab® programs. It is necessary to take into account the reactions between air and fuel, the emissions generated from combustion, the relationship between dimensions and mass, the increase in power and consumption indicators, as well as the compression ratio, mean effective pressure power per liter, piston power, crankshaft rotation frequency, and, most importantly, the reliability of the engine when designing the engine [49-51]. Furthermore, when starting up or formulating the technical task, fuel type, ignition method, horsepower, the number of cycles, speed characteristics, and dynamic properties are assumed, as well as crankshaft rotation frequency. Internal combustion engines use fuel, air, exhaust gases, and possibly recirculated gases as the working fluid. The elemental composition (by mass) $-gC + gH + gO = 1\ kg-, y$ of petroleum motor fuel is If gC, gH, gO represent the masses of carbon (C), hydrogen (H), and oxygen (O) in a substance, then the equation simply states respectively [52-54].

In addition to its elemental composition, the fuel is characterized by its lower heating value Hi y and average molar mass Mo. Knowing the composition of the fuel, the amount of air with density ρa, theoretically necessary for the complete combustion of 1 kg of fuel [55-58]

$$L'o = (8/3\ gC + 8gH - gO)/0.23\ \ kg \qquad (1)$$

The amount of air needed to complete the combustion of 1 kg of fuel is measured in moles.

$$Lo = \ (gC/12 + gH/4 - gO/32)/0.21kmol\ /kg \qquad (2)$$

During combustion CO_2, H_2O, CO, etc., y is produced, and chemical energy is converted into heat. The First Law of Thermodynamics for the system is $dU = \delta Q - \delta L$, y where dU ; the change in internal energy; δQ,the heat added to the system; $y\ \delta L$, the mechanical work done by the system; the ideal gas law is given by $pV = n\bar{R}T$. An overall chemical reaction that

describes combustion is given by

$$C_X\,H_Y\,O_Z + a \cdot (O_2 + 3.76N_2) \rightarrow b \cdot CO_2 + c \cdot H_2O + d \cdot N_2 \quad (3)$$

$$a = X + (Y/4) - (Z/2); b\ = X; c\ = Y/2\,; \quad (4)$$

$$d\ =\ 3.76[X + (Y/4) - (Z/2)] \quad (5)$$

Considering the mole masses of the components, the air-fuel ratio (AF) is calculated.

$$AC = \frac{m_{aire}}{m_{comb}} = \frac{a\cdot(O_2+3.76N_2)}{C_X\,H_Y\,O_Z} \quad (6)$$

For any moment during the combustion process, thermodynamic calculations are used to determine the pressure and temperature of gas in the engine cylinder. It is necessary to take into account several factors when computing the ignition process, including the angle of advancement of the ignition, the nature of the combustion, and the average ignition speed [59]. A thermodynamic calculation aims to determine the pressure and temperature of the gases in the engine cylinder at any given point during combustion [60]. The process is calculated based on the angle of ignition advance, the nature of the combustion, and the average ignition speed. The heat analysis of the engine depends on the data determined or prescribed initially, which include the engine type, power, speed, number and arrangement of cylinders, stroke-to-diameter ratio, and compression ratio, which are then used to determine the engine's performance and fuel economy [61]. A heat analysis is then used to plot an indicator diagram. A speed curve graph and dynamic stress calculations are based on the parameters obtained through heat analysis. An engine's main parts and systems are designed based on the results of heat analysis, which is also used to determine external speed characteristics. A simplified working cycle of a four-stroke reciprocating engine includes a constant temperature and pressure intake phase [62]. The compression phase, which can be assumed to take place with a constant polytropic coefficient when modeling; the combustion phase, which contributes to the work of the engine during operation [63]. A polytropic expansion phase with a constant polytropic coefficient; and an exhaust phase with a constant pressure. Model simplifications are consistent with the accuracy required for preliminary design of purpose [13]. Given the compression ratio of the engine and the polytropic compression exponent, the pressure, temperature, and compression volume can be found using the following formulas:

$$p_c = p_a \cdot \varepsilon^{n_1} \quad (7)$$

$$T_c = T_a \cdot \varepsilon^{n_1-1} \quad (8)$$

$$V_C = V_a/\varepsilon \quad (9)$$

Similarly, the pressure, expansion temperature, and degree of subsequent expansion are determined by:

$$p_b = p_z/\delta^{n_2} \quad (10)$$

$$T_b = T_z/\delta^{n_2-1} \quad (11)$$

$$\delta = V_a/V_z \quad (12)$$

Based on qualitative assumptions, the evolution of the mass of fuel burned as a function of the angle of crankshaft rotation can be expressed as

$$x = 1 - expln(1 - x_z)(\varphi/\varphi_z)^{m+1} \quad (13)$$

The particularities of the combustion process are taken in to account in the equations by means of the combustion character index m, which unambiguously determines the position of the maximum dimensionless heat release rate. The lower the exponent m, the steeper the heat release characteristic and the closer the maximum heat release rate is to the start of combustion. The determination during the calculation of the working cycle Determining the main dimensions of the engine (cylinder diameter, piston stroke) during the calculation of the working cycle allows for the kinematic analysis of the elements of the crank-connecting rod mechanism, MBM(piston, connecting rod, crankshaft) and scaling the main composition measurements, as well as calculating the velocities and accelerations of these parts for the subsequent dynamic calculation and prediction of the engine's service life. The initial data for the main composition measures and also calculate the speeds and accelerations of these parts for the subsequent dynamic calculation and prediction of the engine's service life. The initial data for the kinematic calculation is the piston stroke and the construction scheme chosen for the crank-connecting rod mechanism. For the centered MBM, the main kinematic parameter, the crank radius, is determined as half the complete piston stroke $(R = S/2)$; the value of another geometric parameter, dimensionless, λ , which represents the ratio of the crank radius R to the connecting rod length L ($\lambda = R/L$), is generally taken from the range 0.24... 0.31. The kinematic calculation, considering the dimensions of the mechanism and the angular velocity of rotation of the crank $\omega = d\varphi/dt = \pi n/30$ (rad/s), allows us to predict the displacement Sp, velocity vp y and acceleration jp of the piston (in the centered MBM), according to the expressions:

