ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICALCHEMICAL AND MATERIALS ENGINEERING

DESIGN OFWATER SPRAY SYSTEM FOR OLD MODEL DIESEL ENGINES CARBONMONOXIDE (CO) EMISSION REDUCTION

A Thesis Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

HABTAMU GEBREMARIAM

Advisor: Mr. MEKONNEN LIBEN (Asst. Professor)

MECHANICAL SYSTEM AND VEHICLE ENGINEERING PROGRAM

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**design of water spray system for old model diesel engines carbonmonoxide (co) emission reduction** " in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from February, 2017 to January, 2018 under the supervision of Mr. MEKONNEN LIBEN (Asst. Professor), Department of Mechanical and Vehicle Engineering, Adama Science and Technology University-Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Name Signature Date

HabtamuGebremariam ______________ ______________

Candidate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name Signature Date

__________________ ______________ ______________

Advisor

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Approved by board of Examiners

Chairman, program graduate committee

Advisor

Internal Examiner

External Examiner

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All praises to the ALMIGHTY OF GOD for His unseen hand, which guided and strengthened me, even at times when I felt; I were not capable of doing it myself.

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ACRONYMS AND SYMBOLS

DEF: Dieselexhaustsfluid

ERG: Exhaust gas re-circulation

DPF: Diesel particulate filter

SCR: Selective catalytic reduction

DOC: Diesel oxidation catalyst

$CCC_{s:}$Closed-couple catalyst

VGT: Variable geometry turbo charging

PM: Particulate matter

NO_x:Oxides of nitrogen

HC: Hydrocarbon

CO:Carbon monoxide

COP: Conformity of production

CATIA V5: Computer Aided Three Dimensional Interactive Application version 5

ANSYS: Analysis of System

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ABSTRACT

The diesel engine combustion process almost always leaves by products ofNO_x, CO, HC, smoke and particulate matter. Out of these emissions, the hydrocarbons and carbon monoxide are gaseous emissions most harmful to the human health. The purpose of this study is emission reduction for old model diesel vehicles by water spray. The methods employed were data collection, identification of harmful gas, computation of the volume of the harmful gas, computationofthe pressure of the gas, design of components, modeling of the components parts using CATIA V5, analysis of the loads on the components using ANSYS and comparison of the existing and the modified engine system. The total carbon monoxide emitted was found maximum before application of water spray. When water is sprayed the amount of carbon monoxide was found reduced. From the above result it is clearly proved that the water spray can reduce the amount CO. Were the designed reciprocating water pump is of paramount importance if it is fixed at the exhaust tail pipe.

Key words*: diesel engine, Emissions, pollutants, exhaust gases*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Automotive engines emit several types of pollutants into the atmosphere which significantly contributes to air pollution. When petroleum-based fuels such as petrol or diesel burn in an engine the main toxic substances present in the exhaust gases are incomplete combustion oxides of hydrocarbon containing CO, NO_x, HC, and particulates. CO emission is the most toxic substance found in exhaust gases and is colorless, tasteless and odorless. HC and CO emissions are primarily products of incomplete combustion [1]. Fine particles are usually invisible although in certain operating conditions, diesel will produce visible particles appearing as smoke. Diesel engines are typically characterized by low fuel consumption and predominantly used to drive tractors, heavy Lorries and trucks. Diesel engines provide important fuel economy and durability advantages for large heavy-duty trucks, buses, and passenger cars however, for many years the continuous pollution of atmosphere from damaging particles that are owed in the first place in transports has led to the phenomenon of greenhouse. The exhaust gases that are produced by Diesel engines are NO, CO, HC and smoke are dangerous for the environment while the smoke is dangerous mainly for the human health [2]. As a result, it is better to design emission reduction means for diesel automobile by using water spray in to the reaction chamber. Besides the photochemical smog, it causes the acid rain as well. The incomplete combustion results like hydrocarbons (HC) contribute to a great degree to ozone formation, which constitutes the main source of photochemical smog. Finally, smoke is in the general category of air pollutant transfer and thus it is considered dangerous for the lungs and generally for human health, mainly when molecules are less than five micrometers in diameter. Under these circumstances molecules are not filtered from the respiratory system. this paper will be examining how the water vapors spray in the exhaust gas emission (CO) in diesel automobile.

1.2 Statement of problem

There are increased number of cars and vehicles, which run on gasoline or diesel fuel. As a result of this the production of air pollution increased. There are several types of air pollutants. Some of these pollutants can be created by human activities, such as cooking, smoking, Car emissions, and other industrial inputs into the atmosphere. The exhaust gases that are produced by Diesel engine are NO_x, CO, HC. They are dangerous for the environment and for human health. These pollutants have the following effects such as smog, the greenhouse effect and hole in the ozone layer. Diesel exhaust causes lung cancer, cardiovascular diseases, and other serious health problems. Health experts have expressed their concern that diesel PM may contribute to chronic lung diseases such as asthma, bronchitis, and emphysema [2]. Reducing or if possible totally eliminating emittedpollutants is of paramount importance. Therefore, this thesis focused on studying the possible ways of reduction of mentioned problems. Among different pollutants one has been preferred; which is CO reduction by using water spray method.

1.3 Objectives

1.3.1 General objective

The general objective of this project is design ofwaterspraysystemfor old model diesel enginescarbon monoxide (CO)emission reduction.

1.3.2 Specific objectives

The specific objectives are to:

- ✓ Identifying the pollutant that can be reduced by water spray method;
- ✓ Designing the system for reduction of the pollutant;
- ✓ Developing 3D model of the system;
- ✓ analysis of the system using ANSYS.
- ✓ Preparing the prototype;
- ✓ Comparing the amount of the pollutant before and after water spray;

1.4 Significance of the study

This thesis introduces application of a new method of emission reduction system for reducing pollutants from diesel engines. The successful achievement of the desired results will contribute in:

- ✓ introducing new system of pollutant reductionto the automotive industry;
- ✓ improving the quality of the environment;
- ✓ improving the health of the people;
- ✓ Reducing the level of carbon monoxide.

Beneficiaries: Automotive industries, vehicle owners, society and country as a whole.

1.5 Scope of the study

- Identifying the pollutants from diesel engine;
- How they are produced;
- Which pollutant is reduced by water spray mechanism;
- Design the reduction system;
- Preparing the proto type.

1.6 Organization of the study

The study is organized in five chapters. The first chapter introduces the background, statement of the problem, objective, scope, significance, organization. The second chapter states literature review of the study. Chapter three includes the materials and methods that are to be used in the project. Chapter four focuses on results and discussion; Finally, the fifth chapter deals with the conclusion and recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Diesel engines provide important fuel economy and durability advantages for large heavy-duty trucks, buses, and non-road equipment and passenger cars. They are often the power plant of choice for heavy-duty applications. While they have many advantages, they also have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NO_x) and, to a lesser amount, hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants. Particles emitted from diesel engines are small in most cases less than 2.5 microns in diameter. The particles are complex, consisting of a carbon core, adsorbed hydrocarbons from engine oil and diesel fuel, adsorbed sulfates, water, and inorganic materials such as those produced by engine wear. Because of their extremely small size and composition, the particles emitted by diesel engines have raised many health concerns.

AhmetKesken [3], catalytic reduction techniques installed on a vehicle's exhaust system can reduce total PM typically by as much as 25 to over 50 percent by mass, under some Conditions depending on the composition of the PM being emitted. Diesel oxidation catalysts can also reduce smoke emissions from older vehicles. Oxidation catalysts can reduce more than 90 percent of the CO and HC emissions and more than 70 percent of the toxic hydrocarbon emissions in diesel exhaust. The lifetime cancer risk from diesel particulate matter has been found to exceed the risks from all other hazardous air pollutant [3].

2.2 Approaches for Reducing Diesel Emissions

2.2.1 Engine Controls

Engine manufacturers started as early as the late eightieth to develop cleaner diesel engines by employing a number of strategies. These approaches include advanced common rail fuel injection, electronic engine controls, combustion chamber modifications, air boosting, improved air/fuel mixing, and reduced oil consumption.

Engine manufacturers are focusing on ways to control engine operation to reduce pollutants

as low as possible. Variable valve timing (VVT) is being used to introduce some fraction of exhaust gas in to the combustion process and reduce HC and NO_x emissions. Exhaust gas recirculation (EGR) is used to dilute intake air with some fraction of exhaust gas to lower the combustion temperatures resulting in lower engine-out NO_x emissions. This can come at the price of increasing particulate matter in the exhaust.

Understanding and controlling the combustion process is the first step in reducing emissions and minimizing the burden on the emission control systems. This allows catalyst developers to design smaller, less costly exhaust controls.

In diesel engines, controlling combustion is the key approach to reducing particulate emissions by optimizing the mixing between the fuel and air in the combustion chamber. Some common ways to increase mixing is through combustion chamber modifications to facilitate turbulent flow as well as fuel injector and injection port design to modify the spray pattern. Variable geometry turbo charging (VGT), which delivers variable quantities of pressurized air based on driving conditions, has been effective in reducing PM emissions by maintaining lean combustion in the engine.Reducing the compression ratios has been shown effective in lowering combustion temperatures and, in turn, NO_xemissions.Engine manufacturers have been able to achieve improvements to combustion control during cold-start by making modifications to the design of intake air valves resulting in a 40-50 percent reduction in HC emissions [4].

2.2.2 Exhaust controls

The majority of hydrocarbon and carbon monoxide emissions from diesel engines that have exhaust catalysts occur during cold-start before the catalyst can achieve optimum operating temperatures. Engine and exhaust system manufacturers have been working together with catalyst companies to develop ways to heat up the catalyst as quickly as possible. The greatest benefit came from the introduction of close-coupled catalysts (CCCs). This positioned the diesel oxidation catalyst (DOC) close to the exhaust manifold to allow rapid heating and therefore rapid oxidation of CO and hydrocarbons. The exothermic heat generated in the DOC by these oxidation reactions facilitates the rapid heat up of the downstream catalysts, such as diesel particulate filters lean NO_x catalysts, and SCR catalysts.

2.2.3 State of art of previous research

Zheng et al [5],exhaust gas recirculation (EGR)is being used on new light- and heavy-duty diesel vehicles as the primary method of reducing engine-out NO_x. EGR is capable of achieving a 50 percent reduction in NO_x emissions or more; however, it can result in an increase in engine-out

PM emissions. NO_x catalysts have demonstrated NOx reductions of 10 to 40 percent whereasNO_x adsorbing catalysts (also known as NO_x traps) are capable of 70 percent or more NO_x reduction. These NO_x catalysts also provide oxidation capabilities that result in significant reductions in exhaust hydrocarbons, CO and the soluble fraction of PM.

Janice hattom[6],used urea as a reducing agent and has shown it to be the most effective control technology for reducing NO_x emissions, exhibiting conversions of up to 90 percent while simultaneously reducing HC emissions by 50 to 90 percent and PM emissions by 30 to 50 percent.

Maiwada et al [7], In recent time, the internal combustion engine powered vehicles have come under heavy attack due to the various problems created by them. The most serious of these is air pollution. The main pollutants contributed by the automobile are Carbon Monoxide (CO), Unburned Hydrocarbons (UBHC), Oxide of Nitrogen (NO_x), Lead, Sulphur Oxide (SO_x) and other particulate emissions.

Johnson [8], has shown that the vehicle emissions regulations have focused primarily on criteria pollutants, such as hydrocarbon (HC), NO_x, CO, and particulate matter (PM). These regulations had and still have a profound impact on powertrain technologies, ranging from fuels and lubrication oils, to engine technologies and emission control systems, across all vehicle and equipment categories. Many argue that no other trend has influenced powertrain technology more than this 99% minor of pollutant emissions.

Hussain et al [9],showed that The diesel engine's status as a noisy, smoky, and slow power plant has changed due to modern diesel engine technology which allows one to combine the natural low fuel consumption with excellent driving performance and low emission characteristics. After carbon dioxide (CO_2) was identified as a greenhouse gas contributing to global warming, diesel engines have emerged as an alternative to gasoline engines due to their low fuel consumption and hence low CO_2emission.The formation of NO_x as well as PM is closely linked to the combustion process which depends on engine design variables such as combustion chamber and fuel injector design, pressure and timing of the injection (modern injection system such as common rail also allow multiple injections), swirl ratio, valve timing, compression ratio, etc. In general, these variables can only be optimized for the reduction of one of these two main pollutants.

Balashowry[10], showed thatdiesel engine is highly efficient, its power density and exhaust emissions are traditionally being less desirable than spark ignition (SI) combustion engines. In a diesel engine, the combustion rate is controlled by the fuel injection rate, mixing and diffusion rates which are usually slower than the premixed combustion rate in typical gasoline engines. Diesel engines usually emit more particulate and NO_X than their gasoline counter parts. The high temperature and pressure environment in the diesel engine cylinder because of its high compression ratio and high combustion temperatures makes it impossible to completely prevent NO_X from forming.

Different technics are taken by researcher's in order to minimize or eliminate the pollutants from diesel engines. Among the major pollutants CO is the one which cause different problems to the environment.So, Design the system to reduce or if possible to eliminate emission of CO from diesel engine exhaust gas.

2.3 Design Procedure

The step-by-step procedure in the design of a mechanical machine (system) is as follows:

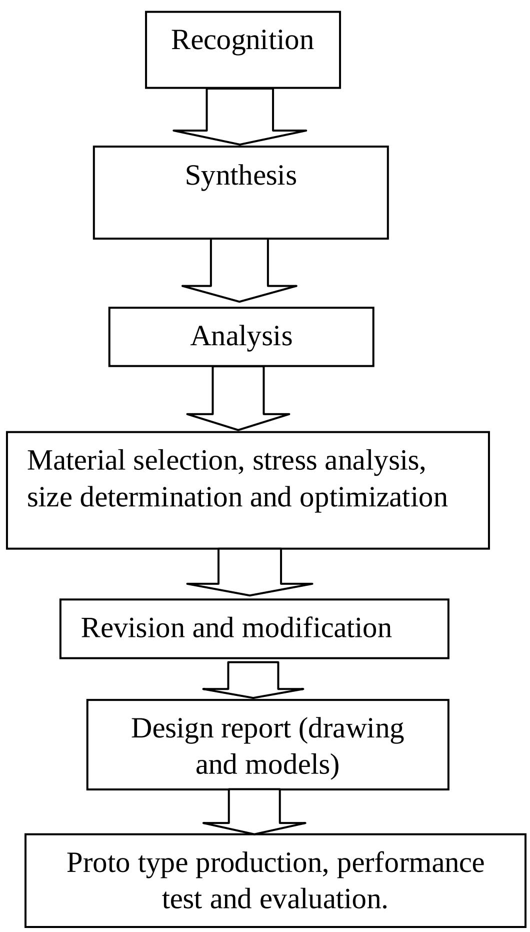


Figure 2. 1: Flow chart of design procedure

2.4 Connecting rod and its cross section I-Section

The connecting rod is subjected to alternating axial (compressive and tensile), bending, twisting and fatigue (fluctuating or cyclic) types of loads. As a result of these, a combined or complex stresses will setup within this member. In the design of a connecting rod, the major load or force which tends to cause buckling or crushing is the maximum axial-compressive load also called the buckling or crushing load. Since the compressive forces are much higher than the tensile forces, the cross-section of the connecting rod is designed by considering it as a 'strut' having an I-section, and hence the 'Rankine' formula will be used or applied as this formula gives a fairly correct result for both long and short struts.

