# DESIGN AND DEVELOPMENT OF AUTOMATIC AIR BLEEDING SYSTEM FOR HYDRAULIC BRAKE SYSTEM

Wakuma Wakjira Wayu

A Thesis Submitted to

The Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the degree of Master of Science in Automotive Engineering

**Office of Graduate Studies**

**Adama Science and Technology University**

March 2023, G.C

Adama, Ethiopia

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Advisor: Ramesh Babu Nallamothu (PhD)

Co-Advisor: Mekonnen Liben (Asst. Prof)

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# CANDIDATE'S DECLARATION

I hereby declare that this master thesis entitled Design and development of automatic air bleeding for hydraulic brake system is my original work. That is, it has not been submitted for the award of any degree, diploma or certificate in any other university. All source of material that are used for this thesis have been duly acknowledged through citation.

Wakuma Wakjira Wayu _____ _____

Name of the student Signature Date

# RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled ‘Design and development of automatic air bleeding for hydraulic brake system’ prepared under our guidance by wakuma Wakjira submitted in partial fulfillment of the requirements for the degree of Masters of science in automotive engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

| | | |
|---|---|---|
| Ramesh Babu Nallamothu (PhD) | _____ | _____ |
| Major Advisor | Signature | Date |
| Mekonnen Liben (Asst. Prof) | _____ | _____ |
| Co-Advisor | Signature | Date |

## APPROVAL OF BOARD OF EXAMINERS

We, the advisors of the thesis entitled 'Design and development for automatic air bleeding for hydraulic brake system and developed by Wakuma Wakjira, herby certify that the recommendation and suggestions made by board of examiners are appropriately incorporated into the final version of the thesis.

| | | |
|---|---|---|
| Ramesh Babu Nallamothu (PhD) | _____ | _____ |
| Major Advisor | signature | date |
| Mekonnen Liben (Asst. Prof | _____ | _____ |
| Co-Advisor | signature | date |

We, the undersigned, members of the board of Examiners of the thesis by Wakuma Wakjira have read and evaluated the thesis entitled 'Design and development for automatic air bleeding for hydraulic brake system' and examined the candidate during open defence. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in automotive engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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## ACKNOWLEDGEMENT

First, I would like to thank the Almighty God for all his mercy, blessing and endless love for he has given to me. Then my gratitude goes to my advisor Ramesh Babu Nallamothu (PhD)and Mr. Mekonnen Liben (Asst. Prof) for their excellent guidance and support throughout this thesis work. I would like to give my deepest gratitude to my mother Ms. Bizunesh Bayeta and my father Mr. Wakjira Wayu for their immeasurable support since my childhood; completion of this work would not have been possible without the help of them. I also would like to thank my sisters and brothers for their cooperation and moral support. In addition, I want to thank Adama Science and Technology University for offering this program. Finally; I would like to thank my family and friends who helped me directly or indirectly to complete this work.

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# ACRONYMS

| | |
|---|---|
| ABS | Antilock Braking System |
| ASR | Automatic Stability Regulation |
| BAS | Brake Assistance System |
| CP | Centipoise |
| EHBS | Electronic Hydraulic Brake System |
| ESC | Electronic Stability Control |
| IBS | Intelligent Braking System |
| ISO | International Standard Organization |
| ISOR | International Standard Organization Research |
| *OEM* | Original Equipment Manufacturer |
| Pa-s | Pascal Second |
| SUS | Say Bolt Universal Seconds |
| UGV | Unmanned Ground Vehicle |

# ABSTRACT

*Passenger cars are causing collision frequently in Ethiopia. Even though there are many different reasons, brake pedal sponge reaction time delay may be one of the reasons behind such collision. The purpose of this thesis work is to improve hydraulic pressure system with operative temperature of light vehicle by altering the design without changing system dimension and development of automatic air bleed for vehicle brake control system. The methods employed in this thesis work are modeling component parts using AutoCAD; CATIA V5 software and ANSYS software also production of component parts and construction of prototype for demonstration purpose. The model was developed with the automatic air release valve and brake components. The brake components used for the construction of the prototype are selected from TOYOTA 3K car model. Also, automatic air release valve which is used for release air pocket that is collected at each high point of a full pressure line. Automatic air bleeding system is developed based on the brake system of TOYOTA 3k car model. The developed system is demonstrated successfully. It is concluded that, if this system is implemented on vehicle, stopping distance reduces leading to reduction in collision.*



***Keywords****: air remover, boiling point, operating temperature, working fluid.*

# CHAPTER ONE
# INTRODUCTION

## 1.1. Background

The transportation in Ethiopia is a sector that opens the door for growth of many additional industries such as Oda transport industry, Gada transport industry, cement product industries, metal product industries and pipe industry etc. as such growth of this industry will survey flow. Oda transport Share Company report (2013).