$$S_p = R[\left(1+\frac{\lambda}{4}\right) - \left(cos\varphi + \frac{\lambda}{4}Cos2\varphi\right)] \quad (14)$$

$$=\text{R}\ [(1\text{-}\cos\varphi) + \frac{\lambda}{4}\ (1 - cos2\varphi)] \quad (15)$$

$$v_p = R(\frac{\pi n}{30})\,[sin\varphi + \frac{\lambda}{2}\ sin2\varphi] \quad (16)$$

$$= R.\omega[sin\varphi + \frac{\lambda}{2}\ sin2\varphi] \quad (17)$$

$$j_p = \text{R}\ (\frac{\pi n}{30})^2\ [cos\varphi + \lambda cos2\varphi] \quad (18)$$

$$=\text{R}\omega^2[cos\varphi + \lambda cos2\varphi] \quad (19)$$

Applying Dealmaker's principle, the behavior of the MBM can be analyzed under the principles of dynamic equilibrium, and the forces acting on the components can be found by treating the system as static. The forces acting on the system are those due to the pressure of the combustion gases and those due to the inertia of the masses. Figure 1 shows and summarizes the expressions for the forces on the components of the crank-slider mechanism, required to perform the design calculations of the structural components of the engine and to study the vibrations of the engine. In the following expressions, p is the pressure inside the cylinder for a given position of the crankshaft; $p0$ is the pressure under the piston mm is the unbalanced mass, with respect to the axis of rotation of the crankshaft elements associated with the crank: $m_m = m_{mb} + 2m_{c\rho}/R$; mmb is the mass of the connecting rod journal; mc is the unbalanced mass of the connecting rod journals; ρ is the distance between the axis of rotation and the center of gravity of the unbalanced mass of the connecting elements. The values of $m_{mb}, m_c, y\ \rho$ can be determined from statistical data on these magnitudes according to trends in current engines, such as those available in manufacturers' databases, of which Mahle is one [14-15]. Once the forces on the components have been calculated, the preliminary determination of the cylinder dimensions is addressed. its number, the bore-stroke ratio, the need to use supercharging, and the assessment of its pressure. The latter makes it possible to guarantee a given power output in a justified manner, while ensuring acceptable wear resistance and thermal stress.

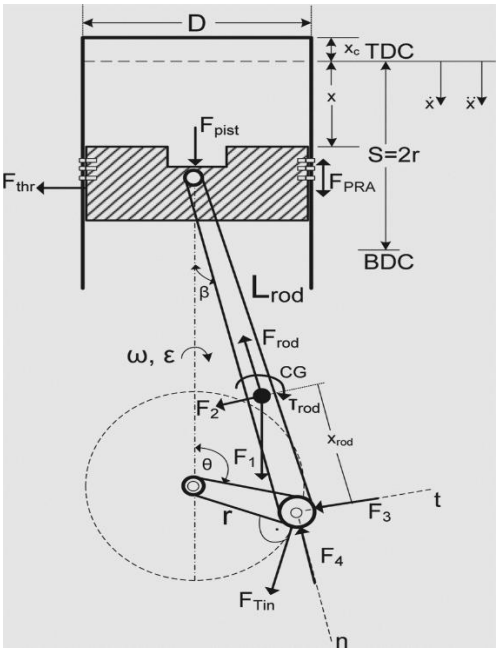


Figure 1. Forces in the mechanism

2.1 Total force on the piston

$$P = P_g + P_j \; ; P: \tag{20}$$

Where,

$P\rightarrow$ total force on the piston.

$Pg\rightarrow$ force due to combustion gas pressure.

$Pj\rightarrow$ force due to reciprocating masses (inertia).

2.2 Force due to reciprocating masses

$$P_j = -mjR\omega^2(cos\varphi + \lambda cos2\varphi); P_j: \tag{21}$$

Where,

$m_j\rightarrow$ reciprocating mass.

$R\rightarrow$ crank radius.

$\omega\rightarrow$ angular velocity of crankshaft.

$\phi\rightarrow$ crank angle.

$\lambda = R/L\rightarrow$ ratio of crank radius to connecting rod length.

Negative sign indicates the force direction opposite to the piston motion.

2.3 Force due to gas pressure

$$P_g = 10^6(P - P_o)F_p \; ; P_g: \quad (22)$$

Where,

$P0\rightarrow$ ambient pressure.

The factor 106 is likely a unit conversion constant depending on the system (maybe from bar to N/cm² or similar).

2.4 Components of piston force along the connecting rod

$$S_b = P/cos\varphi : \quad (23)$$

Where,

$Sb\rightarrow$ force along the connecting rod.

$\beta\rightarrow$ angle of the connecting rod with the piston axis.

2.5 Transverse (lateral) component

$$N = P\ tg\varphi : \quad (24)$$

Where,

$N\rightarrow$ side (transverse) force on the piston/cylinder wall.

Sometimes represented as $N = P\sin\ \beta$.

2.6 Components relative to crank

$$K = (P \cdot \cos\ (\varphi + \beta)/\cos\ \beta\ , T = (P \cdot \text{sen}\ (\varphi + \beta)/\cos\ \beta \quad (25)$$

Where,

$K\rightarrow$ longitudinal component along crank.

$T\rightarrow$ transverse (torque-related) component.