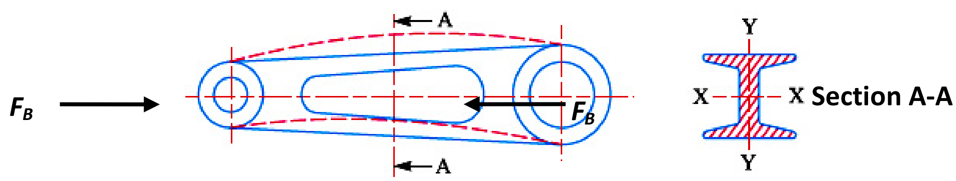


Figure 2. 2:Buckling of a connecting rod and its cross-section.

The 'End conditions' of a connecting rod considering it as a 'strut' are:

- 'both ends hinged' about the x-axis, and
- 'both ends fixed' about the y-axis.

According to Rankine's formula,

- About the x-axis

$$\Rightarrow F_B = \frac{\sigma_c \times A}{1 + a \times \left(\frac{L}{k_{xx}}\right)^2} = \frac{\sigma_c \times A}{1 + a \times \left(\frac{l}{k_{xx}}\right)^2} \text{ and } \quad L = l \quad \text{for 'both ends hinged'}$$

- About the y-axis

$$\Rightarrow F_B = \frac{\sigma_c \times A}{1 + a \times \left(\frac{L}{k_{yy}}\right)^2} = \frac{\sigma_c \times A}{1 + a \times \left(\frac{l}{2k_{yy}}\right)^2} \text{ and } \quad L = \frac{l}{2} \quad \text{for 'both ends fixed'}$$

where, F_B= 'Buckling or Crushing' load.

σ_c= 'Compressive yield stress' of aluminum alloy

A = 'cross-sectional area' of the connecting rod.

a = 'Rankine's constant'

L = 'Equivalent length' of the connecting rod.

l = 'length' of the connecting rod.

k_{xx} and k_{yy} are the 'Radius of gyration' of the section about the x- and y-axes respectively.

$$k_{xx} = \sqrt{\frac{I_{xx}}{A}} \text{ and } k_{yy} = \sqrt{\frac{I_{yy}}{A}}$$

I_{xx} and $I_{yy}$are the 'Moments of inertia' of the section about the x- and y-axes respectively.In order to be a connecting rod equally strong in buckling about both x- and y-axes, the buckling load about the two axes must be equal. Hence,

$$\frac{\sigma_c \times A}{1 + a \times \left(\frac{l}{k_{xx}}\right)^2} = \frac{\sigma_c \times A}{1 + a \times \left(\frac{l}{2k_{yy}}\right)^2} \Rightarrow \left(\frac{1}{k_{xx}}\right)^2 = \left(\frac{1}{2k_{yy}}\right)^2$$

$$\Rightarrow k_{xx}^2 = 4k_{yy}^2 \text{ or } I_{xx} = 4I_{yy}$$

This shows that, the connecting rod is four times stronger in buckling about the y-axis than about the x-axis. In actual practice, $I_{xx}$is kept to be slightly less than $4I_{yy}$. It is usually taken in between 3 to 3.5. Hence, the connecting rod is designed for buckling about the x-axis and which means the design will always be safe for buckling about the y-axis. I-section proportions and dimensions are as shown below:

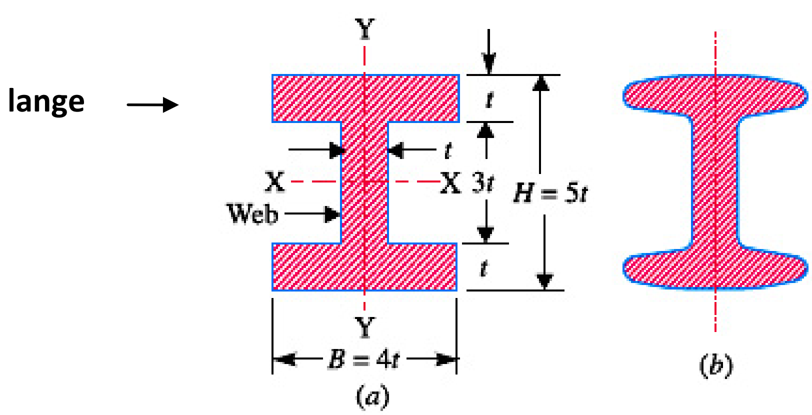


Figure 2. 3:Proportions and dimensions of I-section.

Once the proportions of the section are known, the ratio of I_{xx} to I_{yy} has to be checked whether it is within the required limits of 3 to 3.5. Hence,

$$I_{xx} = \frac{1}{12} \times \left[4t \times (5t)^3 - 3t \times (3t)^3\right] = \frac{419}{12} t^4 = 34.92\ t^4$$

$$I_{yy} = \frac{1}{12} \times \left[2 \times \left(t \times (4t)^3\right) + (3t)t^3\right] = \frac{131}{12} t^4 = 10.92 t^4$$

$$\frac{I_{xx}}{I_{yy}} = \frac{34.92\ t^4}{10.92 t^4} \approx 3.2$$

As the value of $\frac{I_{xx}}{I_{yy}}$ lies in between 3 and 3.5, the chosen I-section is quite satisfactory[11].

CHAPTER THREE

3. MATERIALS AND METHODS

3.1MATERIALS

Materials that are needed for this project are listed below: -

Table 3. 1: Materials required

NO	Item	Quantity
1	Piston	1
2	Connecting rod	1
3	Crank shaft	1
4	Solid shaft	1
6	Spray nozzle	1
7	Cylinder	1
8	Sheet metal	8
9	Small water tank	1
10	Discharge and suction valves	1 for each
11	Water line pipes	2

3.2 METHODS

In this attempt, the data have been collected from both primary and secondary sources. The primary data have been collected observation, and interviewing technician and development of emission reduction in diesel automobile. In secondary data sources of different forms such as literatures, data record, text book, and Research papers were referred. The following methods are used to accomplish the research

1. Data collected from different literate and mechanics
   - How the pollutants are produced;
   - Which type of pollutant is harmful;
   - What type of pollutant reduction mechanism is done by researchers;

2. Design of component parts;
3. Modelling of the component parts using CATIA V5;
4. Analysis of the loads on the components usingANSYS;
5. Comparison of the existing and the modified;
6. Preparation of proto type;

The following flow chart shows sequences for accomplishing the thesis:

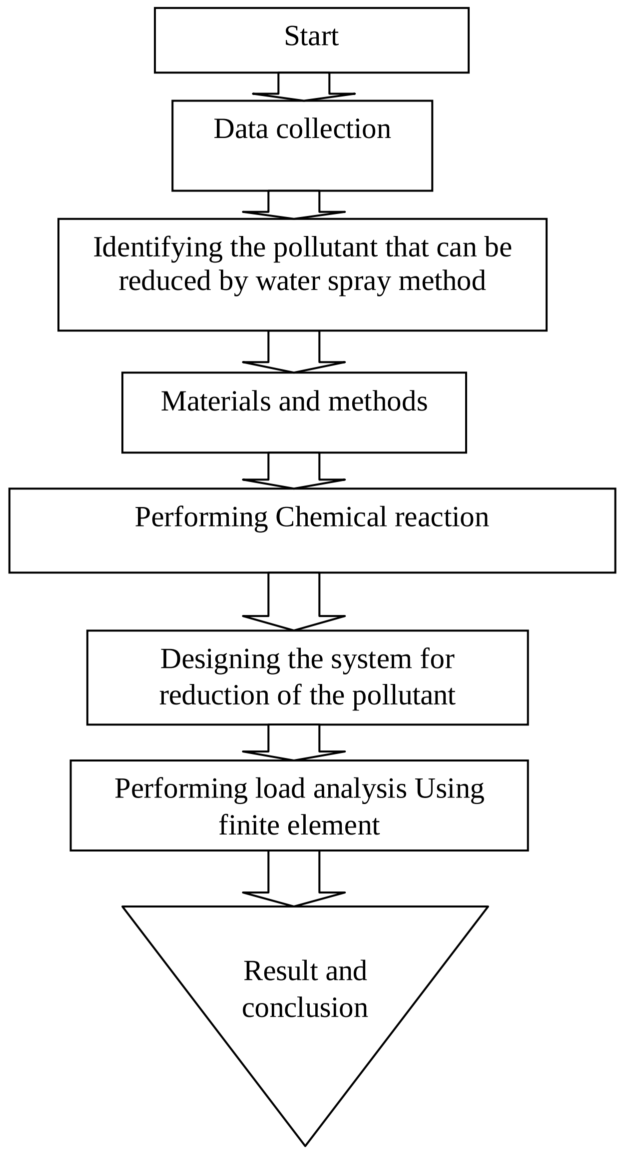


Figure 3. 1: Flow chart of method

3.3 CHEMICAL REACTION OF EXHAUST GASES WITH WATER

The empirical chemical formula for diesel fuel is $C_{12}H_{23}$ and during incomplete combustion the exhaust products are CO_2, H_2O, N_2, O_2, CO, H_2, H, O, OH, NO, CH_4. In order to make a combustion fuel, air and heat are required. The incomplete combustion chemical reaction for diesel fuel is given as follow: -

$C_{12}H_{23}+\lambda\, a_{th}(O_2+3.76N_2)\rightarrow n_1CO_2+n_2H_2O+n_3N_2+n_4O_2+n_5CO+n_6H_2+n_7H+n_8O+n_9OH+n_{10}NO+n_{11}CH_4$. Where λ is lambda the equivalence ratio for air-fuel. For rich mixture λ from 0 to 0.5 above 0.5 to 1.6 is combustible zone and beyond 1.6 it is lean mixture for diesel engine. Andath is the theoretical air for diesel engine it is 17 to 80. Coefficients n_1, n_2, n_3,........$n_{11}$are mole numbers for each product gases [12].

This project is work on reduction of carbon monoxide (CO) which is produced during incomplete combustion. During rich mixture the most pollutant gas is CO. Let as write the incomplete combustion of diesel fuel during rich mixture.

$$C_{12}H_{23}+\lambda\, a_{th}(O_2+3.76N_2)\rightarrow ACO_2+BH_2O+C\,CO+DN_2 \qquad (1)$$

The range for lambda is 0 to 0.5;For this analysis 0.25 has been taken. Taking the amount of air in volume from 17 to 80 the suitable theoretical air for the chemical reaction has been checked.

For O $\quad 0.25\times2\times a_{th}=2A+B+C$

For C $\quad 12=A+C$

For H $\quad B=11.5$

For N $\quad 1.88\times ath=2D$

To solve this simultaneous equation a_{th} should be known to get the proper value by checking from 17 to 80 in order to get the correct value for the mole number. So the value fora_{th} is 50 and A, B, C, D is 1.5,11.5,10.5 and 47 respectively. The reactant and product side have equal mole numbers now inserting the mole numbers in equation one.

$$C_{12}H_{23}+12.5(O_2+3.76N_2)\rightarrow 1.5\,CO_2+11.5\,H_2O+10.5\,CO+47\,N_2$$

The amount of CO in the exhaust gas from the incomplete combustion is 10.5 mole.

Sum the mole numbers of the product gases 1.5+11.5+10.5+47 = 70.5 mole

To calculate the product gas composition on mole fraction bases by using the following relation: -

$Y_{ni=}$ ni/M……………………………………………. ………… (2)

Where n_i = mole of each product gas

M = total mole number of the product gas

Now inserting the mole number of each product gas and total mole to equation two and computing one by one.

Yco_2 = 1.5/70.5 = 0.0212 = 2.12%

YH_2O= 11.5/70.5 = 0.1631= 16.31%

Yco = 10.5/70.5 = 0.1489 = 14.89%

YN_2 =47/70.5 = 0.6666= 66.66 %

Now let as write the reaction of water with product gases to check whether the product is toxic or not to the atmosphere and in this process the three product gases are considered because the forth one is water react with itself it is not harmful.

When water reacts with carbon monoxide produces carbon dioxide and hydrogen which is not toxic for our environment.

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Reaction between water and carbon dioxide it produces carbonic acid also which is not toxic even it is good for blood circulation.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

The next reaction is water with nitrogen

$$N_2 + H_2O \longrightarrow N_2O + H_2$$

Now calculate the pressure and volume of the exhaust gas by using ideal gas equation which is

PV =mRT…….…………………………………… …………. (3)

wherep = pressure in pa

V = volume in m^3

M = mass in Kg

R = gas constant

T= temperature in K.

First of all, calculate mass for each gas the mass of substance is the number of mole multiplied by the molecular weight.

Table 3. 2: Exhaust gas mass value

No	Product gases	No. of mole In mole(n)	Molecular weight In kg/kmole(M)	mass= n×M in Kg
1	CO_2	1.5	44	0.066
2	H_2O	11.5	18	0.207
3	CO	10.5	28	0.294
4	N_2	47	28	1.316

Now calculate the gas constant (R)for each gas.

$$R = R_u/M \quad \text{……………………………………………………...….. (4)}$$

Where, Ru = universal gas constant

M = molar mass in Kg/Kmole

$R_{co_2} = R_u/M_{co_2}$ = 8.314/44 =0.188 kg/kg.k the same procedure done for the rest three gases H_2O,CO and N_2 the result are 0.461,0.296 and 0.296 respectively.

So the total gas constant is by adding up them and tacking the average which is:

$$R_{total} = RCO_2 + RH_2O + RCO + RN_2$$

$$= 0.188 + 0.461 + 0.296 + 0.296 = 1.241/4 \text{ KJ/ Kg.K} = 0.31025 \text{ KJ/ Kg.K}$$

Finally calculate the volume of each gas.