Similarly, when construction and renovation of housing are increasing, the demand for transportation of construction materials increases, thereby directly opening the door for the growth of the transport industry. All in all, light vehicles have a great role in this industry, Road traffic accidents are becoming a major public safety and development obstacle. Various studies have indicated that Ethiopia has one of the highest fatality rates per vehicle in the world, it is in excess of 100 fatalities per 10000 vehicles. Compared with Kenya and the United Kingdom where the number is about 19 and 2 per 10000 vehicles respectively thus Ethiopia loss about $ 65 million annually due to traffic accidents.

The road accidents occurred in Ethiopia is shown in figure 1.1 and figure 1.2.

Figure 1.1. Road traffic accident in Ethiopia Sululta

Source: from internet (Traffic accident in Ethiopia)

Figure 1.2. Road traffic accident killed 8 in east Shewa

Source: from internet (Traffic accident in Ethiopia)

In addition, the victims are mainly public transport travelers in the working age group (18-30year). Brakes are required to stop the vehicle with the least possible distance and this is done by converting kinematic energy of the vehicle into heat energy which is dissipated into the atmosphere. The brakes are very important in any vehicle the brake makes a car or any vehicle to stop while it's on the move. This very function makes it one of the most important components of a car. As the brake plays such an important role in the wellbeing of vehicle it's very important for every automobile Industry to take care of it. The master cylinder is considered the heart of vehicle brake system. This is because it is located at the center of the system. It pumps brake fluid to the wheel cylinder or caliper whenever. The calipers convert the energy of the fluid that is pressurized into pressure; this is what makes the Brake. But the presence of air in the master cylinder may be very dangerous to the brakes; even the brakes may become totally useless. Because, while the brake fluid is an incompressible liquid, air bubbles are compressible gas and their presence in the brake system greatly reduces the hydraulic pressure that can be developed within the system. Hence bleeding of the brakes is very essential. Brake bleeding is the procedure performed on hydraulic brake systems whereby the brake lines (the pipes and hoses containing the brake fluid) are purged of any air bubbles.

An accident still occur either a minor or major accident even the vehicle is equipped with a good braking system like ABS. IT is believed that the overall stopping distance is strongly affected by driver reaction time. This reaction time during emergency event generally includes the time period from the perception of the hazard until some or all brakes are locked or the ABS modulation begins. Road safety plan of Ethiopian reported that 477,204 road accidents in 2010, the number of injuries 12,000 of which more than 4000 were seriously injured, the number of fatalities from road accident was 6915, which is an average of 19 deaths on the country road every day. The fatality index was 2.9 per 10,000 registered vehicles in Ethiopian while it is 2 in the developed countries. The implementation of UNECE regulation through vehicle type approval will assist the industry to offer five star vehicles to the road users include. The new system should have components Brake pedal mechanism, a push rod, a tandem master brake cylinder, an EHBS actuator, a valve control unit, and DC motor amplified system with rack-pinion, fuzzy controller and wheel brake. A rack-pinion is a type of linear actuator that engages a pair of gears, which convert rotational motion into linear motion.

Intelligent Braking System (IBS) introduced in commercial vehicles providing rapid brake response and release for every single wheel therefore ensuring safety. The extremely rapid response time provided by the electronic control can be used for crucially shortening the braking distance by introducing advanced control of braking system operation. Such a complex task imposed to the control of braking system cannot be based on the driver abilities and need to be done independently of the driver. An improved IBS braking forces management would certainly enable to reach the given task. The advanced strategy for the braking force management, proposed here, is based on intelligent controlling of the braking forces distribution between the front and rear axle of power-driven vehicle and/or between towing/trailer combination and/or between tractor/semi-trailer. Intelligent braking system has a lot of potential applications especially in developed countries where research on smart vehicle and intelligent highway are receiving ample attention. The system when integrated with other subsystems like automatic traction control system, intelligent throttle system, and auto cruise system, etc. will result in smart vehicle maneuver. The driver at the end of the day will become the passenger, safety accorded the highest priority and the journey will be optimized in term of time duration, cost, efficiency and comfort ability. The impact of such design and development will cater for the need of contemporary society that Aspires quality drives as well as to accommodate the advancement of technology especially in the area of smart sensor and actuator. The emergence of digital signal processor enhances the capacity and features of universal microcontroller. The overall system is designed so that the value of inter-vehicle distance from infrared laser sensor and speed of follower car from speedometer are fed into the DSP for processing, resulting in the DSP issuing commands to actuator to function appropriately. The most popular systems like Antilock Braking Systems (ABS), Traction Control and Stability Control employ different types of sensors to constantly monitor the conditions of the vehicle, and respond in an emergency situation.(National highway traffic safety administration 2013)