2.7 Torque on crank

$$M_t = T \cdot R \quad (26)$$

Where,

$Mt\rightarrow$ torque generated by piston force.

$R\rightarrow$ crank radius.

2.8 Usually in rotational dynamics

$$K_{br} = -(1-\kappa)\cdot m_{mb}\cdot R\cdot \omega^2 \quad (27)$$

Where,

$KbrK_\{br\}Kbr$ → Braking torque or restoring torque

kkk → A constant (ratio factor, correction factor, or stiffness ratio)

mmm → Mass

mbm_bmb → Another mass (possibly bob mass or rotating body mass)

RRR → Radius

$\omega\backslash omega\omega$ → Angular velocity (rad/s).

2.9 Multiply by mass

$$K_{mr} = -m_m\cdot R\cdot \omega^2 \quad (28)$$

Where,

If speed increases → ω\omega ω increases.

Since ω2\omega^2ω2 term is present → torque increases rapidly

System tries to reduce speed (restoring effect).

2.10 Resultant forces in crank mechanism

$$K_r = K_{br} + K_{mr} \quad (29)$$

$$R_{ab} = [T^2 + (K_{mr} + K_{br})^2]^{1/2} \quad (30)$$

Where,

Kbr→ longitudinal force component on big end.

Kmr→ longitudinal force component on main bearing.

Rab→ resultant force acting at crank pin.

$$\Psi = \text{arctg}\,[\text{T}/(K_{mr} + K_{br})] \quad (31)$$

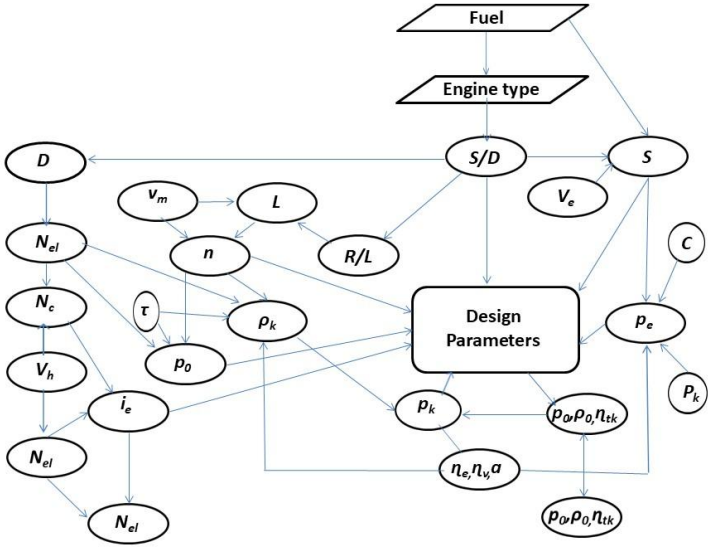


Figure 2. Preliminary design parameters

Figure 2 shows the interrelationships between the parameters considered in the preliminary design of an engine based on the initial data. In the diagram,$S$is the stroke D, the diameter R, the crank radius L, the connecting rod length n, the crankshaft rotation frequency v_m, the average piston speed N_{el}, the liter power N_c,the power per cylinder N_e,the nominal power τ, the number of strokes i_c, the number of cylinders p_θ, the average pre-pressure p_e,the average effective pressure p_k, the supercharging pressure p_o atmospheric pressure; ρ_k, the density of the supercharged air ρ_o , the density of atmospheric air n_k, the polytropic compression exponent C, the ratio between the lower calorific value of the fuel and the mass of air theoretically required for the combustion of one kg of η_v fuel the volumetric efficiency ηe,the effective efficiency; α, the air excess coefficient and y ε, the compression ratio. Among the most important structural parameters of the engine are the cylinder diameter (D), the piston stroke (S), and the ratio between them (S/D) These also allow the following to be defined.

2.11 Thermal efficiency formula

$$\eta_t = 1 - \frac{1}{\varepsilon^{\gamma-1}} \frac{\lambda_{p\rho^{k-1}}}{[\lambda_p - 1 + k\lambda_{p(\rho-1)}]} \quad (32)$$

Where,

$\eta_t\rightarrow$ thermal efficiency of the cycle.

$\varepsilon = V_"max"\ /V_"min"\ \rightarrow$ compression ratio (maximum volume divided by minimum volume).

$\gamma = c_p/c_v \rightarrow$ adiabatic index of the working gas (≈1.4 for air).

$\lambda_p = V_3/V_2 \rightarrow$ expansion ratio during the constant-pressure part of combustion (Diesel-like).

$\rho = V_4/V_3 \rightarrow$ expansion ratio during the constant-volume part of combustion (Otto-like).

$k \rightarrow$ proportionality factor for pressure (often equals γ for ideal gases).

These also allow the following to be defined the thermal efficiency of the cycle in general is evaluated by expression engine and ratio $S/D \leq 1$ can be found using expression [3]:

2.12 Mean effective pressure

$$p_m = 0.034 + 0.0113 \ v_{p.m} \ ; \tag{33}$$

$$v_{p.m} = \frac{s \cdot n}{3 \times 10^4} \tag{34}$$

$$p_i' = \frac{p_c}{\varepsilon - 1}\left[\frac{\lambda}{n_2 - 1}\left(1 - \frac{1}{\varepsilon^{n_2 - 1}}\right) - \frac{1}{n_1 - 1}\left(1 - \frac{1}{\varepsilon^{n_1 - 1}}\right)\right] \tag{35}$$

$\lambda p \ is \ the \ pressure \ ratio$ ($\lambda_p = \frac{p_z}{p_c}$), n_1 y n_2 are the polytropic exponent compression and expansion respectively, and ε is the compression ratio. The indicated pressure is.