Table 3. 3: Exhausts gas volume value

No	Product gases	Density of each gases in Kg/m^3	Mass of exhaust gas in Kg	Volume $\rho \times m$ in m^3
1	CO_2	1.98	0.066	0.03333
2	H_2O	1000	0.207	0.207×10^{-3}
3	CO	1.14	0.294	0.258
4	N_2	1.251	1.316	1.052

$$V_{total} = 0.03333 + 0.207\times10^{-3} + 0.258 + 1.052$$

$$= 1.343 \text{ m}^3$$

Now calculate the pressure produced by the exhaust gas usingequ. (3).

$$P\frac{1.883kg\times310.25\times823}{1.343}\text{=358kPa}$$

3.4 DESIGN OF COMPONENTS

Design of the spray mechanism parts includes;the flat blade, shaft, spring, crank shaft, connecting rode, cylinder and piston.

i. Engineering Design: is a process or a series of activities to develop a new machine (system) and/or to modify the existing machine (system) by converting the design engineer's creative idea into reality [13].

ii. Design of flat blade: the material is ferritic stainless steel grade 439operating temperature is range from 1000 to 1150^{0}C and have a great thermal stress resistance with 13.6×10^{-6} linear thermal expansion coefficient and young's modulus of 220 ×10^3 N/mm^{2}from the design book. The flat steel has 100×60×1mm dimension. The sheet metal is designed by considering the thermal stress.

So the thermal stress can be calculated by the following relation ship

$$\varepsilon = \beta \times \Delta(T) \qquad (5)$$

$$(E) = \sigma/(\varepsilon) \qquad (6)$$

Where ε = strain

β= refers to the linear coefficient of thermal expansion

ΔT= change in temperature

E= Young's modulus of elasticity

σ = stress

by substituting equation 5 in equation 6 and multiply both side by equation 5 and the final thermal stress is: -

$$\text{Thermal stress } (\sigma) = A \times \Delta(T) \times E \qquad (7)$$

Using equation 7 to calculate the material thermal stress

$$\sigma_T = 220\times10^3 N/mm^2 [\ 13.6\times10^{-6}\ cm/cm^0C\ (600^0C - 500^0C)]$$

$$S_T = 299.2\ N/mm^2$$

The thermal stress for ferritic stainless steel with operating temperature 1000 to 1150 ^{0}C is448.8 N/mm^2 so the selected material safely works. now calculate the force developed on the sheet metal due to the pressure of the exhaust gas.

First calculate the area of the plate which is width*length it is 60cm^2 and the pressure is calculated early it is 358kpaPa. force can be calculated as follow

$$F = P/A \quad \text{……………………………………………………..….. (8)}$$

where p = pressure

A = area in m^2

$$F = 358KPa \times 0.006m^2$$

$$= 2.15KN$$

So in order to find the speed of the rotating flat blade the force generated on the flat sheet metal is the mass of the rotating part multiplied by acceleration but the acceleration is due to the circular movement by using the following relation it is possible to find the speed. The Mathematical relation for the above statement is

$$F = ma \quad \text{……………………………………………………..……. (9)}$$

Where F= force

M=mass

a= acceleration

but $a = v^2/r$

v = velocity and r= radius.

And solving for v: -

$$V = \sqrt{Fr/m} \quad \text{………………………………………………….(10)}$$

The mass can be calculate using the density and volume of the flat sheet metal

$$M = \rho \times v \quad \text{……………………………………………….………... (11)}$$

The density of ferritic stainless steel is 7740 kg/m^3 and the volume is 1.5×10^{-3} m^3.now substituting the above values in equation 11 the mass is 0.12kg multiply by total number of blades to get the total mass which is 0.96kg and the radius is taken from the sheet metal and it is 0.11m.

$$V = \sqrt{0.11 \times 2150/0.96}$$

$$V = 15.7m/s$$

To find the revolution per minute(N) of the blade use the linear velocity to angular velocity relationship.

$$V = \omega \times r \quad \text{and} \quad \omega = 2\pi N/60$$

Where ω=angular velocity

N=revolution per minute

$$N= v\times60/2\pi r$$

$$= 15.7\times60/2\times3.14\times0.11$$

$$N = 162.77\text{rpm}$$

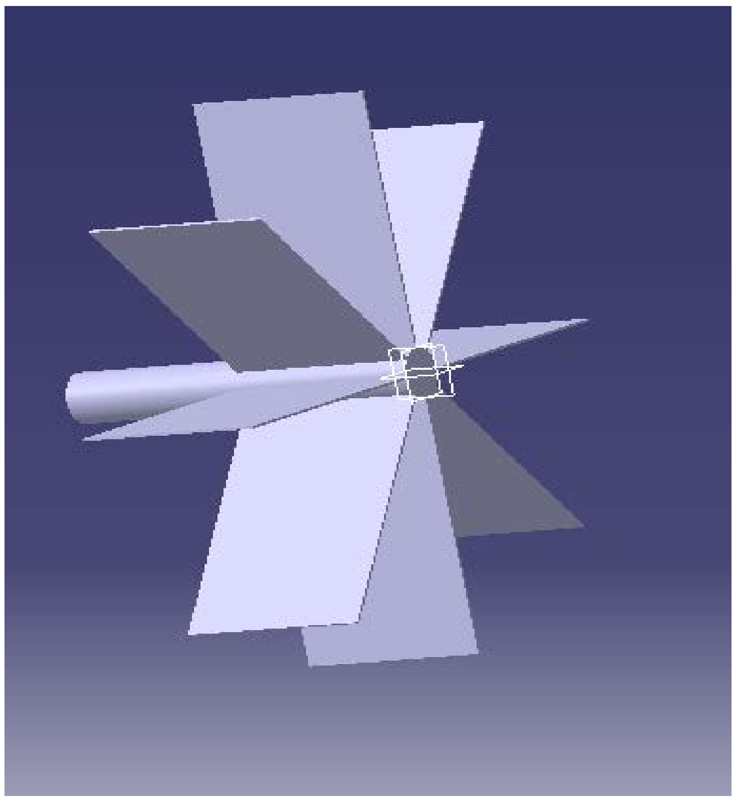


Figure 3. 2: Flat blade 3D assembly drawing

iii.Design of Piston, Piston Rings and Piston Pin

The main purposeofpiston is by reciprocating with in the cylinder pumping the water through the dischargepipe.A piston is constructed to possess: head, ring grooves, skirt and pin-hole. The ring grooves houses piston rings (compression and oil control rings); aluminum alloy is preferable material than cast iron becauseit is 3 times lighter than cast iron. This decreases the mass of the piston and hence the inertia load (force) [14]. Stroke, bore, crank radius and connecting rod length are discussed below.

The stroke and the bore is specified by considering the small reciprocating pump. Since the stroke and bore are 30×40mm respectively.

Crank radius (r) = s/2 =15 mm

Connecting rod length =2×s = 60mm

Table 3. 4:Mechanical properties for Aluminum Alloy 4032

No	PARAMETERS	AlGHS 4032
1	Elastic Modulus(GPa)	79
2	Ultimate Tensile Strength (MPa)	380
3	Yield Strength (MPa)	315
4	Poisson’s Ratio	0.33
5	Density (Kg/m3)	2684.95

Size determination

a.Piston diameter (d_p): The piston diameter (d_p) is given by;

$$d_p = d - c_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(12)}$$

where, c_d = diametral clearance which is 0.08

d= bore

=40 –0.08

=39.92mm

The thickness of the piston head (t_H) should be compared with the value obtained from the following empirical relations,

$$t_H = 0.075\, d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(13)}$$

= 0.075×40

=3mm.

b.Radial thickness of the Compression Ring (t_r): The radial thickness of the compression ring can be obtained by considering a radial pressure between the cylinder wall and the ring. From 'bending stress' consideration, the radial thickness is given by,

$$t_r = d\sqrt{\frac{3\times p_r}{\sigma_r}} \quad \text{...} (14)$$

wherep$_r$= the radial pressure on the piston rings it is 0.025Mpa

σ_r = the allowable stress for the piston rings material is

The material for piston ring is cast iron with allowable stress =82MPa.

$$t_r = 40\sqrt{\frac{3\times 0.025}{82}}$$

=1.2 mm

c. Axial thickness of the Compression Ring (t_a): The axial thickness of the compression ring can be determined as,

$$t_a = \frac{d}{20\times n_R} \quad \text{...} (15)$$

where, d = 'bore' in 'mm'.

n_R=number of compression rings

$=\frac{40}{20\times 2}$

=0.6mm

d.Axial thickness of the Oil-control Ring (t_{2o}): The axial thickness of the oil-control ring can be determined as,

$t_{a0}=2t_a$.. (16)

$=2\times 0.6$

=1.3mm and t_{20} =1.35mm

e. 'End gap' of the compression ring (e_1): The 'end gap' of the compression ring when it is put inside the cylinder can be determined as.

$$e_1=0.002d \quad \text{……………………………………………………………. (17)}$$

Where, d = 'bore' in 'mm'.

$$= 0.002\times40$$

$$= 0.08\text{mm}$$

f. 'Free end gap' of the compression (e_2): The 'free end gap' of the compression ring when it is outside of the cylinder can be determined as,

$$e_2=3t_1 \quad \text{…………………………………………...……………………. (18)}$$

And for the ring Groove $t_1=t_r+(0.3\text{mm})$

= 1.5mm and substitute in equation 18

$$e_2=3\times1.5$$

$$= 4.5\text{mm}$$

g.Top land (b_1): The distance from the top of the piston to the first compression ring groove (b_1) is made to be a bit larger than the thickness of the piston head. Hence, it can be taken as,

$$b_1=1.2t_H \quad \text{…………………………………………………...………….. (19)}$$

$$=1.2\times3$$

$$= 3.6\text{mm}$$

h. Ring land (b_2): first calculate the 'Ring Groove $t_2 = t_a+0.3\text{mm}=0.63$

$$b_2=t_2+0.5\text{mm} \quad \text{…………………………………………………….……….. (20)}$$

$$= 0.63+ 0.5$$

$$=1.13\text{mm}$$

i. Piston Barrel Thickness (t_3):

It is the cylindrical portion of the piston. The maximum thickness of the piston barrel may be obtained from the following empirical relation:

$$t_3=0.03d+t_1+5\text{mm} \quad \text{…………………………………………….…………. (21)}$$

$$=0.03\times40+1.5+5$$

$$= 7.7\text{mm}$$

j.Piston Wall Thickness at the Bottom (t_4):

$t_4 = 0.5t_3$ …………………………………………………………..………… (22)

$= 0.5 \times 7.7$

$= 3.85mm$

K. Piston Skirt Length (*L*): the length of the piston skirt (*L*) is*0.6d*.

$= 0.6 \times 40$

$= 24mm$

L.Total Length of the Piston (l_p):

$$l_p = b_1 + n_R(t_2 + b_2) + t_{2o} + L \quad \text{….. ……………………………} (23)$$

$=3.6+3(0.63+1.13) +1.35+24$

$=34.23$

M.Length of the Piston Pin (l_{pp}): The total length of the piston pin (l_{pp}) will be about 0.85 of d_p.

$l_{pp} = 0.85d_p$ …………………………………………………….………. (24)

$= 0.85 \times 39.92$

$= 33.9mm$

N.Length of the Piston Pin (l_1): The length of the pin inside the connecting rod bushing (l_1) will be about 0.45 of the piston diameter (d_p) allowing for the end clearance of the pin.

$l_1 = 0.45d_p$ ……………………………………………………….……... (25)

$= 045 \times 39.92$

$= 17.9mm$

O.Outer Diameter of the Piston Pin (d_o): outside diameter of the piston pin (d_o) can bedetermined by equating the load on the piston due to the maximum gas force (F_{g-max}) and the load on the piston pin due to bearing pressure (p_{bp-pp}) at the small end of the connecting rod or piston pin bushing.

Allowable bearing pressure on the piston pin (p_{bp-pp}) for reciprocating pump is 1.75N/mm^2.From this, the outside diameter of the piston pin (d_0) can be determined as,

$$F_{g-max} = Bearing\ \ pressure \times Projected\ area$$

$$= p_{bp-pp} \times d_o \times l_1$$

$$\Rightarrow \quad d_0 = \frac{F_{g-\max}}{p_{bp-pp} \times l_1} \quad \text{……………………………………………………………….…….......} (26)$$

$= \frac{165.96N}{\frac{1.75N}{mm2} * 17.9mm}$ = 5.3mmInner Diameter of the Piston Pin (d_i):The inner diameter of the piston pin will be about 0.6 of the outer diameter of the piston pin (d_o).

$d_i = 0.6d_0$ …………………………………….……………...……... (27)

$= 0.6 \times 5.3$

$= 3.2mm$

The outside diameter of the piston pin (d_o) may also be determined by considering the bending stress and assuming a uniformly distributed maximum gas load or force as,

$l_2 = l_1 + \frac{d_p - l_1}{2} = \frac{d_p + l_1}{2}$ and $R_R = R_L = \frac{F_{g-max}}{2}$

$= 39.92 + 17.9/2 = 28.9mm$ $R_R = 165.96/2$

$= 82.96N$

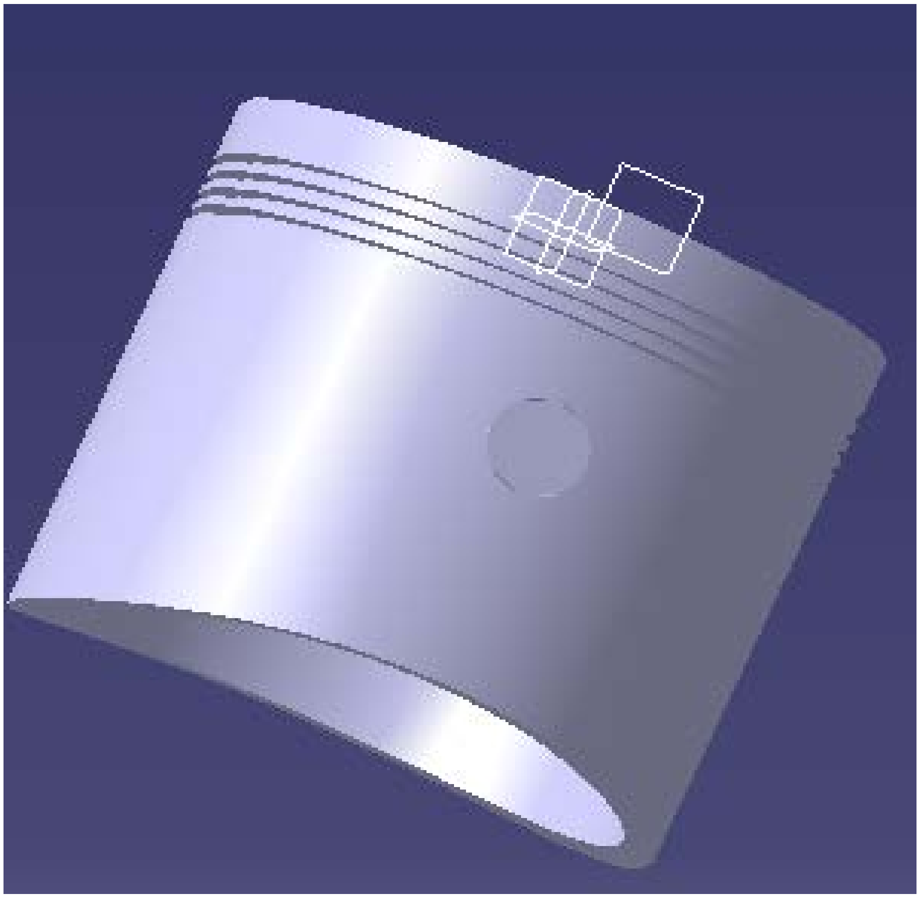


Figure 3. 3:Piston 3Ddrawing

iv.Design of Connecting Rod

The main purpose of connecting rod is to transmit energy or power (force and motion) from the rotation of crankshaft to the piston.

