

Development of Computer Aided Design Software for Piston Movement

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Abstract

Piston is a component that plays vital roles in internal combustion engines such as in reciprocating engines, rotating pumps and so on. It is found in the cylinder of an engine block. The computations involved in piston movement in the cylinder of an engine are complicated and rigorous because of all the parameters involved. In order to obtain the required details, a computer aided design (CAD) software package is importantly needed not only to expose and do the intricate engineering analysis but also to show high accuracy of the developed software during simulation. The software was designed using Microsoft Visual Studio package because it supports and has built in languages such as C/C++ (visual C++), VB.Net (visual basic.Net) and C# (visual C#). However, the programming language used in the development of this software was Microsoft C#. The CAD developed for the piston movement was tested to be highly accurate, faster and convenient. This makes the CAD software developed viable to be used in monitoring piston movement.

Keywords: CAD, Piston movement, Internal Combustion Engines, Software package, Simulation

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1. INTRODUCTION

Computer Aided Design (CAD) is the use of computer technology for process of design and documentation. CAD describes the process of drafting with a computer. Groover et al. (1992) defined CAD as any design activity that involves the use of computer to create, modify and document engineering design using interactive computer graphics. CAD has been on a continuous development since its evolution. CAD software or environment provides the user with input- tools for the purpose of streamlining design processes; drafting, documentation and manufacturing processes. CAD output is often in the form of electronic files for print or machining operations. CAD environment often involve more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information such as materials, processes, dimensions, and tolerances, according to application specific conventions (Sahai et al., 2016).

CAD is an important industrial art and it has found extensive applications in automotive, ship building and aerospace industries,

industrial and architectural design, mechanical engineering and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. Because of its enormous importance, CAD has been a major driving force for research in computational geometry, computer graphic (both hardware and software), and discrete differential geometry (Sheng-Hong, 2015). CAD has been used for gear design. Using CAD, Babu and Tsegaw (2009) developed an involute spur gear template; design, modelling and manufacturing of helical gear was done by Venkatesh et al. (2010) which was later improved upon by Venkatesh and Murthy (2014) through the introduction of structural analysis using ANSYS. Bartlomiej and Adam (2013) and Akinnuli et al. (2015) used CAD to design a comprehensive analysis of spiral bevel gear. Agboola et al. (2016) also developed CAD for worm gears and was tested accurate, faster and convenient. CAD software was also developed for welding hollow cylinder (Adekunle and Adejuyigbe, 2012); for shaft under various loading conditions (Adekunle et al., 2012); for mechanical chain drives (Adekunle et al., 2015) and so on.

Software development is concerned with the conception, development and verification of a software system. This deals with identifying, defining, realizing and verifying the required characteristics of the resultant software. The software characteristics may include; functionality, reliability maintainability, availability, testability, ease of use, portability and other.

The piston rides inside the combustion chamber. Around the piston are series of position rings that seal the combustion chamber and allow the piston to move up and down. The piston is connected to the crankshaft by a connecting rod. The crankshaft converts the reciprocating motion of the piston into a circular motion that is ultimately transmitted to drive the wheels. The crankshaft is connected to the camshaft by a timing belt or timing chain. The timing chain keeps the crankshaft and camshaft in tune with each other and is a vital link for smooth engine operation. The crankshaft and camshaft gears are sized so that the crankshaft will turn twice for every one turn of the camshaft. In some engines, the camshaft sits in a galley just above the crankshaft and used push rods that went up the inside of the engine to a rocker arm. The rocker arm then opens the valve sitting in the head, called an overhead valve arrangement. In the overhead cam arrangement, the camshaft is in the cylinder head and opens the valves directly. In a V- type engine, this means there are four camshafts, two in each cylinder head. The camshaft has a series of lobes that determine when and for how long the valves open. Each valve has its own lobe. In engines with a mechanical fuel pump, there will be an extra lobe to operate the pump. Using CAD/CAM/CAE in the MSC Adams software, Bialy and Szlachetka (2017) performed crank-piston model of internal combustion engine. Through the simulation studies, load distribution in a dynamic state for selected kinematic pairs was determined. Zhao (2012) using Pro\ENGINEER software performed structural analyses to gain results that improves and optimises the piston structure.