The Brake Assist System (BAS) is a safety feature that supplements driver's brake pedal effort during panic-braking makeovers. BAS was co-developed by TRW and Daimler-Benz in the 1990s. Starting in 1997, BAS has been a standard feature on Mercedes-Benz vehicles. BAS was developed after simulator research demonstrated that many drivers fail to engage a vehicle's maximum braking potential during panic stops. In particular, inexperienced drivers do not apply sufficient braking effort (i.e., brake pedal force) in

emergency situations. Therefore, in addition to the proper engineering of the braking system, accounting for driver limitations in brake pedal application represents an additional approach for reducing the vehicle's stopping distance. The objective of this study was to evaluate how drivers perform avoidance makeovers when using BAS-equipped vehicles. The human performance experimental methods described in this document were developed to determine how driving a vehicle equipped with an anti-lock brake system (ABS) compares to driving a vehicle equipped with both ABS and BAS during panic braking. This study focused on driver performance. As such, BAS was evaluated from the user's perspective, not that of the underlying mechanics or electronics. Since various types of BAS were available at the time of the study (such as mechanical or electronic BAS), it was considered possible that the braking performance could vary depending on the BAS type. To ensure that this study was relevant to future BAS designs, the opinions of original equipment manufacturers (OEM) and other experts on BAS trends were used to select the most appropriate system(s) for this study. (Bartle by book story 3rd page).

### 1.2. Statement of the problem

Brake bleeding is the procedure performed on hydraulic brake systems whereby the brake lines are purged of any air bubble. This is necessary because, disk brake systems can generate extremely high temperature, under high but short duration braking loads. One consequence of the high disk and pad is a gradually heating of the brake hydraulic fluid, which can lead to boiling of absorbed water. Therefore, there is a need to improve the performance of hydraulic brake system by incorporating automatic air bleeding system for the hydraulic brake, to remove automatically air bubble formed in the brake fluid during brake operation.

### 1.3. Objectives

#### 1.3.1. General objective

The general objective of this thesis is to Design and develop automatic air bubble bleeding system for hydraulic brake system.

#### 1.3.2. Specific objectives

The specific objectives of the thesis are as follows.

- ✓ To gather the data related to brake system of related vehicle (TOYOTA 3K).
- ✓ To prepare the part drawings of the automatic bleeding system
- ✓ To manufacture the parts.

- ✓ To assemble the parts and preparing the physical model of the system.

### 1.4. Significance

The significance of the thesis work is as flows.

- It helps to minimize the accidents.
- It reduces the property damage and injuries due to accidents.
- It increases brake performance.
- It reduces maintenance cost, labor cost.

Accordingly, this thesis work benefits automotive Industries, contractors, vehicle owners, researchers, society and the country as a whole.

### 1.5. Scope and delimitations

#### 1.5.1. Scope

The thesis work includes designing of automatic brake bleed with developed basic brake system calculation for hydraulic brake system.

#### 1.5.2. Delimitation

This thesis is delimited to design of the automatic bleeding for light vehicle 2007 model hydraulic brake, the truck vehicle not included. Dynamic analysis like modal and harmonic analysis are not included.

### 1.6. Limitation

The limitation of the study is that there is no reference available to know about the stopping distance of light vehicle model 3k.