2.13 Mean piston speed

$$p_i = \varphi_r p'_i \tag{36}$$

Where φ r is the rounding coefficient of the indicator diagram. The total displacement in liters is calculated as:

$$V_l = \frac{30\tau N_e}{p_e n} \tag{37}$$

The displacement for a single piston, VH, is obtained by dividing by the number of cylinders.

The cylinder diameter in mm is defined by:

$$D = 100 \times \sqrt[3]{\frac{4V_h}{\pi S/D}} \quad (38)$$

Where,

VL- engine displacement (total swept volume)

τ-number of strokes (τ = 4 for four-stroke, τ = 2 for two-stroke)

Ne-effective power

pe- effective mean pressure.

By modeling dynamic load, it is possible to: a) understand the structure of the reciprocating mechanism and the different construction solutions according to the type of engine; b) evaluate the kinematic and dynamic characteristics of the crank-slider mechanism; c) determine the polar load diagrams on the support and connecting rod journals of the crankshaft; and d) determine the torque on the engine crankshaft.

3. Graphs and Results from The Use of Spread Sheets

The spreadsheet designed allows you to determine the amount of air theoretically required for complete combustion of hydrocarbons based on their chemical composition. The moles and molar masses of the reactants and combustion products, assuming stoichiometric combustion. The fractions of carbon dioxide are determined in the gases burned with dry and wet reference. The parameters of a different engine for which thermodynamic calculations are performed (cycle diagram and dynamic loads). The results of the thermodynamic calculations, force on the piston and torque, considering that the theoretical cycle with addition gives heat at constant volume, depending on the fuel used, natural gas or petrol. The extreme values of pressures and temperatures, in the case of petrol use, are shown in Table 1, while Figure 3 shows the shape of the indicated *p-v* diagram of the corresponding ideal cycle.

Table 1. Initial and Final Values of the P-V Diagram

Pressure (kPa)		**Temperature (K)**		**Vertices**	**Specific volume (m^3/kg)**
P_0	86	T_0	297	0	1.19
P_1	1056.60	T_1	606.12	1	0.20
P_2	8153.59	T_2	4677.25	interval	0.04
P_3	663.65	T_3	2284.18	2	1.20

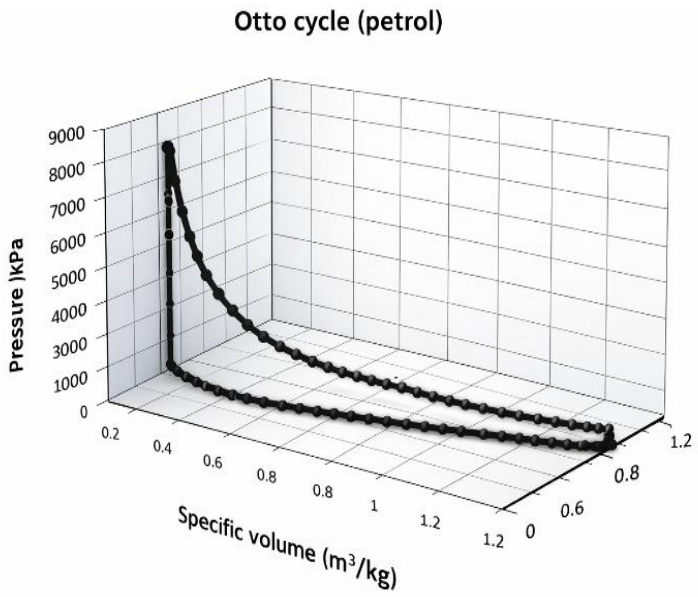


Figure 3. Ideal P-V Diagram for Petrol

Figures 4-7 show the displacement, velocity, acceleration, and over acceleration of the piston. By performing the thermodynamic calculation with detailed consideration of the heat release law, using the Wiebe model [3,6], the pressures and temperatures are obtained as a function of the crankshaft rotation angle, predicting the duration and angles of combustion initiation.