The computations involved in piston movement in the cylinder of an engine are so complicated and rigorous because of all the parameters involved in the manual analysis. To analyse all the required details, a computer aided design software package would be required. This would not only expose the intricacies involved in engineering analysis, it will also assist with very high accuracy levels

during simulation and subsequent software development. Hence, this work aims at developing CAD software for piston movement in cylinders of an engine.

2. PISTON

2.1 Description of Piston

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained in a cylinder. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall. Pistons have nine parts and sections. The pistons top property is called the crown; below this are the ring grooves into which are fitted the piston rings. The raised areas between the ring grooves are called the lands. Below the ring assembly is the piston pin hole. The piston pin –passes through this hole and passes; through the connecting rod. Around the piston pin are pin bosses that support its ends. The bottom of the piston is called the skirt.

2.2 Explanation of the Operation of a Piston Engine

An engine converts chemical energy into mechanical energy. In some engines, pistons deliver this mechanical energy. Common types of piston engines are two-stroke and four-stroke. This refers to the number of time the piston travels along a part in the cylinder. The operations of the two-stroke and four-stroke engines are based on combustion of a fuel–air mixture. In the two-stroke engine, the piston serves as the combustion chamber. In the four-stroke engine, combustion takes place in the cylinder.

The piston in a two-stroke engine is pushed down from the energy of the combustion. The motion of the piston and the compression of the exhaust gases deliver power to the crankshaft. The four-stroke engine uses valves at the top of the cylinder to introduce fuel–air mixes and allow exhausts gases to escape. The fuel mixture is ignited by the spark plug when both valves are closed in a four-stroke engine. The four-stroke engine generally has a distributor that supplies a spark when the piston is at the position known as top dead center (TDC). Two-stroke engines are generally simpler and used in such

applications as lawn mowers and smaller motorcycles.

3. METHODOLOGY

The development of this software was done using Microsoft visual studio package. The main reason for using Microsoft visual studio was for its world wide use, easy interface, being an open system and its case of file formats acceptability. It was used during the entire cycle of this software development (analysis phase, design phase and implementation phase).

3.1 Microsoft Visual Studio

Microsoft visual studio is an integrated development environment (IDE) from Microsoft. It was used to develop console and graphical user interface (GUI) application along with window forms application, website, web applications and web services in both native code together with managed code for all platforms supported by Microsoft windows, windows mobile, windows CE, NET framework, net compact framework and Microsoft sliver light.

Visual studio includes a code editor supporting intelligence as well as code refractory. The integrated debugger works both as a source lead debugger and a machine level debugger. Other built in tools include forms of designer for building GUI applications, web designer, class designer and data base schemer designer. It accepts plug in that enhance the functionality at almost every level include adding support for source control systems (like sub version and visual source safe) and adding new tools sets like editors and visual designers for domain specific languages or tool sets for other aspect of the software development life cycle (like team foundation server client: team explorer). Visual studio supports different programming languages by means of language services, which allow the code editor and debugger to support (to varying degrees) nearly any programming language. Built in languages include C/C++ (via visual C++), VB.NET (via visual basic.NET), C# (visual C#) and F# (as of visual studio). It supports for programming languages is aided by using specific visual studio package called a language service. A language service defines various interfaces which the visual studio package

implementation can implement to add support for various functionalities. The programming language used in the development of this software was Microsoft C#.

Visual studio includes a host of visual designers which was incorporated in the development of this software. These tools include:

i. Window Forms Designer

This was used to build GUI application using window forms. Layout can be controlled by housing the controls inside other containers or locking them to the side of the form.

ii. Window Presentation Foundation (WPF) Designer

This was introduced with visual studio. Like the windows forms designer, it supports the drag and drop metaphor. It was used to author user interfaces targeting windows presentation foundation.

iii. Data Designing

It was used to graphically edit data base schemas including typed tables, primary and foreign key and constraints. It was used to design queries from the graphical view.

iv. Class Designer

It was to generate C# code outlines for the classes.