### 1.7. Organization of the thesis

This thesis report consists of five chapters. The first chapter is an introduction to the study. It includes: Background of the thesis, Statement of the problem, Objectives of the study, Significance of the study, Scope and delimitations of the study, Limitation of the study, and Organization of the thesis. Chapter two focuses on the literature review based on the previous related works. Chapter three describes materials and methods used to complete this work. Chapter four consists of results and discussion. Chapter five consists of conclusions, recommendations, and future work areas.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Historical development of hydraulic brake system

Modern brake pads and shoes generate the friction necessary to stop a car, but even earlier wheeled vehicles like oxcarts and carriages required brakes. Up through the time of steam-driven automobiles of the 1880's, stopping power was achieved with blocks of wood which could be pressed against the side of steel-rimmed wheels with a lever and rod. Then around 1880 came Michelin with the production of solid rubber tires which revolutionized small-scale wheeled travel. Suddenly wood blocks were not a tenable braking method any more. It was at around this point near the turn of the century that things in the braking world started to change exponentially. Horse-drawn travel was gradually giving way to steam and gasoline engine, road speeds were increasing and the automotive world needed a better solution of momentum (D V Tretsiak, 2014).

Daimler envisioned that a cable could be wrapped around a big drum that could then be bolted to the vehicle chassis. While it was Daimler who had the original idea, Renault ran with it, creating the first functional design. Soon, the first production-ready drum-and-cable brake system was developed for a Mercedes. They were mechanical, and operated with a hand-lever. This early drum brake execution was revolutionary, but it had some major downsides the external cable arrangement would frequently slip on hills and the metal-on-metal design didn't last long at all and required constant adjustment. Safety and longevity were major problems with this new brake system. Gradually, however, metal cables and bands gave way to woven asbestos and copper brake linings improving stopping power. Yet even these braking systems remained completely external and operated on only one axle until around 1915 when mechanically connected 4-wheel brakes started to enter the scene. Early on, these 4-wheel braking systems were considered to be top-tier options if not an outright luxury. The 1915 Duisenberg racer was equipped with the new style of braking system. Soon after Renault's design took off it was determined that moving the friction pads inside of the drum produced improvements in both braking consistency and brake pad life and they took the industry by storm. Internal-expanding drum brakes remained mechanically actuated through 1918 when Malcolm Lockheed began development of the first hydraulic braking systems. The decision to integrate hydraulic technology with braking systems was another leap in the technology of brakes. This earliest hydraulic system concept used a single pedal to transfer force from the main

cylinder through a series of tubes and cylinders to the brake shoes, thus reducing the amount of force needed by the operator to slow the vehicle and increasing system reliability (Yu, 2017).

The ABS system consists of wheel speed sensors, a processing computer, and a hydraulic modulator. The wheel speed sensors generate frequency signals that are read and constantly interpreted by a dedicated ABS computer. This computer contains complex algorithms called maps that continually compare the sensor inputs between any given wheel and the other three, and then this data is compared against the map. During hard or panic braking one or more wheels may lose traction. The ABS system then acts to regulate hydraulic pressure to the affected wheel to optimize stopping distance. It does this through three sets of lightning-fast calculations for the rapid pressure build pressure hold, and pressure release cycles. Often, the driver will notice what feels to be a grinding or vibrating sensation during hard braking: this is the ABS doing its job and regulating the pressure of the brakes. ABS has done a remarkable job in reducing stopping distance, and can be combined with other functions such as automatic stability regulation (ASR) to increase safety and performance even more. The extensive use of this entire complex, computational technology raises a question have these super-advanced systems put servicing and repair of modern brake systems out of the reach of independent repair shops and DIY mechanics. Not at all there is an abundant amount of information from the internet, repair books, and journals to perform most automotive repair work independently: everything from a simple brake pad replacement to a more involved task such as replacing brake lines. Fortunately, innovation and thoughtful repair solutions are equally abundant in the solutions presented by the automotive aftermarket.

Electronic hydraulic brake is one of the brake by wire system. The EHBS has its own characteristic compatible with ABS and ESC system. The EHBS is an improved system of a conventional hydraulic system that has complex hoses. However, this study has emphasized more to electro hydraulic braking system with an additional force assisted by of DC motor. The study was to present hydro mechanical braking system for the passenger car to reduce the road accident by developing the additional braking force with boosting the master cylinder hydraulic pressure (Rolan Siregar, 2020).

The bubble eliminators are the tapered tube device designed such that a chamber with a circular cross-section gradually becomes smaller and connects to a cylindrical chamber.