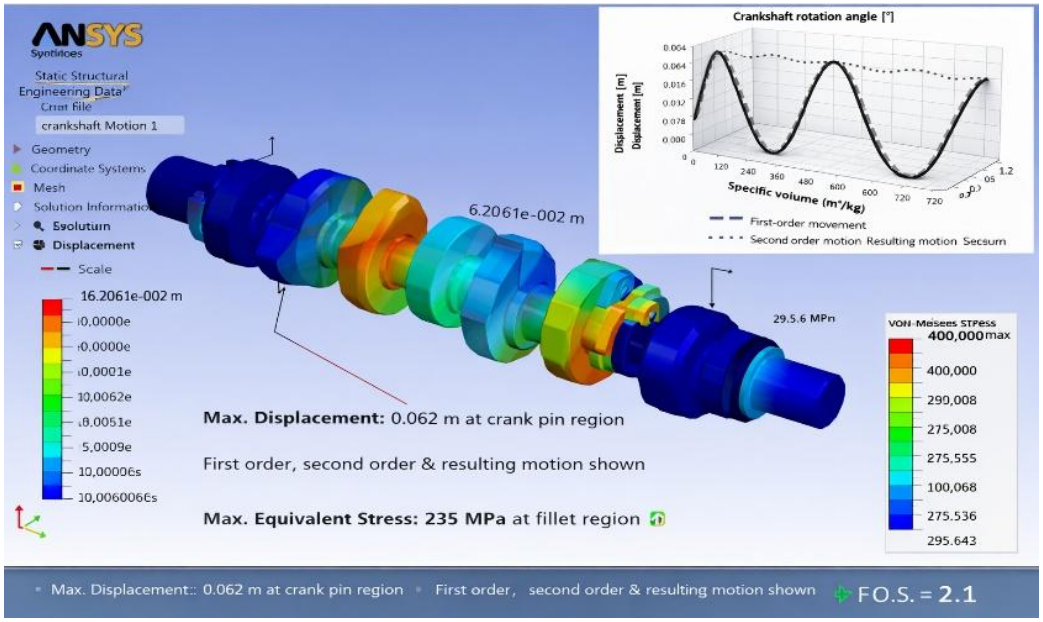


Figure 4. Piston Displacement

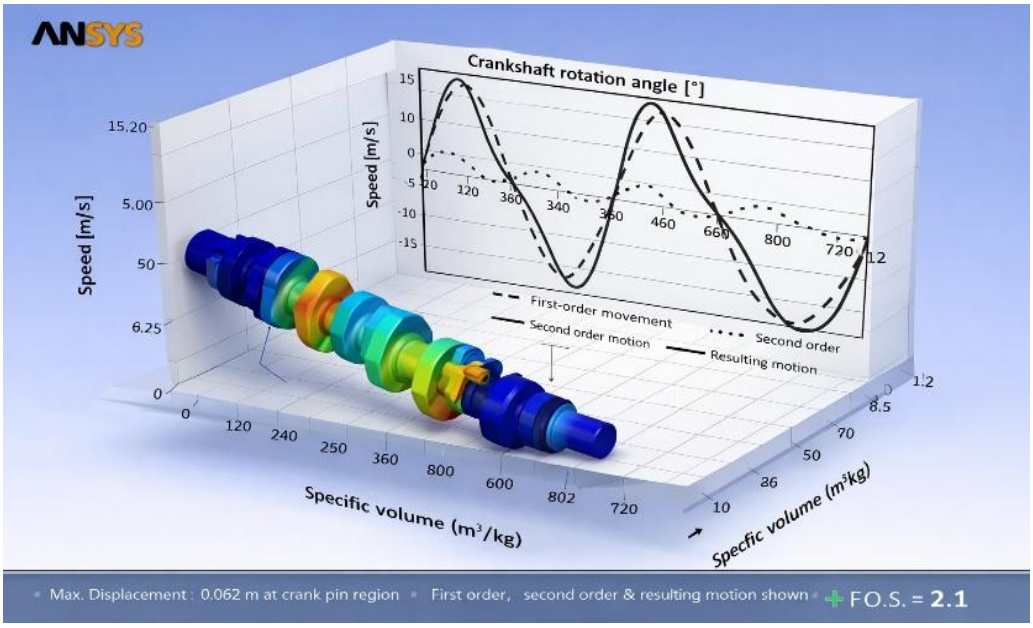


Figure 5. Piston Velocity

The numerical results of the systematized model are illustrated in Table 2; Figures 8 and 9 illustrate the behavior of the burnt mass fraction and the heat release rate, respectively.