3.2 Algorithm and Flowchart for the CAD Designed

Step 1: This section allows for input of the parameters needed

Enter the Piston Input Parameters such as diameter or bore, height, gasket thickness, gasket bore, stroke, volume occupied by the piston head (V_{ph}), combustion chamber volume (V_{cc}) and expected speed.

Step 2: Determination of output parameters

Calculate TDC volume, BDC volume, depression volume, compression ratio, swept volume, piston head volume, cylinder volume etc

Step 3: Start Piston movement

Step 4: Stop

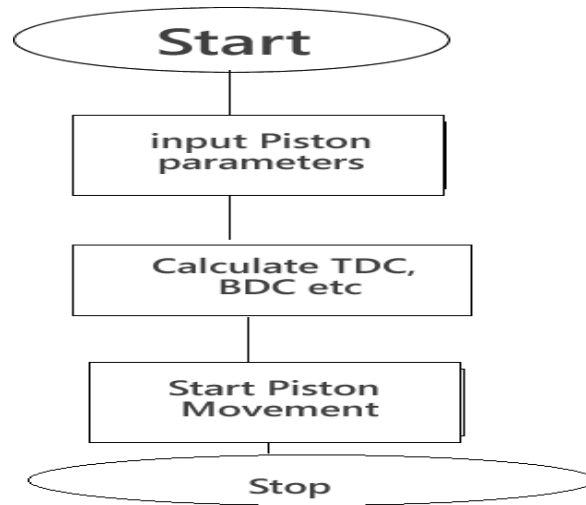


Figure 1: Flow chart for the CAD designed

3.3 Analysis

Equations [1] - [7] were used to generate the output parameters from the piston input parameters supplied which will aid in the piston movement. The equations used are as shown below:

(i) Depression volume, V_{dp}

It is volume (V_{dp}) swept by moving the piston down (Piston depression) a certain distance.

$$V_{dp} = B^2 \times Pd \times F \quad [1]$$

(ii) Nett piston head volume, V_{ph}

The true piston head volume can be calculated by subtracting the volume (V_{dp}) swept by moving the piston down (Piston depression) a distance from the gross piston head volume (V_{phg}).

$$V_{ph} = V_{phg} - V_{dp} \quad [2]$$

(iii) Gasket volume, V_g

It is the volume of the hole in the gasket. It is based on the inner and outer diameters of the gasket and the gasket's thickness.

$$V_g = Gb^2 \times Gt \times F \quad [3]$$

(iv) TDC Volume, V_{tdc}

It is the volume obtained at the furthest position of the piston inside the internal combustion cylinder at which the piston changes its upward movement position to downward stroke.

$$V_{tdc} = V_{cc} + V_g + V_{ph} \quad [4]$$

(v) Swept volume, V_{sw}

It is the theoretical volume of air drawn into a cylinder when the piston moves from top dead centre (TDC) to bottom dead centre (BDC) i.e. the volume of a cylinder of the diameter of the bore of the cylinder with length of the engine stroke while ignoring frictional losses and thermal effects.

$$V_{sw} = B^2 \times S \times F \quad [5]$$

(vi) BDC Volume, V_{bdc}

It is the volume obtained at the furthest position of the piston inside the internal combustion cylinder at maximum lower position of piston

$$V_{bdc} = V_{tdc} + V_{sw} \quad [6]$$

(vii) Compression ratio, CR

This is the ratio between the cylinder volume above the piston at bottom dead centre (V_{bdc})

and the volume above the piston at top dead centre (V_{tdc}).