Working oil with bubbles tangentially flow into the tapered from the inlet port and form a swirl flow that circulates the fluid through the flow passage. The swirl flow accelerates downstream. Bubbles are trapped in the vicinity of the difference between the specific gravity of oil and that of bubbles. They are range of the vent port, where the pressure is applied by a check valve located on the downstream side of the bubble eliminator, the bubble is pushed through the vent port. The gas dissolved in the fluid is also eliminated via the bubbles extracted on the pump-suction side under negative pressure. programmable logic controller technology which is used for controlling bleeding process of brakes of the three wheelers in programmable logic controller, human machine interface and the mechanical process of online brake bleeding system high lights the problems associated with existing human machine interface and probable solution over it International (Zhao, 2017).

The presence of foreign material in the system oil accounts is for the majority of system troubles due to mechanical wear of components, sticking of different parts. Mechanical filters are used for this purpose to separate solid particles from the system oil. As a hydraulic filter gets accumulated with dirty throughout its service life. The pressure drop over the filter element increases. This pressure drop is typically used for determining the life time of a filter element. Once a predetermined pressure drop at certain flow conditions has been reached, the filter has accumulated enough dirty to require servicing to replacement (Bako Sunday, 2019).

Preliminary; experimental analysis automotive brake damping pressure pulsation. The test have been conducted in the form of complete two – level experiment having selected the following parameter variables flexible hoses type, pressure value in the pressure line rotational speed of the pump shaft, pressure line length the acquired. Curves have been analyzed in time domains value of pressure line damping in relation to the domain pressure peaks have also been determine the aim of the undertaken test has been confirm or over flow the common belief that the pressure line with fixable hose itself Damper of pressure pulsation in hydraulic pump (Material science and engineering, 2017).

In hydraulic brake components and operational factors influencing the hysteresis losses. This part presents an experimental analysis of the factors influencing the hysteresis pressure losses in a hydraulic brake system. The factor under investigations is the brake

pedal stroke velocity, the gaps between the brake pads and the brake disc, and the configuration of the brake system (Mu-Jung Kao, 2007).

On automotive brake pipes characteristics and their effects on brake performance, The distribution of the brake fluid pressure between axle wheels is one element that has a large effect on braking performance and vehicle dynamic behavior during braking. Fitting improves brake efficiently for the vehicle in its straight motion and in its cornering motion depending on the variation of load distribution, road curvature and moving speed, and Ahnpark introduced a new braking force distribution control system that improves vehicle dynamic behavior during braking throughout the generation of a yawing moment by adjusting the distribution of braking force to all four wheel marting and colarell I investigated the measurement of brake force on each wheel to determine brake balance. It also provides a measure of side to side variation on both the front and rear axle. Determine brake balance. If also provides a measure of side variation on both the front and rear axle. Imbalance side to side can spot a potent till handling problem in a panic brake application (Wu, 2016).

According to the characteristics and required braking function of front and rear dual motor driven hybrid electric vehicle, braking control strategy for an electro hydraulic braking system with conventional braking and regenerative braking is proposed. The strategy ensures full utilization of motor. Braking force which can improve the energy Recover rate in regenerative braking model and under specific condition, can assist as conventional braking a new type of pressure control system was designed based on the function requirements of operating mode for regenerative braking conventional braking and ABS braking. At the same time, working modes is realized through the ABS based hard ware pressure coordinated control (Yevtushenko, Kuciej, & Och, 2014).

The effects on brake performance is The distribution of the brake fluid pressure between axle wheels is one element that has a large effect on braking performance and vehicle dynamic behavior during braking. Fitting improves brake efficiently for the vehicle in its straight motion and in its cornering motion depending on the variation of load distribution, road curvature and moving speed (Belhocine, 2013).

Hydraulic brake components and operational factors influence on the hysteresis losses and this paper presents an experimental analysis of the factors influencing the hysteresis pressure losses in a hydraulic brake system. The factors under investigations are the brake

pedal stroke velocity, the gaps between the brake pads and the brake discs and the configuration of the brake system. Experimental were carried out on the brake test equipment at the automotive engineering department faculty for mechanical engineering techniques (Tobler, 2017).

This paper explains about the design of a straight and vented brake discs in solid work. It also includes the deck preparation in hyper mesh. Meshed part with applying the temperature. Finally, both the brake discs are been analyzed in analysis for the stead static thermal analysis. In this result, we get that, by changing the straight vent to curved vents in the brake disc ionizes the stresses and displacement vector sum and mass of the brake disc has been reduced. And also curved vented brake disc is generated a light thermal flux than a straight vented brake disc (Thuresson, 2000).