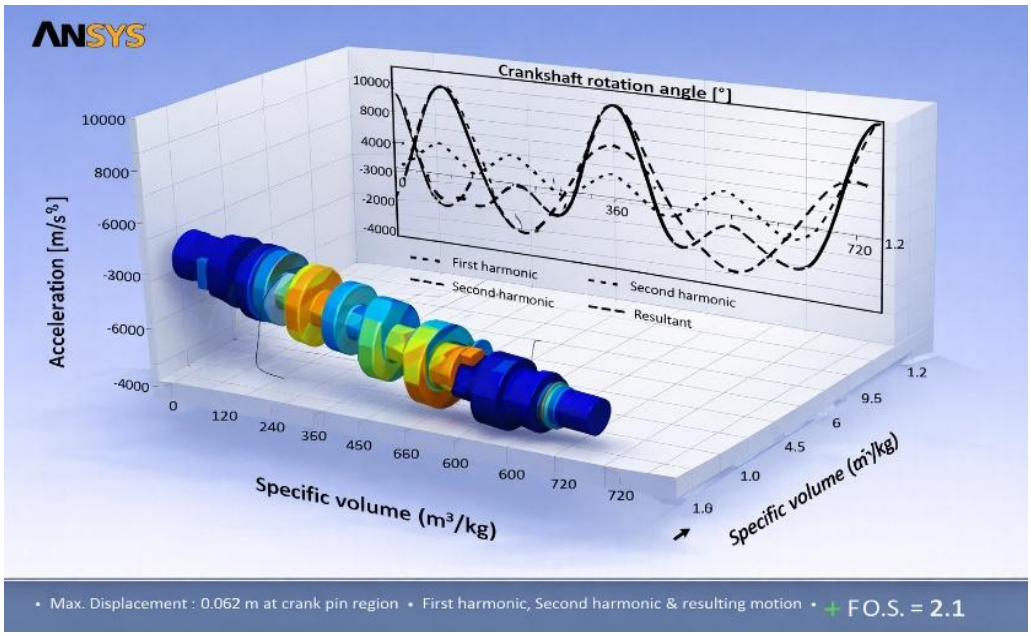


Figure 6. Piston Acceleration

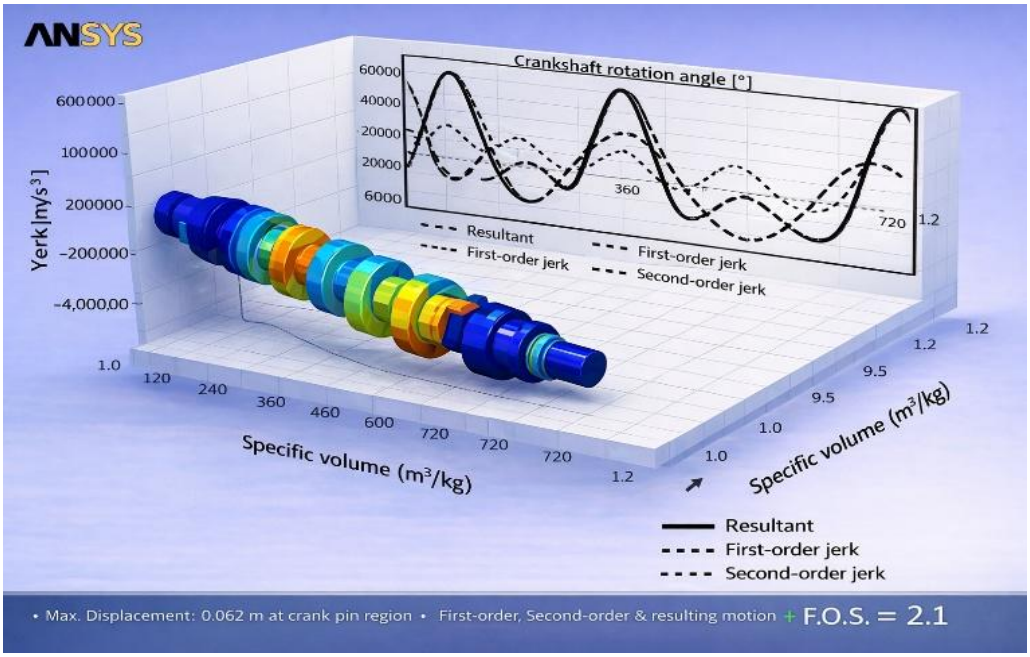


Figure 7. Jerk (over-acceleration). Source

Table 2. Calculated Thermodynamic Parameters				
Parameter	Range of Value	value	Parameter Provided	
			$\boldsymbol{\omega^2}$ **ad** $[\boldsymbol{m^2/s^2}]$	
P_K [Mpa]	Without supercharging $P_K = P_O$, $T_K = T_O$ y $\rho_K = \rho_O$	0.086	$Pa\ [MP_a]$	0.09
T_K [K]		296	$Pr\ [Mpa]$	0.11
ρ_K [kg/m³]		1.012336	γ_r	0.09
K_n	2.5 to 4	3.2	$T_a\ [K]$	370.92
ω_{ad} [m/s]	50 to 130 m/s	70	lo [kg]	14.96
Ɛ	4 to 12.5	6	$Va\ [m3\ /kg]$	1.30
ΔT [K]	10 to 30 K	15	Pc [MPa]	0.90
T_r [K]	900 to 1100 K	1050	Tc [K]	706.98
P_r = B.PO	1.1 to 1.25	1.25	$Vc\ [m3\ /kg]$	0.22
gC	Number of moles of C, H and O contained in 1 kg of fuel.	0.855	$Vy\ [m3\ /kg]$	0.23
gH		0.145	$P_y\ [MPa]$	0.83
gO		0	$T_y\ [MPa]$	691.43
$m_T\ [kg/kmol]$	110 to 120	114	$Lo\ [kmol]$	0.52
α	0.9 to 1.2	0.9	δ	0.77
$\mu_a\ [kg/kmol]$	molar mass of air	28.97	ξ	0.70
n_1	1.4 to 1.39	1.36	$q_z\ [kJ/kg]$	19071.68
λ	0.22 to 0.31	0.282	$E_2\ [MPa]$	176.96
θ (rad)	0.18 to 0.27	0.2	μ_0	1.08
Hi [kJ/kg]	Petrol (44000) and Natural gas (50050)	44000	$Vz\ [m^3/kg]$	0.23
			Pb [MPa]	1.60
Ψ	0.86 to 0.92	0.9	$T_b\ [K]$	7276.96
m	3 to 4	3.5	δ_2	6
n_2	1.23 to 1.30	1.25		

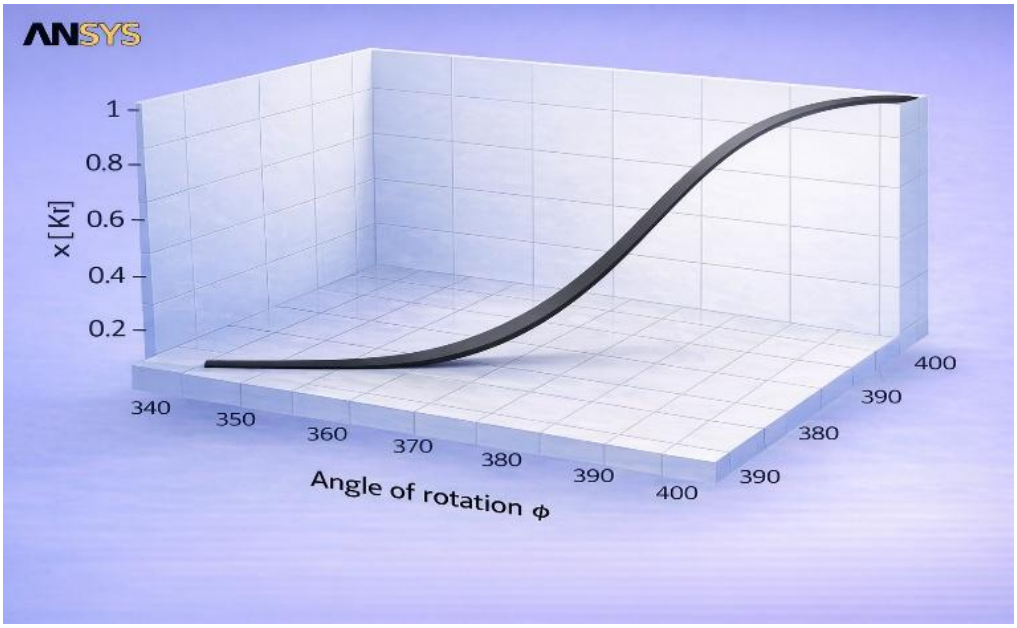


Figure 8. Fraction of Fuel Burned (x)