$$CR = \frac{V_{bdc}}{V_{tdc}} \quad [7]$$

Where

B = Bore of the cylinder

Pd = Piston Depression

V_{ph} = Piston Head Volume

V_{phg} = Gross Piston Head Volume

Gb = Gasket Bore

Gt = Gasket Thickness

V_{tdc} = Volume at the top dead center

V_{bdc} = Volume at the bottom dead centre

V_{cc} = Combustion chamber volume

S = Stroke of the engine

$F = 0.0007854$

4.0 RESULTS AND DISCUSSION

4.1 Usage of CAD files to generate piston movement

Computer Aided Design (CAD) program can use CAD files to generate piston movement. The program application developed has enabled the user to work on CAD file. When definition is complete, the same program converts it to Computer Aided Design (CAD) commands that can be immediately tested for detailed running.

4.2 Piston movement operation captured

After the CAD software had been developed, it was used to simulate piston movement. The default window for the CAD developed is as shown in figure 2.

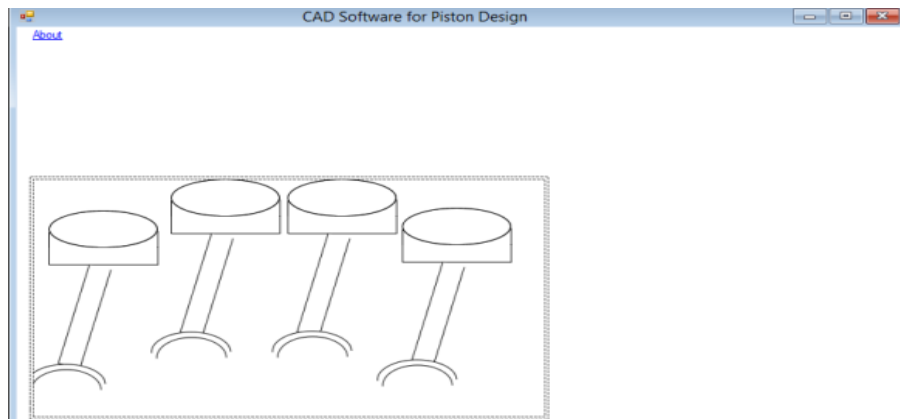


Figure 2: Piston movement CAD default window

Figure 3 shows the input parameter window where the input parameters will be supplied before computing to derive the output values as required. The input parameters to be supplied include diameter or bore, height, gasket thickness, gasket bore, number of strokes, piston head volume and so on. After the input parameters have been supplied, the

CAD software was able to generate the following analysis and gives output such as depression volume, piston head volume, gasket volume, TDC volume, swept volume, BDC volume, compression ratio and cylinder volume as shown in figure 4.