Construction: A connecting rod is constructed to possess: a long shank, small end, big end, bearings, cap and bolts (studs). The cross-section of the shank is I-section is preferred because of its higher section modulus (Z) or its higher strength for the same cross-sectional area. Aluminum alloy6061 is selected.

Table 3. 5: Mechanical properties for Aluminum Alloy 6061

No	Mechanical Properties	Aluminum Alloy6061
1	Density(g/cc)	2.70
2	Modulus of elasticity,(Gpa)	68.9
3	Yield strength, YS,(Mpa)	110
4	Ultimate strength ,Su,(Mpa)	210
5	Poison ratio	0.33

a. Size determination

In designing a connecting rod, the following dimensions are required to be determined:

1. Type of cross-section and its dimensions.
2. Dimensions of the small and the big ends.

In the design of a connecting rod, the major load or force which tends to cause buckling or crushing is the maximum axial-compressive load also called the buckling or crushing load. Since the compressive forces are much higher than the tensile forces, the cross-section of the connecting rod is designed by considering it as a 'strut' having an I-section, and hence the 'Rankine' formula will be used or applied as this formula gives a fairly correct result for both long and short struts. Hence, the thickness '*t*' calculated using the following Rankine's formula about x-axis. And

Buckling load = gas force × F.O.S

And the factor of safety for the connecting rod is 1to 3.by taking the maximum factor of safety the buckling load is calculated as follow

$$F_B = 165.96 \times 3$$

$$= 497.88N$$

$$F_B = \frac{\sigma_c \times A}{1 + a \times \left(\frac{L}{k_{xx}}\right)^2} \quad \text{... (28)}$$

where, $A = 2 \times (4t^2) + 3t^2 = 11t^2$

$\alpha = \sigma_{c/}\, \pi^2 E$ is the Rankin's constant 0.0006

Now substitute the values in the above equation to find the value for 't' after substituting the values the thickness t = 0.59mm.

b.Dimensions of the small and the big ends.

Width of section B = 4t = 4×0.59= 2.36mm

Height of section H = 5t = 5×0.59 = 3mm. Area A = $11t^2$ =11×0.59^2 = $4mm^2$

Height at the big end (crank end) = H2 = 1.1H to 1.25H = 1.1×3= 3.3mm

Height at the small end (piston end) = 0.9H to 0.75H = 0.9×3=2.7mm

Inner diameter of the small end = $Fg/Pb \times l1$= $165.96/1.75 \times 17.9$ = 6mm

Outer diameter of the small end = d_1+$2t_b$+$2t_m$=6+4+10=20mm

Where Thickness of the bush (t_b) = 2 to 5mm

Marginal thickness (t_m) = 5 to 15 mm

Inner diameter of the big end=$Fg/Pb \times l2$ =$165.96/0.5 \times 28.9$= 16mm

Outer diameter of the big end = d_2+$2t_b$+$2t_m$ =16 +4+10 =30mm

Table 3. 6: Dimensions of connecting rod

No	Parameters (mm)
1	Thickness of the connecting rod (t) = 0.59
2	Width of the section (B = 4t) = 2.36
3	Height of the section (H = 5t) = 3
4	Height at the big end = (1.1 to 1.125) H =3.3
5	Height at the small end = 0.9H to 0.75H =2.7
6	Inner diameter of the small end = 6
7	Outer diameter of the small end = 20
8	Inner diameter of the big end =16
9	Outer diameter of the big end = 30

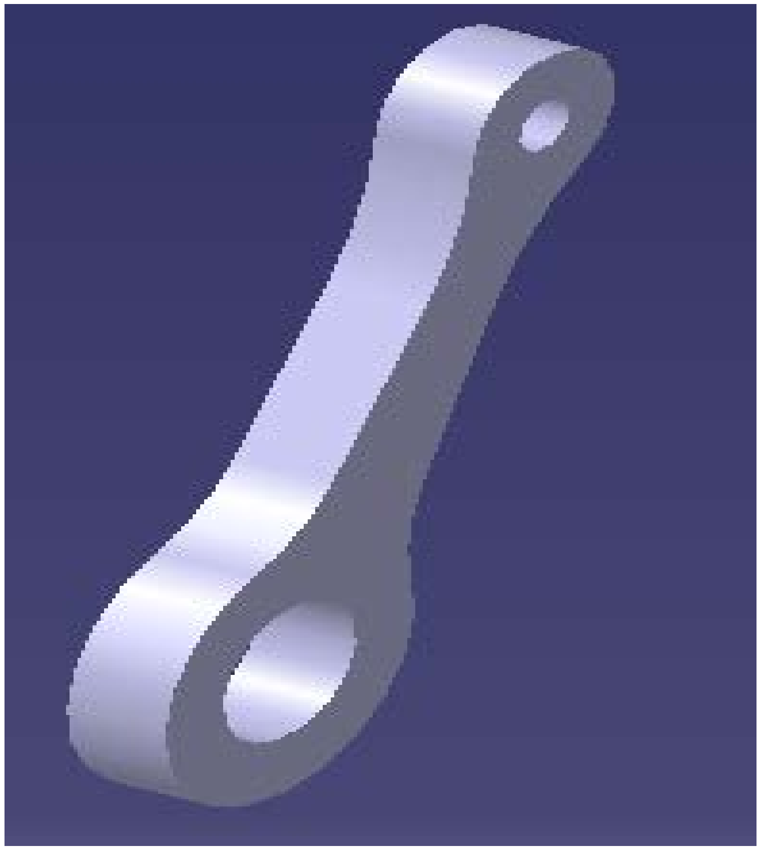


Figure 3. 4: Connecting rod 3D drawing

v.DesignCrankshaft

Purpose: The main purpose of crankshaft in this design is to convert the rotating motion to reciprocating motion of the piston. Crankshaft material has to have adequate: strength, stiffness, toughness, hardness, wear, shock and fatigue resistance. The material for the crank shaft is aluminum alloy working temperature of greater than 500 ^{0}C [15].

Table 3. 7:Mechanical properties for Aluminum Alloy 2024T3

No	Mechanical Properties	Aluminum Alloy2024T3
1	Density(g/cc)	2.78
2	Modulus of elasticity,(Gpa)	73.1
3	Yield strength, YS,(Mpa)	345
4	Ultimate strength ,Su,(Mpa)	483
5	Poison ratio	0.33

a.Size determination

Diameter of crankpin (d_{cp}):

=0.4 d

where, 'd' is the 'bore'.

=0.4×40

=16mm

Length to diameter Ratio of crankpin (R_{ld_cp}):

=0.5

Width of crankweb (w_{cw}):

=0.8 d

= 0.8×40

=32mm

Thickness of crankweb (t_{cw}):

=0.1 d

=0.1×40

=4mm

Diameter of main journal (d_{mj}):

=0.5 d

=0.5×40

=20mm

Length to diameter Ratio of main journal (R_{ldmj}):

=0.5

$$l_L = \frac{l_{mj}}{2} + t_{cw} + \frac{l_{cp}}{2} \quad \text{and} \quad l_R = \frac{l_{mj}}{2} + t_{cw} + \frac{l_{cp}}{2}$$

=13mm *=13mm*

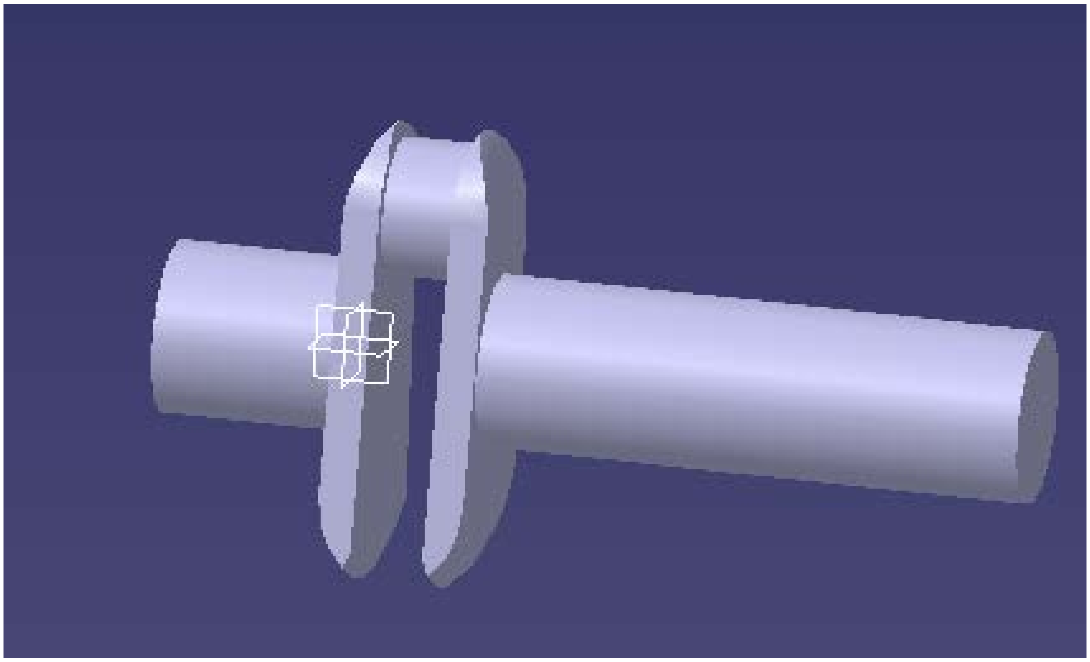


Figure 3. 5:Crank shaft 3D drawing

vi.Design of shaft: A shaft is a rotating machine element which is used to transmit power from one place to another. In these design the shaft must be light in weight and resist twisting moment and the working temperature is suitable for the operation. The material for the crank shaft is aluminum alloy working temperature of greater than 500 ^{0}C with ultimate tensile strength of 483MPa and tensile yield strength of 345MPa. the shaft rotating at 97.5 rpm.

To calculate the shaft diameter, consider the shaft is subjected to twisting moment only and the permissible shear stress is 0.18of the ultimate tensile strength.

$$\frac{T}{J} = \frac{\tau}{r} \quad \text{……………………………………………………………..…} (29)$$

Where T=is twisting moment (torque) acting up on the shaft

J=is polar moment of inertia of the shaft about the axis of rotation

τ=is torsional shear stress and

r =Distance from neutral axis to the outer most fiber

= d / 2; where d is the diameter of the shaft.

for round solid shaft, polar moment of inertia,

$$J= \frac{\pi}{32} \times d^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(30)$$

Now equation (29) is written as

$$T = \frac{\pi}{16} \times \tau \times d^3$$

$$T= \frac{\pi}{16} \times 86.99 \times 20^3$$

$$T=136.643\times 10^3 \text{ N-mm}$$

Now calculate the power transmitted by the shaft

$$T=\frac{p\times 60}{2\pi N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(31)$$

Rearranging the above equation 31 to calculate the power

$$P=\frac{T\times 2\pi N}{60}$$

$$P=\frac{136.643\times 2\times \pi\times 97.5}{60}$$

$$=1.395\text{kw}$$

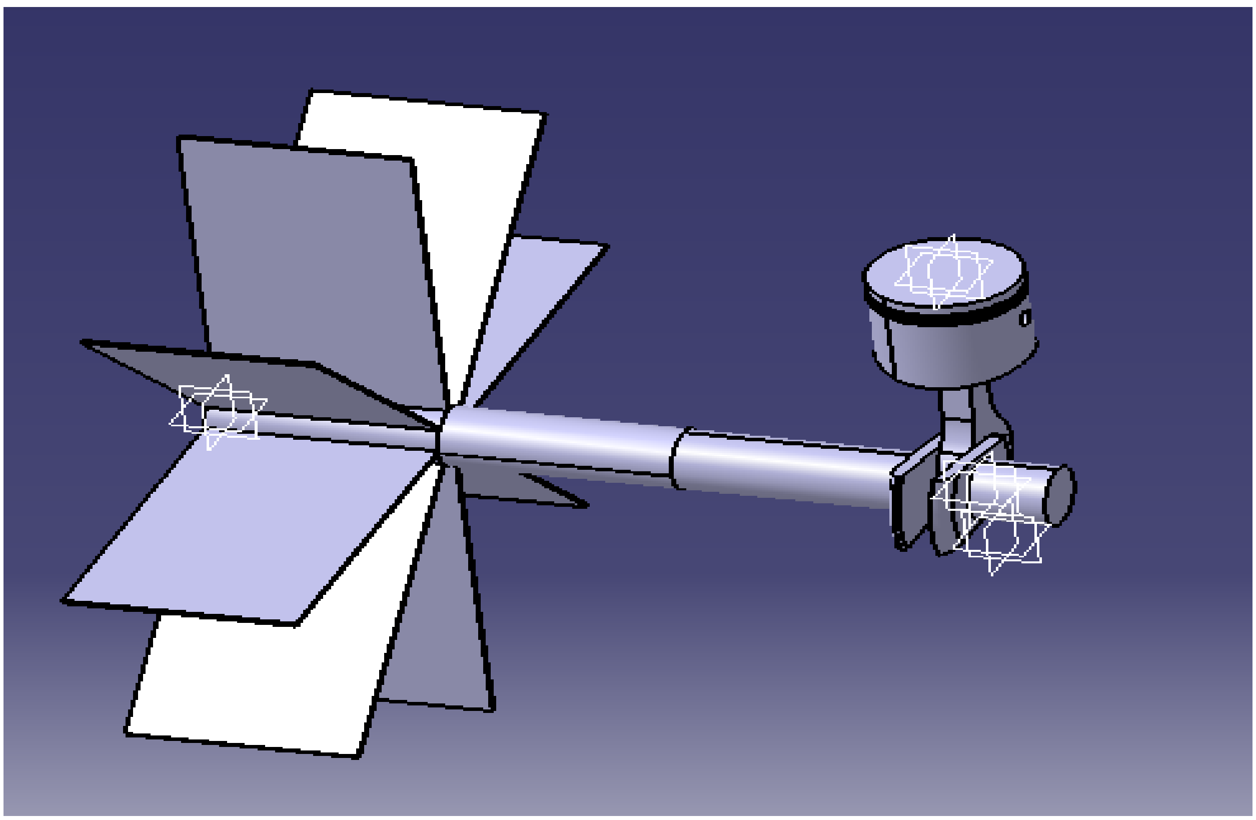


Figure 3. 6: Assembly the shaft drawing

vii.Design of cylinder

Cylinders are usually made from aluminum alloy or cast iron containing nickel or chromium to possess high strength and wear resistance.

a.Size determination

Thickness of the Cylinder Wall (t): -The thickness of the cylinder wall (t) obtained from the following empirical relations,

t = 0.045 d + 1.6 mm

where,$d$is the cylinder 'bore' in 'mm'.