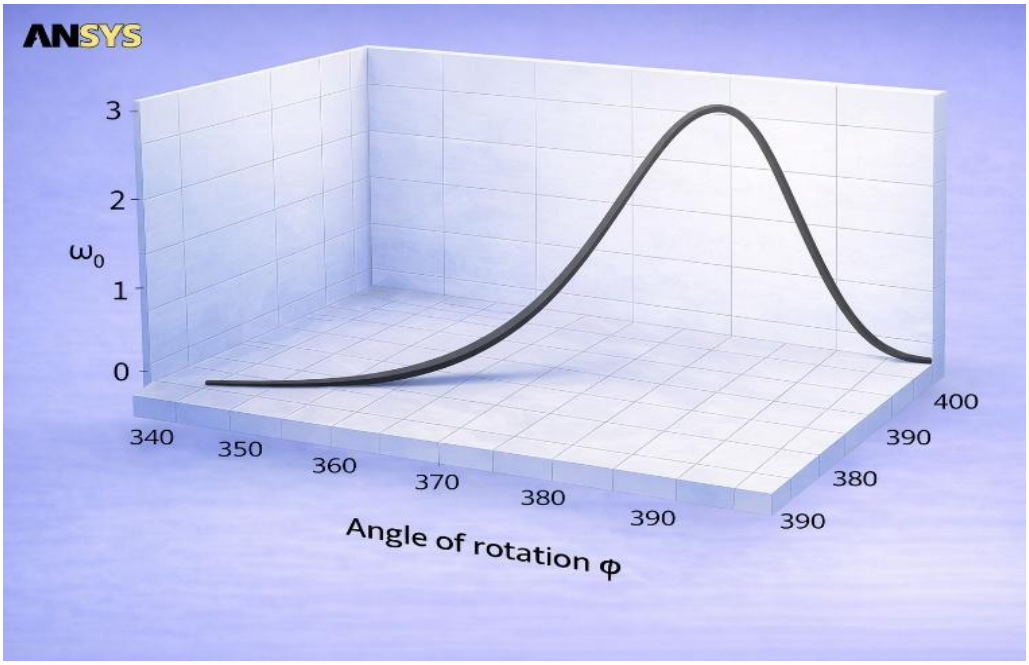


Figure 9. Relative Combustion Speed (ω_0)

Both graphs are a function of the kinetic constant of the combustion reactions (m), which evaluates the process of fuel combustion and is associated with the working rigidity of the engine. To calculate the reactions and torque, it is necessary to enter the following data in the table 3 Information related to the geometry of the crank-slider mechanism and specific parameters particular to this mechanism.

Table 3. Values for Calculating Forces and Torque	
Motor parameters	**Enter the value**
Maximum pressure on the piston [MPa]	8
Pressure in the crankcase [kPa]	86
Piston diameter [cm]	7.20
Cross-sectional area of the connecting rod $[m^2]$	0.005
Connecting rod length [cm]	11
Specific mass of the group parts piston	105
Specific mass of the connecting rod as a whole	130
Percentage of connecting rod mass that participates in the reciprocating motion $[0.25 - 0.275]$	0.25
Specific mass for cast iron crankshaft cast iron	140
Revolution per minute [min^{-1}]	4000
λ $[0.24 - 0.31]$	0.282

The behavior of the forces resulting from the combined action of gas pressure and inertial masses, for a particular speed regime (n=4000 min^{-1}) can be seen in Figure 10. The component forces on the connecting rod journal behave, depending on the angle of rotation of the crankshaft, as illustrated in Figure 11, while the resulting torque on the crankshaft behaves as illustrated in Figure 12. The temperatures, pressures and forces, together with the previous dimensions of the mechanism, constitute the inputs for performing the preliminary design calculations for the engine structure.