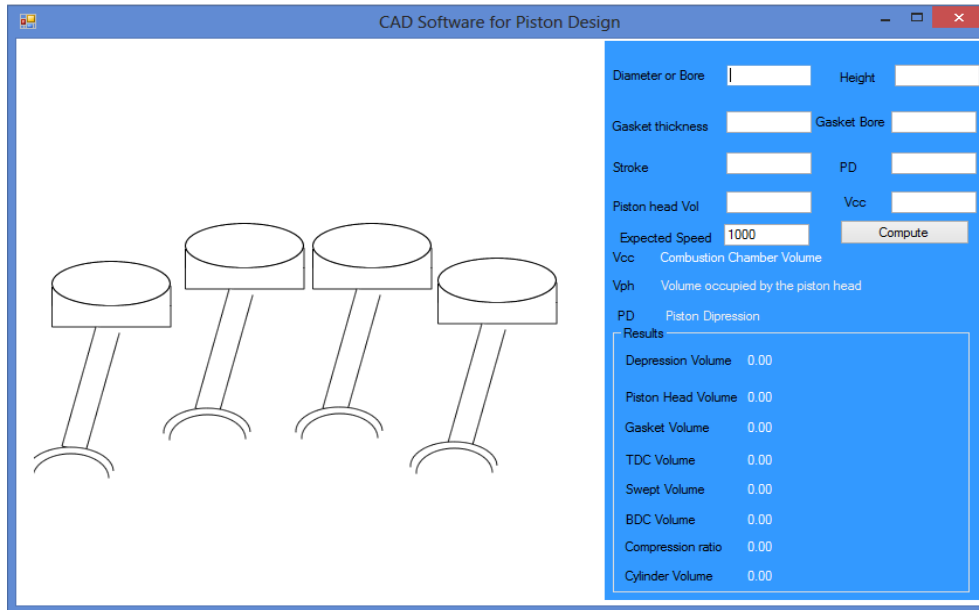


Figure 3: Input parameter window for piston movement CAD

As shown in figure 4, the parameters needed for the piston movement analysis were supplied. After the input parameters such as diameter bore, height, gasket thickness and so on were supplied. As soon as the compute

button was clicked, the output values required were displayed in which the pistons start to move as shown in figures 4 and 5.

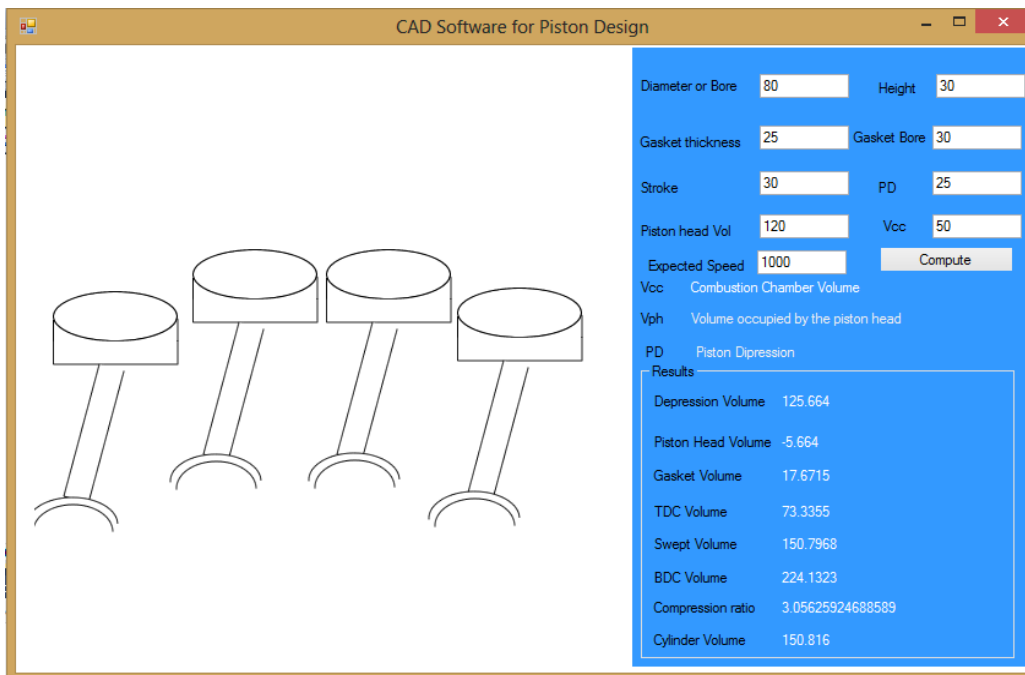


Figure 4: Output parameter window for piston movement CAD (1)