=0.045×40+1.6

=3.4mm

The maximum gas force (F_{g-max}), which imposes mechanical load on the cylinder, produces the following two types of stresses.

a) Longitudinal stress (σ_l), and

b) Circumferential or Hoop stress (σ_c).

Since these two stresses act at right angle to each other, the net stress in each direction may reduce.

The longitudinal stress (σ_l), using a 'thin cylindrical wall' formula, is given by:

$$\sigma_l = \frac{Force}{Area} = \frac{\pi\, r^2\, p_{g-\max}}{2\pi\, r\, t} = \frac{p_{g-\max}\, r}{2\,t} \quad \text{.......} (32)$$

where, $r = d/2$ and d is the 'bore'.

$$\sigma_l = \frac{392.4\text{N/mm}^2 \times 20\text{mm}}{6.8\text{mm}}$$

$=1154\text{N/mm}^2$

The circumferential or hoop stress (σ_c) , using a 'thin cylindrical wall' formula, is given by:

$$\sigma_c = \frac{Force}{Area} = \frac{d\ l\ p_{g-\max}}{2t\ l} = \frac{d\ p_{g-\max}}{2t} = \frac{p_{g-\max}\ r}{t} \quad \text{.......} (33)$$

$$= \frac{392.4\text{N/mm}^2 \times 20\text{mm}}{3.4\text{mm}}$$

$=2308 N/mm^2$

Total Length of theCylinder **(l_{cyl}):-**

$$l_{cyl} = lc + s$$

where, s=is the ‘stroke’ in ‘mm’.

l_c=is the ‘length of the clearance volume’ in ‘mm’.

The size of the clearance volume has to be determined by considering a permissible compression ratio (r) and for small reciprocating water pump r is 4.

= 10+30 =40mm

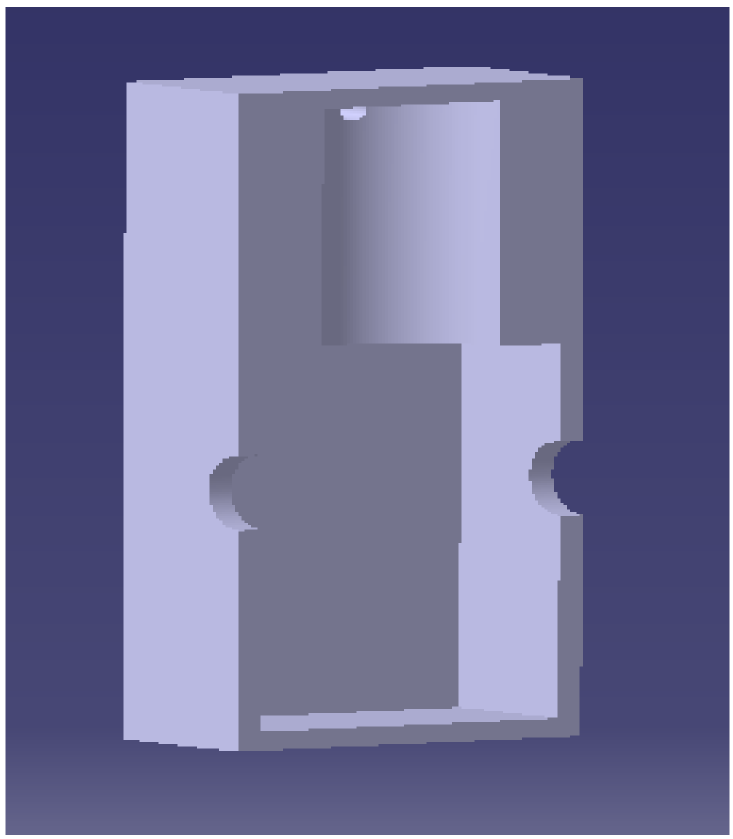


Figure 3. 7: Cylinder block 3D drawing

viii.Bearing selection

Bearing is a device that is used to enable rotational or linear movement, while reducing friction and handling stress. Resembling wheels, bearings literally enable devices to roll, which reduces the friction between the surface of the bearing and the surface it's rolling over. It's significantly easier to move, both in a rotary or linear fashion, when friction is reduced, this also enhances speed and efficiency. Selected material for bearing is high carbon chromium bearing steel, because, it has the

Following properties Easy production, Shock resistance, heat resistance and Corrosion resistance.

Select bearing number 204

Internal diameter of bearing, d_i= 20mm

External diameter of bearing, d_0= 47mm

Width =14mm

Reciprocating pump is a positive displacement pump which fluid is drawn or forced into a finite space by mechanical means. The fluid is then forced out to flow and the cycle is repeated.

The Flow rate of single acting reciprocating pump is calculated as follow

$$Q=\frac{ALN}{60} \qquad (34)$$

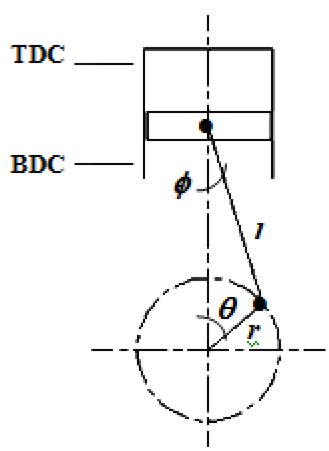
where A is the area of the cylinder

L is the stroke is 30mm and

N is the rotational speed of the crank shaft is97.5rpm

$A=\pi d^2/4 =\frac{\pi\times 40}{4} mm^2=1256.6mm^2$

$Q=\frac{1256.6\times 30\times 97.5}{60} = 60945.1mm^3/s = 6.09\times 10^{-5}m^3/s$



To calculate the velocity of the piston by considering the crank mechanism

Where ϕ=con-rod angel

θ= crank angel

L= connecting rod length

r= crank radius

Figure 3. 8:Crank gear mechanism

The value for the r and l are 15mm and 60mm respectively by applying the pitagors theorem to find the adjacent length.

$$=L^2+r^2=15^2+60^2=\sqrt{3825}$$

$$=66.9\text{mm}$$

by applying the trigonometric function the value for θ and ϕ are 77 and 13^0 respectively

The water moves with the velocity of the piston so piston velocity is calculated as follow

$U_p=d_x/d_t=R\omega\sin\omega t$

where R is the crank radius in mm

$\omega t=\theta=77^0$ from the geometry of clank gear mechanism

ω = angular velocity in rad/s

$$\omega=2\pi N/60 \quad \text{……………………………………………………………..(35)}$$

$$=\frac{2\times\pi\times97.5}{60}$$

$$=10.2\text{rad/s}$$

$$U_p=0.015\times 10.2\times sin77^0$$

$$=0.149\text{m/s}$$

IX. Design of Spring

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. stainless steel wire is selected with allowable shear stress(τ) is 437.5Mpa for light service includes springs subjected to loads that are static or very infrequently varied, as in safety valve springs and modulus of rigidity(G) 70 KN/m^2 and modulus of elasticity(E) 196KN/mm^2 .

Spring Wire Diameter (*d*): -

The diameter of a spring wire (*d*), can be calculated using the following relations,

$$\tau=K\times\frac{8\times F\times C}{\pi\times d^2} \quad \text{………………………………......………………………………..…... (36)}$$

$$\text{Where,}\quad K=\frac{4C-1}{4C-4}+\frac{0.615}{C}\quad ;\quad \textit{is the 'Wahl's Factor'}.$$

$$\text{And, } C=\frac{D}{d}\ ;\ \text{ is the ‘spring index’ } 5$$

$$d^2 = k \times \frac{8\times p\times c}{\tau\times\pi} \quad = 1.3\times \frac{8\times 78.539kN\times 5}{437.5Mpa\times\pi}$$

$$d = 1.5mm$$

Spring Coil Mean Diameter (D)

$D = C\times d$

$= 5\times 1.5 = 7.5mm$

Spring Coil Outer Diameter (D_o)

$D_0 = D+d$

$= 7.5+1.5 = 9mm$

To determine axial deflection by taking 5 for the number of turns

$$\sigma = \frac{40\times p\times D^3}{G\times d^4} \qquad = \frac{40\times 78.593kN\times 7.5\times 10^{-9}m^3}{70KN/mm^2\times 1.5\times 10^{-12}m^3}$$

$= 1.67mm$

For square and ground end, the total number of turns (n'),

$n' = n+2$

$=5+2=7$

Solid length

= (n+2)d

= 10.5

Spring Coil Free Length (L_F)

L_F =total number of turns +deflection +n'-1

= 10.5+1.67+9.5=22mm

Pitch of the Spring Coil (p),

$$p = \frac{L_F}{n'-1}$$

$= \frac{22}{6} = 3.6mm$

Outside diameter of the spring

$D_0 = D+d$

=7.5+1.5=9mm

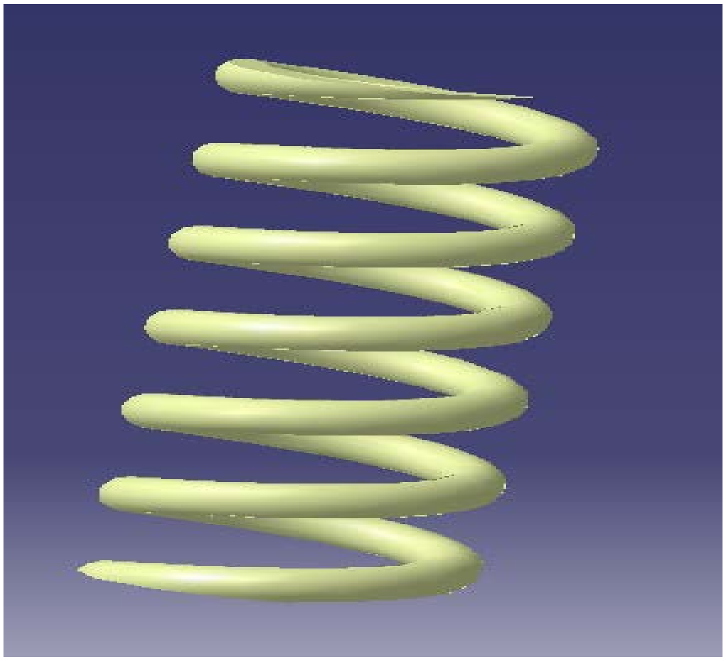


Figure 3. 9: 3D drawing of spring

X.Design of Suction and Delivery Pipe

The pipes are used for transporting various fluids like water, steam, different types of gases, oil and other chemicals with or without pressure from one place to another. Cast iron, wrought iron, steel and brass are the materials generally used for pipes in engineering practice. And for this design copper steam pipe it resists corrosion with allowable tensile stress 25Mpa is selected. The design of a pipe involves the determination of inside diameter of the pipe and its wall thickness as discussed below:

1. Inside diameter of the pipe. The inside diameter of the pipe depends upon the quantity of fluid to be delivered. Let

   D =Inside diameter of the pipe,

   v =Velocity of fluid flowing per minute, and

   Q =Quantity of fluid carried per minute.

   the quantity of fluid flowing per minute is

$$Q=\text{area} \times \text{velocity} = A\times V$$

$$= \pi/4\times d^2\times V$$

$$D=1.13\sqrt{\frac{Q}{V}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(37)$$

$$=1.13\sqrt{\frac{0.0000609}{0.149}} = 10mm$$

In order to calculate the wall thickness, the pressure should be determined so the pressure created due to the flow rate and the crank shaft power is

Power = pressure × flowrate $= p \times Q$ ……………………………………..……………..(38)

where**P**= powerin w

p = pressure in N/m^2

$$p = \text{p}/Q = \frac{1.395}{0.0000609} = 22\text{Mpa}$$

To check the cylinder is thick or thin cylinder if the allowable stress (σt) is less than six times the pressure inside the pipe it is thick and if the allowable stress (σt) is more than six times the pressure inside the pipe it is thin cylinder. so According to thick cylindrical formula (Lame's equation), wall thickness of pipe

$$t = R\left[\sqrt{\frac{\sigma t + p}{\sigma t - p}} - 1\right] \quad \text{………...……(39)}$$

where R = Internal radius of the pipe.

$$=0.005\left[\sqrt{\frac{25+22}{25-22}} - 1\right]$$

t =14mm

now calculate the suction and discharge flowrate, velocity and pressure discharge and suction pipe length are 105.4mmand60mm respectively.

$Q_D = A_D L_D N/60$ ……………………………………………...…... (40)

where A_D = area of discharge pipe in m^2

L_D= length of discharge pipe in m

$$= \frac{\pi \times 0.0001 \times 0.1054 \times 97.5}{60} = 1.3 \times 10^{-7} m^3/s$$

Per day the amount of water required is 11 liters so the water tank should contain this amount of water.