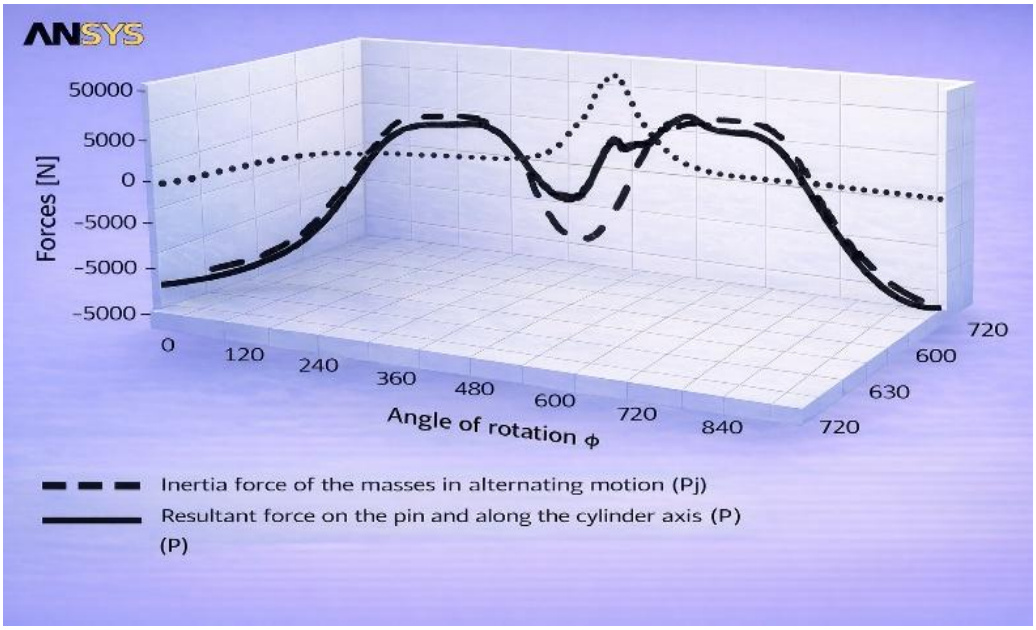


Figure 10. Resultant Force on The Piston Pin

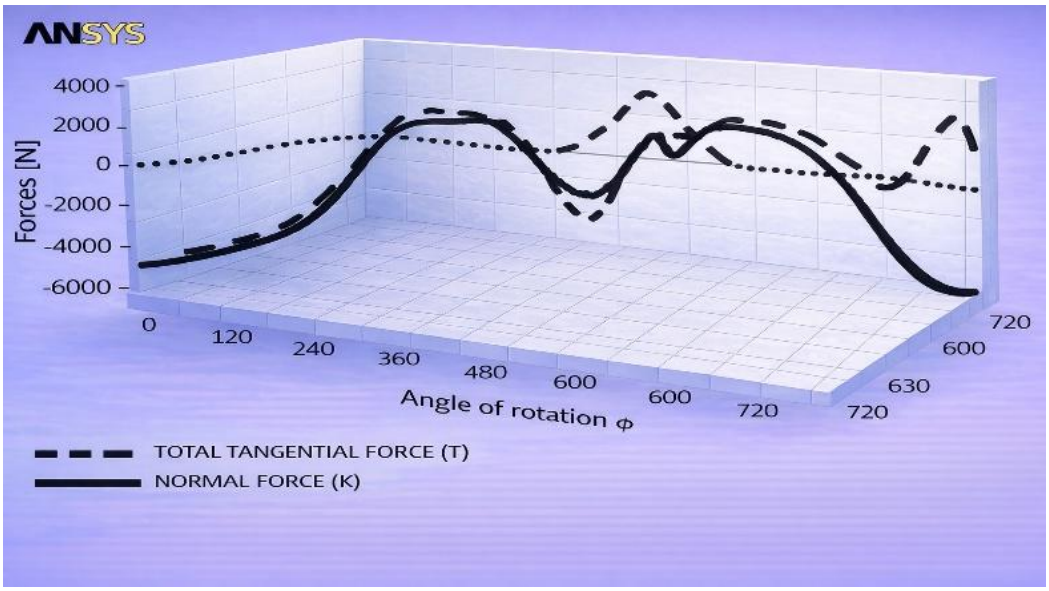


Figure 11. Normal Tangential Force on The Crankshaft

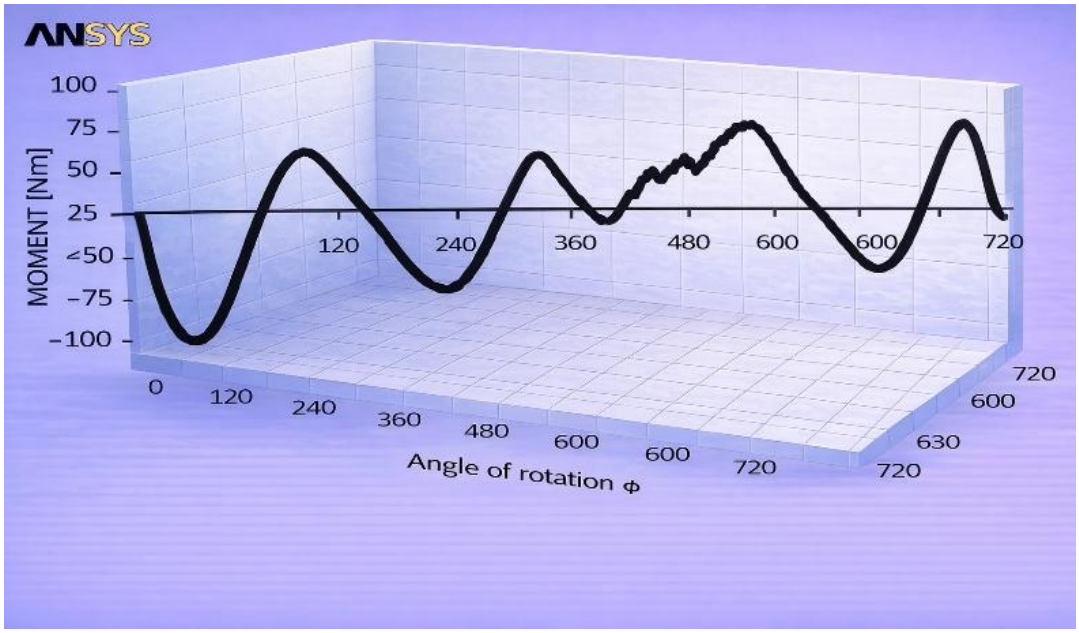


Figure 12. Resulting Torque

4. Conclusions

This article has presented a process for systematizing the main pre-design calculations for a combustion engine in a spreadsheet based on Microsoft Excel®. Starting with initial data and applying knowledge of thermodynamics, machinery mechanics, dynamics and material resistance, the thermodynamic parameters (pressures and temperatures) of the working substance and the mechanical parameters (kinematic and dynamic) required to determine the

forces in the sliding crank mechanism and the torque in the crankshaft have been calculated. Due to space limitations, the full scope of the work has not been illustrated, and only the initial tables and figures are shown. It is true that the calculations can be performed with a structured commercial program, but the advantage of the Excel® tool, a widely available database, is exploited. The information organized in databases and spreadsheets allows for quick results in system design, providing the inputs required for the dimensioning of parts and systems that are to undergo 1D, 2D and 3D modelling and simulation in subsequent design and virtual prototyping stages. Currently, within the same line of research, the working group has made progress in the systematization process, including relationships for the kinematic and dynamic assessment of multi- link solider mechanisms.

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Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.