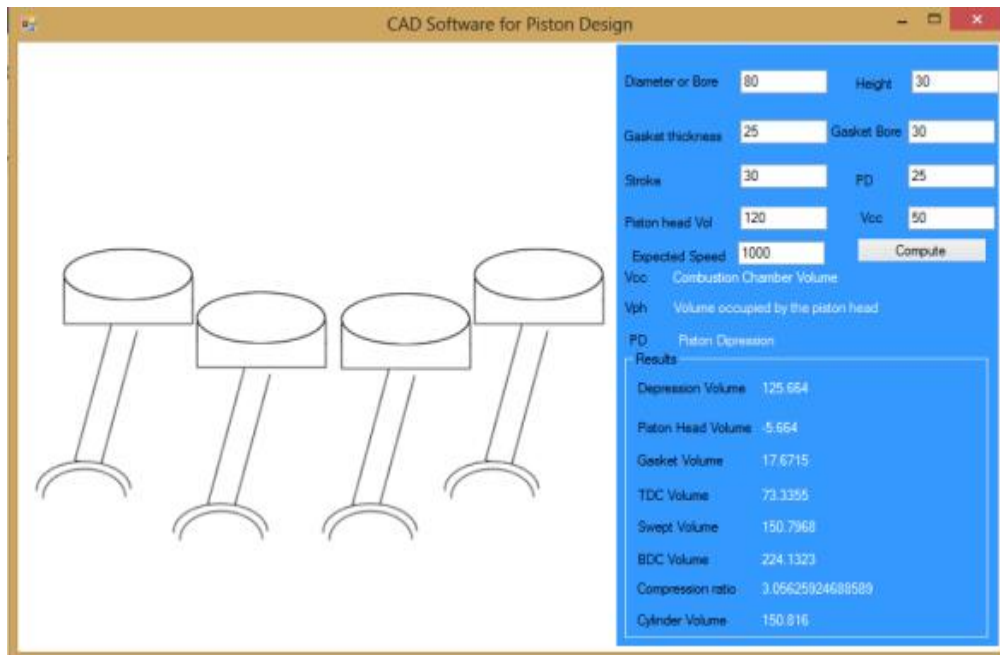


Figure 5: Output parameter window for piston movement CAD (2)

From figure 4, it was shown that the first and the last piston were opened whereas the two middle pistons were closed. However, the first and the last piston were closed while the two middle pistons were opened as shown in figure 5. This showed the movement of the piston as displayed by the CAD designed.

4.3 Manual/hand analysis and the CAD developed analysis

The input values used for the computation of both the manual and CAD analysis are: Diameter or Bore, $B = 80$ mm, Height = 30 mm, Gasket Thickness = 25 mm, Gasket Bore = 30 mm, Stroke = 30 mm, Piston Depression (P.D) = 25 mm, Piston Head Volume = 120 mm³, Combustion chamber Volume (V_{cc}) = 50 mm³. The values obtained for both computations are shown in Table 1.

Table 1: Comparison between the results

S/N	Parameters	Value from Manual/ Hand Computation	Value from CAD computation
1	Depression Volume	125.6	125.664
2	Piston Head Volume	-5.7	-5.664
3	Gasket Volume	17.68	17.6715
4	TDC Volume	73.34	73.3356
5	Swept Volume	150.75	150.7968
6	BDC Volume	224.15	224.1323
7	Compression Ratio	3.0563	3.05625
8	Cylinder Head	150.83	150.816

4.3.1 Accuracy in Calculations

Although the values obtained for both computations are very close, manual analysis of the piston movement in engine is laborious and time consuming. However, this CAD software design will reduce stress involved

with manual analysis and provide accurate result void of errors. The modelled calculation and CAD developed is believed to give more accurate result when compared to manual computations. Also the CAD developed has an advantage over the manual computation in

that the CAD developed can display the piston movement.

4.3.2 Reduction in errors and time savings

In addition to the accuracy of the software, errors and mistakes in computations were drastically reduced. Manual/Hand calculation takes a lot of time. From Table 1, it is observed that manual hand calculation takes average of 20 minutes but by the usage of the CAD software, an average of 3 minutes was used. Hence, the CAD software is capable of reducing time of calculation manually and help to reduce human error in computation.

CONCLUSION

Piston is one of the key components in automobile systems. Most especially in internal combustion engines, piston is a moving component that is contained in cylinder engines. Standard design equations were used in developing the codes for the CAD for the piston movement. CAD software for piston movement was developed and made ease to simulate. It is very easy to access because rigorous manual calculations are eliminated, mistakes can be easily corrected and it is efficient when compared with the manual analysis.

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