And the discharge pressure

$P = p_D \times Q_D$ ………………………………………….......……….(41)

$$P_D = P/Q_D = \frac{1395}{0.00000013} = 10\text{Gpa}$$

And discharge velocity

$$V_D = Q_D \times \frac{1}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(42)$$

$$= 1.3 \times 10^{-7}\,m^3/s \times 12732m^2 = 0.00166m^3/s$$

Now consider the suction pipe flowrate and pressure

$$Q_s = A_S \times L_S \times N/60 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(43)$$

where A_S= area of suction pipe in m^2

L_S= length of suction pipe in m

$$= \frac{\pi \times 0.0001 \times 0.06 \times 97.5}{60} = 7.6 \times 10^{-6}\,m^3/s$$

Pressure in the suction pipe

$$P_S = P/Q_S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (44)$$

$$= \frac{1395}{0.0000076} = 183Mpa$$

Velocity in the suction pipe

$$V_S = Q_S \times \frac{1}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(45)$$

$$= 7.6 \times 10^{-6}\,m^3/s \times 12732m^2 = 0.0967m/s$$

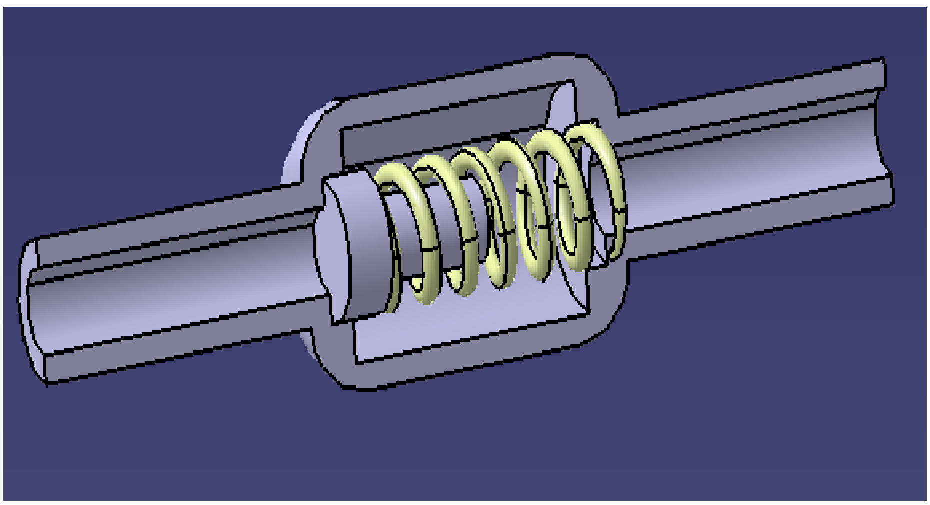


Figure 3. 10: Assembly of Suction and Delivery Pipe with valve and spring

Xi.Design of Water Tank

Tanks are used to store fluids under pressure. In this design the water tank has the dimension 30.1×25×14.6cm is used to store the water the material for the tank is steel with the following mechanical properties.

modulus of elasticity=203.4Gpa

allowable stress =117.9Mpa

Density of steel=7850kg/m^3

The tank plate thickness for rectangular tank is calculated as follow

$$t=L\sqrt{\frac{\beta\times\rho\times g\times H}{s}} \qquad (46)$$

whereβ = factor H/L

g= acceleration due to gravity

H=height

s= allowable stress

$$t= 0.301\sqrt{\frac{0.116\times7850\times9.81\times0.25}{117}}$$

t=1.3mm

And the pressure in the tank is

$$p=\rho g H \qquad (47)$$

whereρ= density of water

g= gravity

H= height of the tank

P=1000kg/m^3×9.81m/s^2×0.25m

=2.452kpa

Now convert the discharge water volume to mole number to know by what amount the CO is reduced

So to convert the volume dived the discharge volume by conversion factor 22.4L.

V_D=1.3×$10^{-7}$$m^3$=0.00013Lwhen it is divided by 22.4L=6×10^{-6}moleis added to the exhaust gas per second. Now by adding the discharge number of mole to the exhaust total mole which is70.5 and calculate the product gas composition from the chemical reaction analysis mole of co is 10.5.

Yni= ni/M

Yco = 10.5/70.5000006

=0.1489361689 mole fraction of co from the total exhaust gas it is after water is added to the exhaust gas to now by how much it is reduced subtract from the original one which means the reaction before water is added

$$CO_{reduction}=14893617.00\times10^{-8} -14893616.89\times10^{-8}$$

$$=1.3\times10^{-9} \text{ mole fraction is reduced.}$$

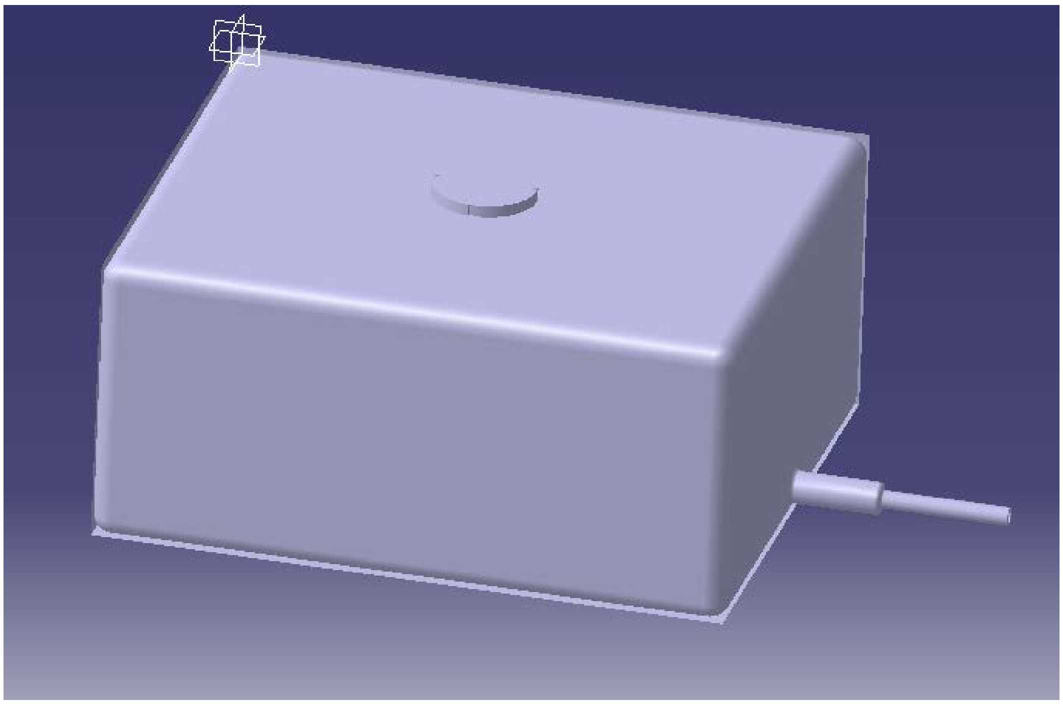


Figure 3. 11: Water tank 3D drawing

Xii. Selection of water spray

In spraying systems, nozzles break the liquid into droplets and form the spray pattern.stain less steel nozzle is last longer than brass or nylon, and generally produces a more uniform pattern over a longer time. extended range flat-fan nozzle is selected for this system because it has excellent spray distribution over a wide range of pressure with 45^0 spray angel.

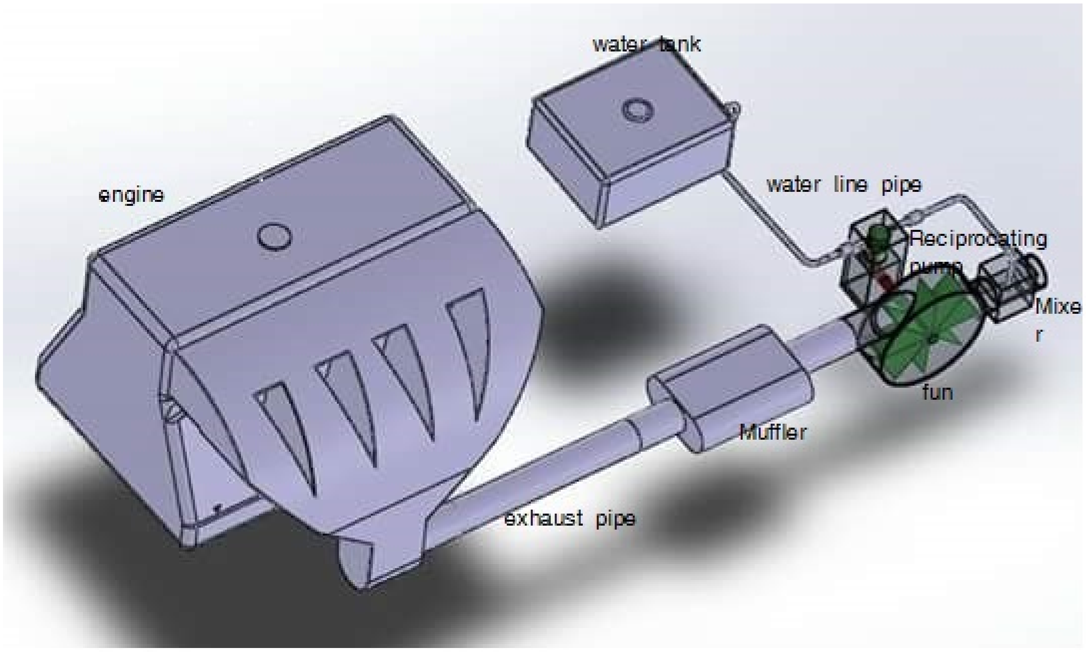


Figure 3. 12: Full Assembly drawing of the system

3.5FINITE ELEMENT ANALYSIS OF RECIPROCATNG PUMPCOMPONENTS

3.5.1 PISTON

Material selection:aluminum alloy4032is preferable material than cast iron becauseit is 3 times lighter than cast iron. This decreases the mass of the piston and hence the inertia load (force). Mechanical properties for the selected material are as follow:

Table 3. 8: Mechanical properties for Aluminum Alloy 4032

No	PARAMETERS	AlGHS 4032
1	Elastic Modulus(GPa)	79
2	Ultimate Tensile Strength (MPa)	380
3	Yield Strength (MPa)	315
4	Poisson’s Ratio	0.33
5	Density (Kg/m3)	2684.95

Boundary conditions:

- Material: aluminum ally4032
- Two end of the piston pin is fixed
- at the top of the piston required load is given F=166N and analyzed
- the analysis results are shown in figures which are given below:

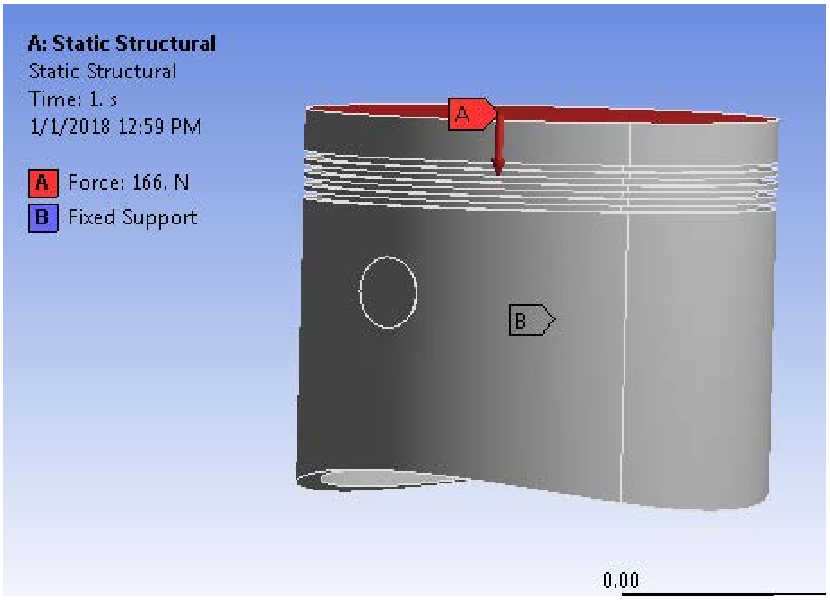


Figure 3. 13: Loads and boundary conditions of the piston

MESHING:

Tetrahedral mesh elements are used in meshing of the piston. In order to get a better result, locally fine mesh is applied in the region which is suspected to have the highest stress.

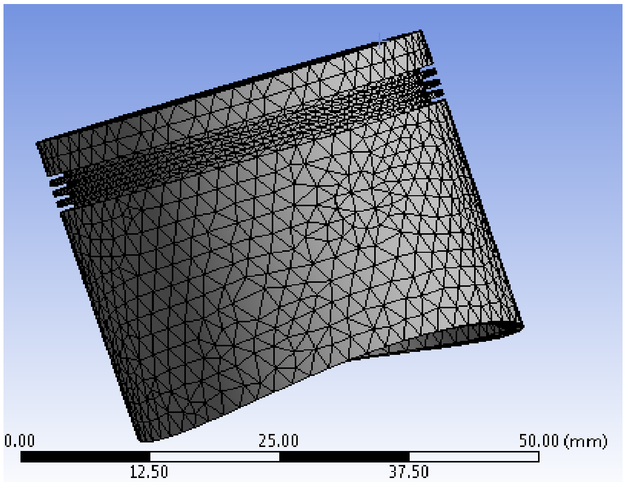
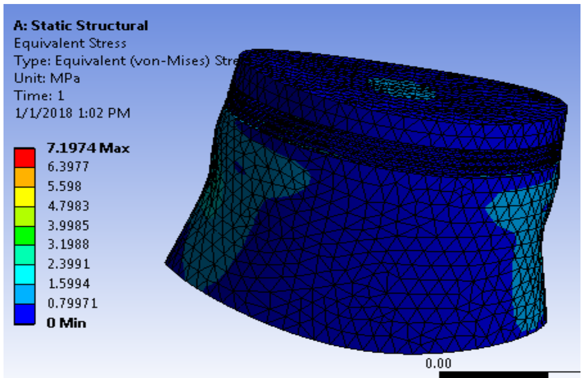
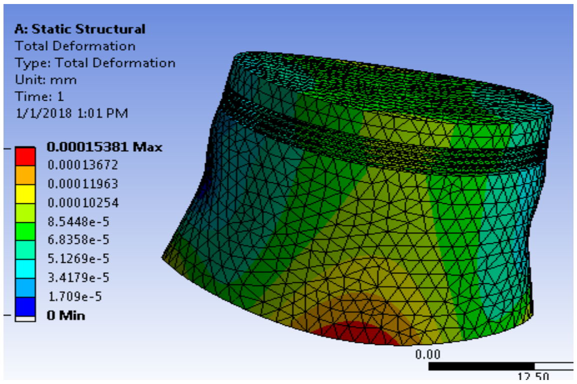
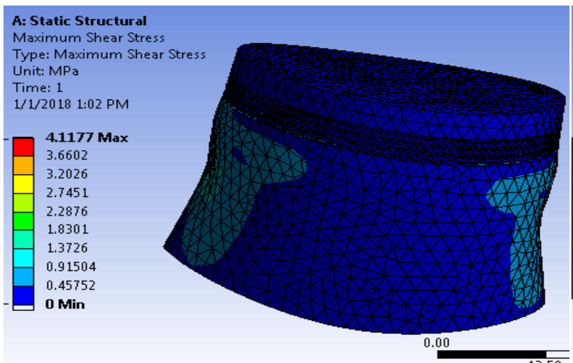


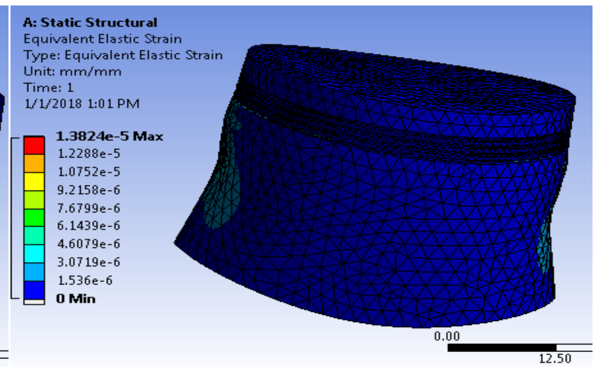
Figure 3. 14: Mesh model of the piston





(A) (B)





(C) (D)

Figure 3. 15: Results of (A) equivalent (von-Mises) stress diagram (B) total deformation diagram (c) Maximum shear stress diagram (D) equivalent elastic strain diagram

3.5.2 CONNECTING ROD

Material selection: Aluminum alloy 6061 is selected.

Table 3. 9: Mechanical properties for Aluminum Alloy 6061

No	Mechanical Properties	Aluminum Alloy6061
1	Density(g/cc)	2.70
2	Modulus of elasticity,(Gpa)	68.9
3	Yield strength, YS,(Mpa)	110
4	Ultimate strength ,Su,(Mpa)	210
5	Poison ratio	0.33

Boundary conditions:

- Material: aluminum ally 6061
- at the crank pin it is fixed

➢ at the small end required load is given F=166N and analyzed

➢ the analysis results are shown in figures which are given below:

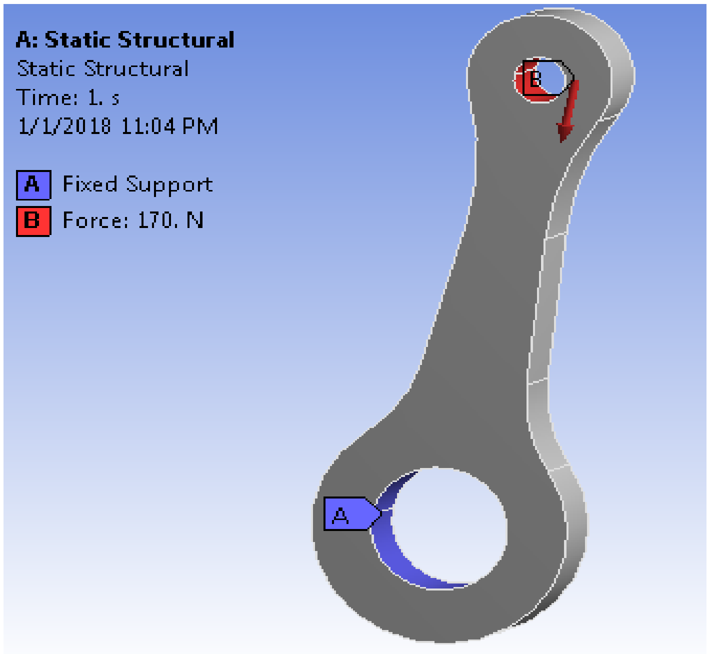


Figure 3. 16:Loads and boundary conditions of the connecting rod

MESHING:

Tetrahedral mesh elements are used in meshing of the piston. In order to get a better result, locally fine mesh is applied in the region which is suspected to have the highest stress.

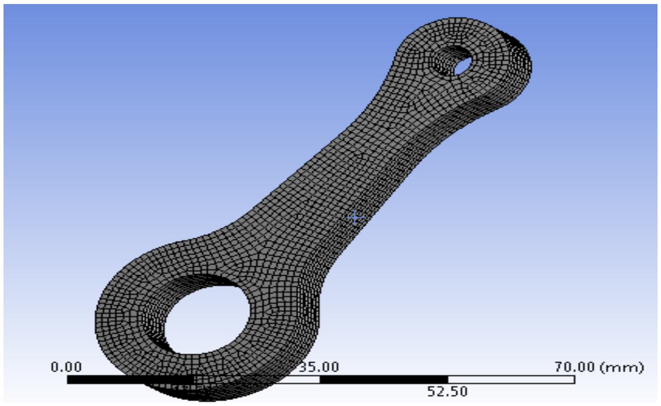


Figure 3. 17:Mesh model of the connecting rod

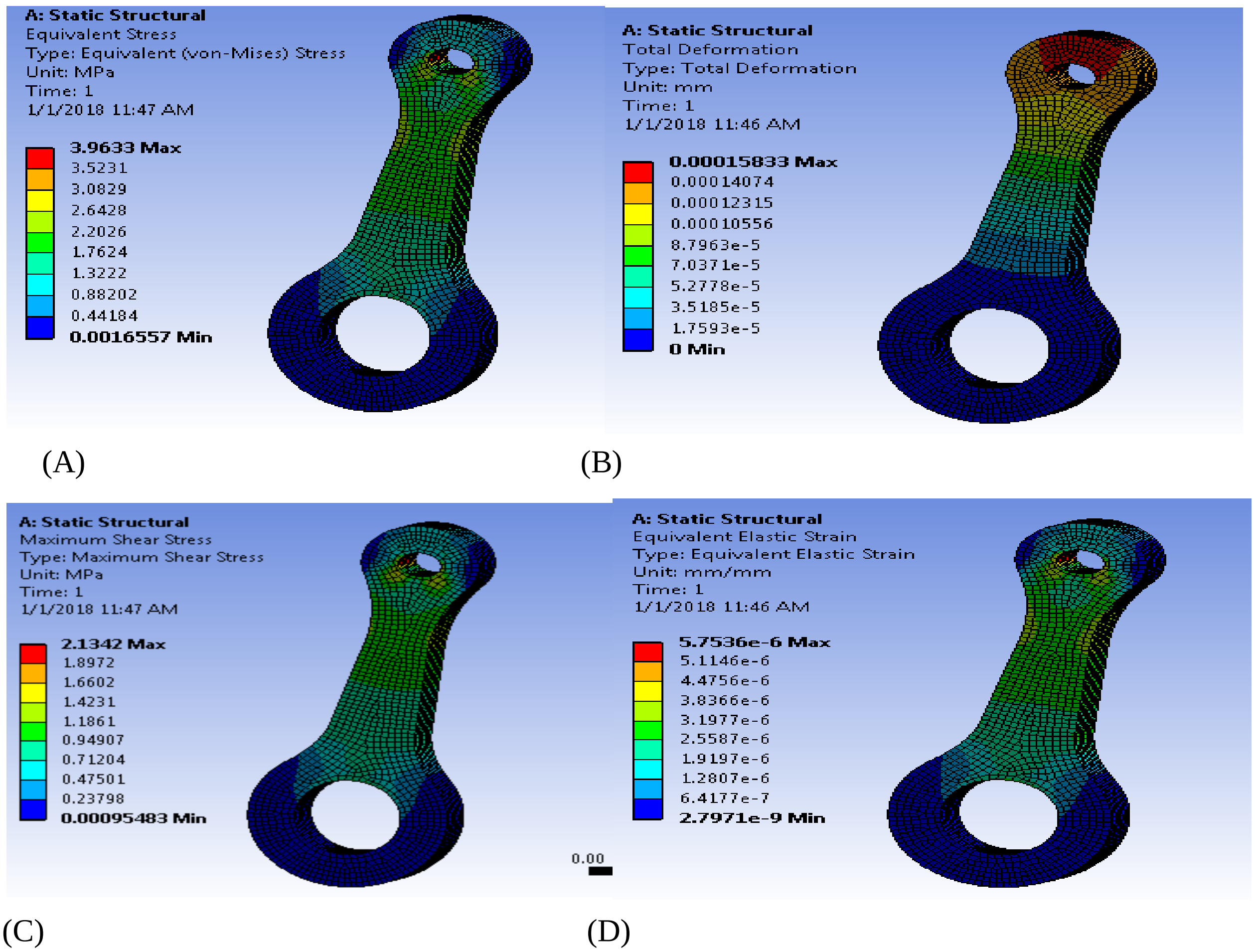


Figure 3. 18: Results of (A) equivalent (von-Mises) stress diagram (B) total deformation diagram (c) Maximum shear stress diagram (D) equivalent elastic strain diagram.

3.5.3 CRANK SHAFT

Material selection: The material for the crank shaft is aluminum alloy2024T3 working temperature of greater than 500 ^{0}C.

Table 3. 10: Mechanical properties for Aluminum Alloy 2024T3

No	Mechanical Properties	Aluminum Alloy2024T3
1	Density(g/cc)	2.78
2	Modulus of elasticity,(Gpa)	73.1
3	Yield strength, YS,(Mpa)	345
4	Ultimate strength ,Su,(Mpa)	483
5	Poison ratio	0.33

Boundary conditions:

- Material: aluminum ally 2024T3
- at the left and right of main journalit is fixed
- at the crank pin required reciprocating load is given F=498N and analyzed
- the analysis results are shown in figures which are given below:

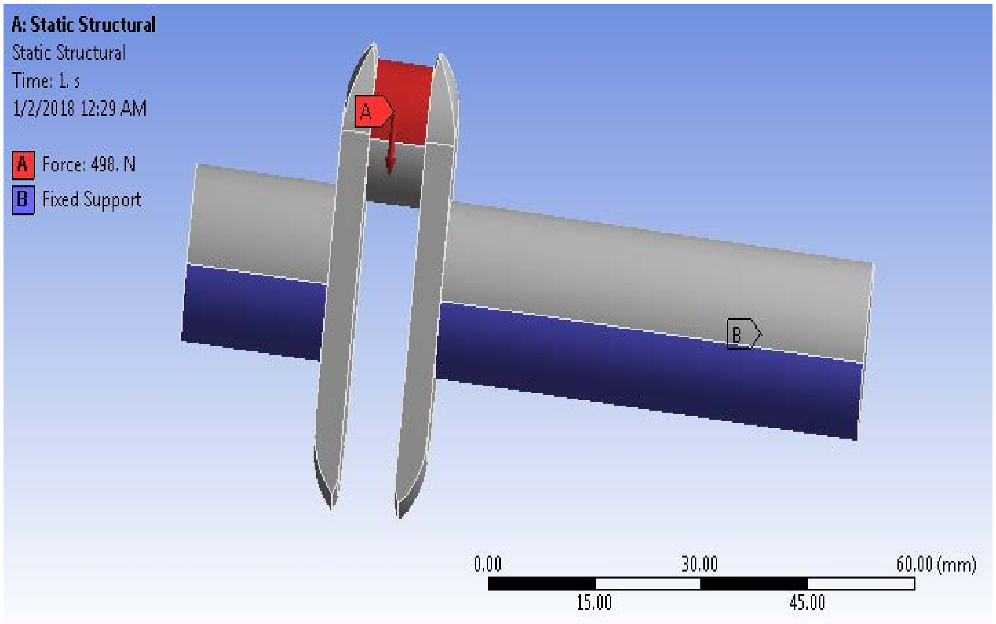


Figure 3. 19: Loads and boundary conditions of the crank shaft

MESHING:

Tetrahedral mesh elements are used in meshing of the piston. In order to get a better result, locally fine mesh is applied in the region which is suspected to have the highest stress.

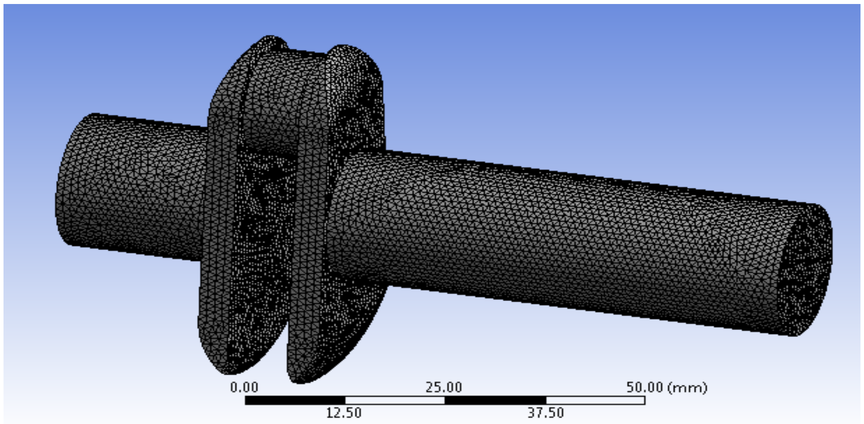


Figure 3. 20:Mesh model of the crank shaft

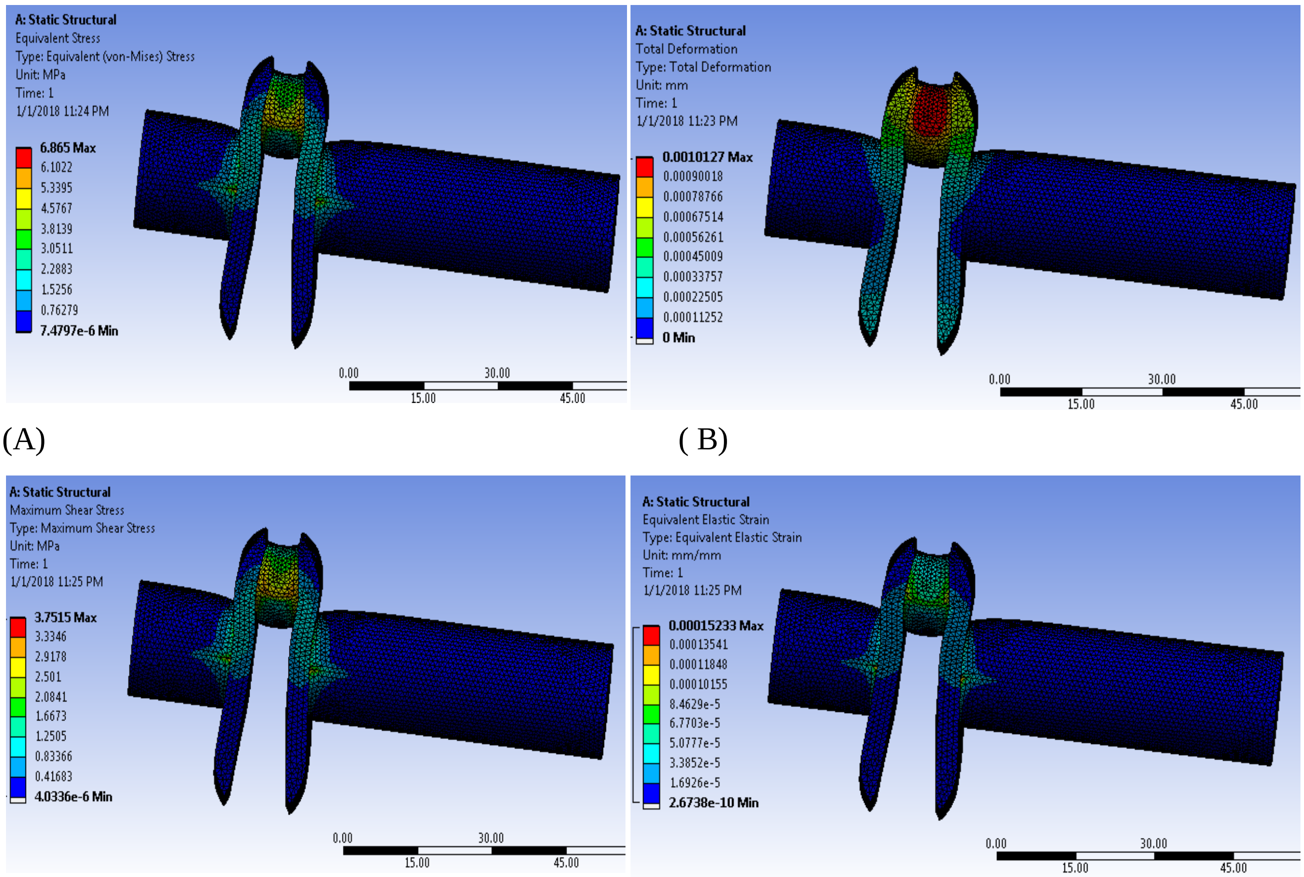


Figure 3. 21: Results of (A) equivalent (von-Mises) stress diagram (B) total deformation diagram (c) Maximum shear stress diagram (D) equivalent elastic strain diagram.

3.5.4 SPRING

Material selection: stainless steel wire is selected and this is used for light service including springs subjected to loads that are static or very infrequently varied, as in safety valve springs.

Table 3. 11: Mechanical properties for stainless steel wire

No	Mechanical Properties	Stainless steel wire
1	modulus of rigidity(G)	70
2	Modulus of elasticity,(Gpa)	196
3	Yield strength, YS,(Mpa)	437.5
5	Poison ratio	0.33

Boundary conditions:

- ➢ Material: stainless steel wire

- one end is fixed
- at the upper end required load is given F=78000N and analyzed
- the analysis results are shown in figures which are given below

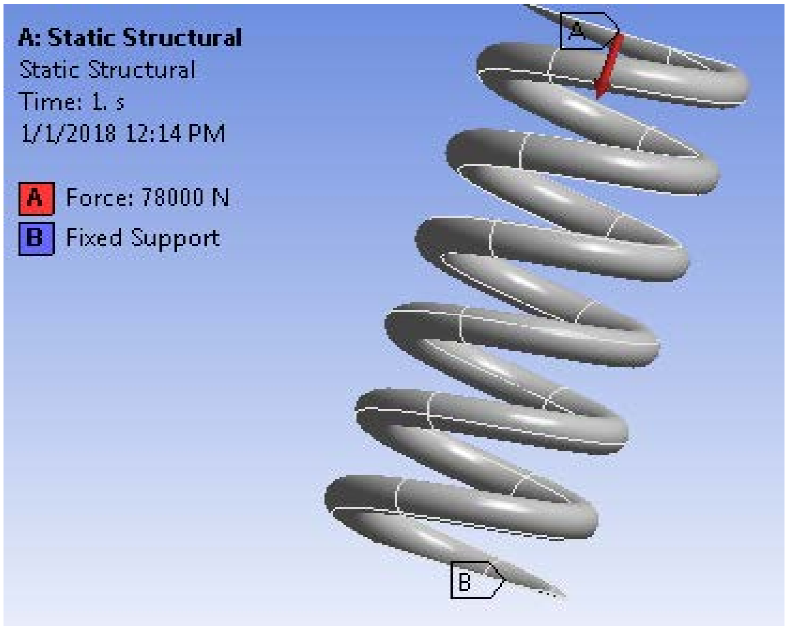


Figure 3. 22: Loads and boundary conditions of the spring

MESHING:

Tetrahedral mesh elements are used in meshing of the piston. In order to get a better result, locally fine mesh is applied in the region which is suspected to have the highest stress.

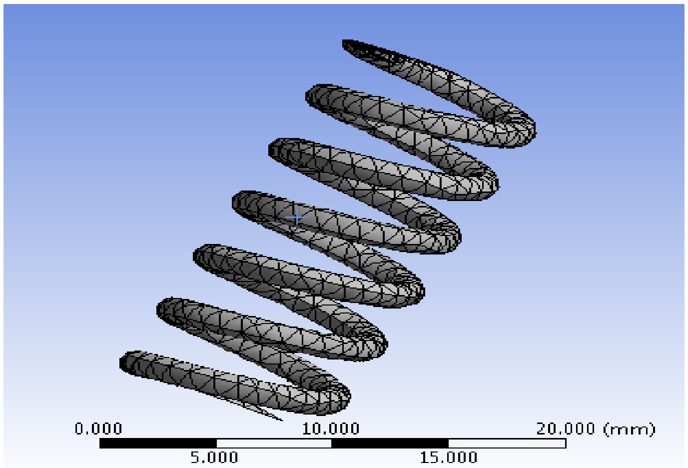
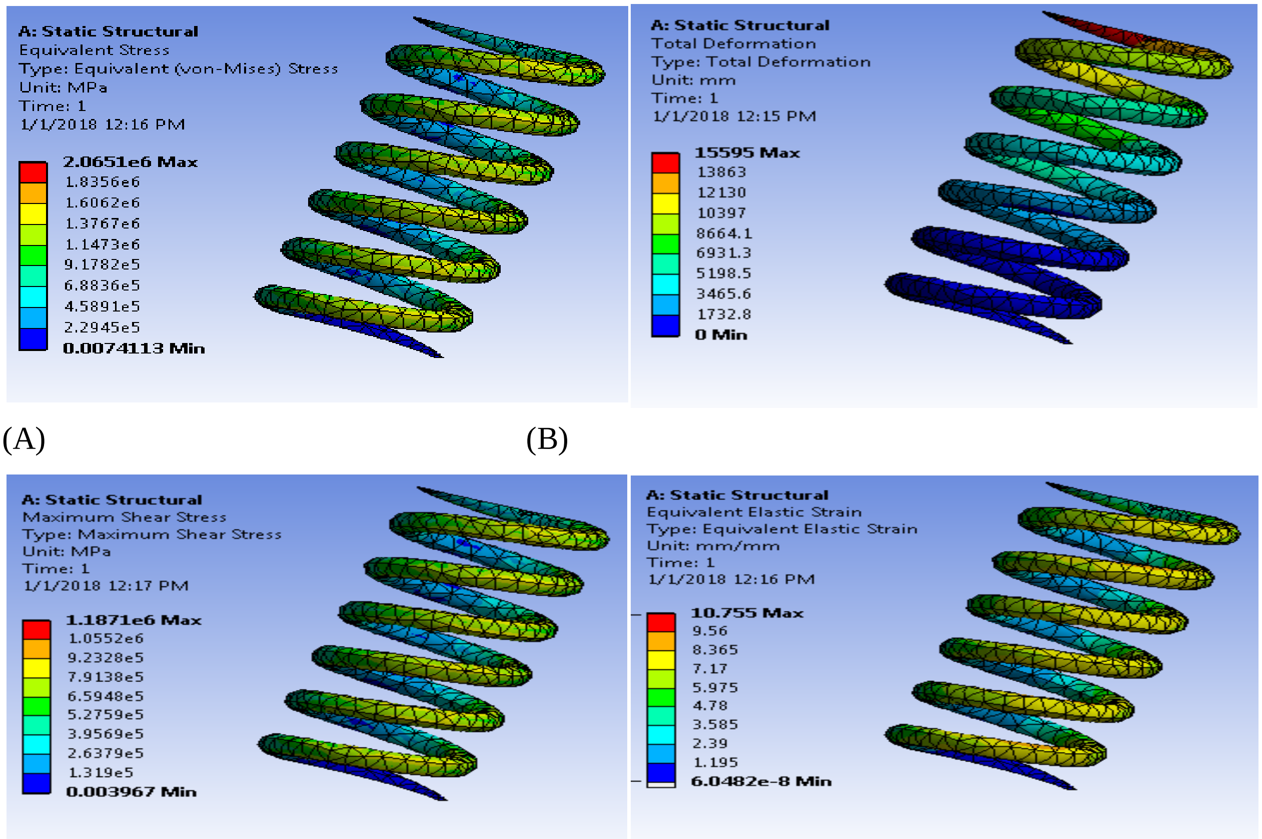


Figure 3. 23: Mesh model of the spring



(A) (B)

(C) (D)

Figure 3. 24: Results of (A) equivalent (von-Mises) stress diagram (B) total deformation diagram (c) Maximum shear stress diagram (D) equivalent elastic strain diagram

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Result and Discussion of Carbon monoxide (CO) reduction

When water from the tank is added to the exhaust gases by the reciprocating pump CO_2 is produced instead of CO.water react with carbon monoxide produces carbon dioxidewhich is not toxic for our environment.

4.2Result and Discussion of Finite element analysis

Table 4. 1:Resultsof Finite element analysis for reciprocating pump components

PARTS	Equivalent (von-Mises) stress(MPa)	Total deformation(mm)	Maximum shear stress(MPa)	equivalent elastic strain
Piston	7.1974	0.00015381	4.1177	0.000013
Connecting rod	3.9633	0.00015833	2.1342	0.000005
Crank shaft	6.865	0.0010127	3.7515	0.00015233
Spring	2065100	15595	1187100	10.755

4.2.1 Piston

The piston has been modeled using CATIA V5 and analyzed using ANSYS workbench16.0. Then the selected material was added to the engineering data in ANSYS workbench 16.0. Then meshing has been done After meshing, at the left and right side of the piston pin was assumed as fixed support and force is applied on the piston head. Then various parameters these are total deformation, Maximum shear stress equivalent (von-mises) stress, equivalent elastic stain, are completely analyzed. So, the result shows, equivalent (von-mises) stress is 7.1774MPa, equivalent elastic strain is 0.000013, the total deflection is 0.00015381mm and maximum shear stress is 4.1177MPa. So, the yield strength of the selected material for the piston is 315MPa, the analyzed stress is much less than the allowable stress of the selected material, it means that the design is safe under such loading.

4.2.2 Connecting rod

The connecting rod has been modeled using CATIA V5 and analyzed using ANSYS workbench16.0. Then the selected material was added to the engineering data in ANSYS workbench 16.0. Then meshing has been done After meshing, at the crank pin assumed as fixed support and force is applied on the small end of the connecting rod. Then various parameters checked these are total deformation, Maximum shear stress equivalent (von-mises) stress, equivalent elastic stain, are completely analyzed. So, the result shows, equivalent (von-mises) stress is 3.9633MPa, equivalent elastic stain is 0.000005, the total deflection is 0.00015833mm and maximum shear stress is 2.1342MPa. So, the yield strength of the selected material for the connecting rod is 110MPa, the analyzed stress is much less than the allowable stress of the selected material, it means that the design is safe under such loading.

4.2.3 Crank shaft

The crank shaft has been modeled using CATIA V5 and analyzed using ANSYS workbench16.0. Then the selected material was added to the engineering data in ANSYS workbench 16.0. Then meshing has been done After meshing, at the left and right of the main journal assumed as fixed support and force is applied on the crank pin of the crank shaft. Then various parameters checked these are total deformation, Maximum shear stress equivalent (von-mises) stress, equivalent elastic stain, are completely analyzed. So, the result shows, equivalent (von-mises) stress is 6.865MPa, equivalent elastic stain is 0.00015233, the total deflection is 0.0010127mm and maximum shear stress is 3.7515MPa. So, the yield strength of the selected material for the crank shaft is 345MPa, the analyzed stress is much less than the allowable stress of the selected material, it means that the design is safe under such loading.

4.2.4 Spring

The spring has been modeled using CATIA V5 and analyzed using ANSYS workbench16.0. Then the selected material was added to the engineering data in ANSYS workbench 16.0. Then meshing has been done After meshing, at the bottom part of the spring coil assumed as fixed support and force is applied on the top part of the spring. Then various parameters checked these are total deformation, Maximum shear stress equivalent (von-mises) stress, equivalent elastic stain, are completely analyzed. So, the result shows, equivalent (von-mises) stress is

2.065100MPa, equivalent elastic stain is 10.755, the total deflection is 15595mm and maximum shear stress is1.10MPa. So, the yield strength of the selected material for the spring is 345MPa, the analyzed stress is much less than the allowable stress of the selected material, it means that the design is safe under such loading.

CHAPTER FIVE

5.SUMMERY, CONCLUSION AND RECOMMENDATION

5.1 SUMMERY

In this thesis carbon monoxide (CO) emission reduction system for diesel engine using water spray system is designed. And for the water spray mechanism reciprocating pump is designed and it is modeled in 3D CATIA software. The water is injected in to the tail pipe of the vehicle through the discharge pipe and reacted with the gas and produce CO_2 and it is not harmful for the environment as well as for human health. After CO is reacted with water it reduces. Static structural simulation is done for the pump components in ANSYS Workbench 16.0. Finally, the result of the analysis was checked and found to be safe.

5.2 CONCLUSION

The following conclusion can be drawn from the results obtained:

- ✓ The most harmful gas that can be reduced by water spray is found to be CO;
- ✓ The pressure induced by exhaust gas is found to be 358 kPa.
- ✓ The designed reciprocating water pump is capable to pump 1.3×10^{-7} m^3/s with the spray of water in the exhaust gas and it reduced.
- ✓ Finally, I conclude that as per the analysis using different material for different components of the system is best and also the models of reciprocating water pump and spray system is safe. So, I recommend the vehicles company, the importers and the owners to use this.

5.3 RECOMMENDATIONS

As a recommendation to Ethiopian investors, researchers, vehicle manufacturing companies:

- ➢ To invest their knowledge and money on further study on CO emission system;
- ➢ To study on environmental protection;
- ➢ Beside increasing the performance of the vehicle also work on reduction of pollutants;
- ➢ Protect our environment from unsafe conditions;
- ➢ Adama Science and Technology University should be concerned in reduction of harmful gasses, so technology transfer of the designed component is essential;

- Microenterprise should be encouraged to manufacture the designed component;

5.4 FUTURE WORK

The following should be considered in the future works:

- Design of spray nozzlefor the reciprocating pump
- Making the spray mechanism using electrical to spray at the proper time and amount

Figure 5.1: prototype

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