The characteristics and required braking function of front and rear dual motor driven hybrid electric vehicle, braking control strategy for an electronic hydraulic braking system with conventional braking and regenerative brake system. The strategy ensures full utilization of motor. The Brake force which can improve the energy recovery rate is regenerative braking model and under specific condition. At the same time, working modes is realized through the ABS based hard ware pressure coordinated control (Mazidi, 2011).

Electromagnetically braking system is an electromagnetic braking system uses magnetic force to engage the brake, but the power required for braking is transmitted manually. The disc is connected to a shaft and the electromagnetic is mounted on the frame. When electricity is applied to the coil a magnetic field is developed across the armature because of the current flowing across the coil and cause armature to get attracted towards the coil. As a result it develops a torque and eventually the vehicle comes to rest. The behavior of two different materials to be used as brake disc which are aluminum and copper was studied. The experiment also aimed to see the effects of increasing the presented to show the best materials to be used as the brake disc for electromagnetic braking system using eddy current project (Yang, 2011).

Fluids are substances that may flow and its constituent particles may continuously change their positions relative to one another. It also offers no lasting resistance to displacement. Fluids may be divided into liquid and gases. Under ordinary conditions liquids are so difficult to compress and for most purposes may be regarded as incompressible, however gases may be more easily compressed. Fluids have unique and district properties that

enable its application in Engineering. It assists the braking system to bring a moving mass to rest. Most of the brake fluids that are in use are glycol ether based, though mineral oil and silicon-based fluids also exist. This brake fluid must meet the standard spelt out by various organizations. Brake fluids are classified according to their physical properties. The standards in the US come from the Department of Transportation (DOT, 197). Thus, we have DOT 3, DOT 4, DOT 5 and DOT 5.1. The society of Automotive Engineers SAE has similar standards of SAE Jl703, 11704and11705.The two commonly available types of brake fluids are Glycol-ester blends and ester base. The glycol-based fluids normally have low compressibility but are hygroscopic in nature. The dry boiling point of glycol-based fluid seldom exceeds 304°C. The second classification which is ester-based has higher dry and wet boiling points. It is not hygroscopic but it is more expensive than the glycol-based fluids. There are several properties which a fluid must possess for it to be considered as a brake fluid. These properties are: Dry and wet equilibrium boiling points, viscosity, pH value, fluid stability corrosion resistant, fluidity and appearance at low temperature, water tolerance, resistant to oxidation, swell test, compressibility test, and compatibility. The brake fluid must possess a high boiling point. Avoid it vaporizing. It must not boil after accepting a certain amount of moisture wet boiling point. The brake fluid must also possess high viscosity and should not change under a wide range of temperatures. The pH value should not be less than 7 and not more than 11.5. Brake fluids should not be corrosive. Brake fluid must maintain low compression despite variance in temperature and must be non-compressible and should have high bulk modulus value (Panka, 2018).

The braking efficiency is said to be 100% when the braking force is equal to the weight of the vehicle. Or when deceleration is $9.81 {}^{m}/_{s^2}$ an efficiency of 100% is not desirable because of the rapid wear to the brake linings and tiers discomfort to passengers and the risk of losing control of the vehicle. It is generally accepted that brake efficiency of 80% to 85% should be aimed at. The main objective of this paper is to determine the suitability of water-based fluid as an alternative brake fluid for light vehicles the foundation of the hydraulic system is from the Pascal's law. The breaking force is derived from the applied pressure in a confined fluid and if the fluid is income (Talati, 2009).

Failure of a brake system is more as a result of brake fluid vaporization under intense braking as per the designated track of the vehicle. Most of the modern-day vehicles equipped with disk brakes is using DOT3 and DOT4 brake fluids, depending on their boiling temperature and the formula cars. Like other categories to brake fluid, they are also

susceptible to moisture content and racing conditions. Ideally, the boiling of a pure brake fluid lies between 200℃-300℃ degree Celsius But due to hygroscopic effects, the brake fluid boiling temperature has gone down to 140℃ and 155℃ for DOT3 and DOT4 fluid over the years. Keeping this factor and the extreme braking conditions during race require adjustments are needed to be made for the formula cars. By virtue of frictional contact during braking, heat is generated at the contact surfaces and dissipated to the components of the brakes. Considering the thermal conductivity and surface area of the disk rotor and brake pads, it can be safely assumed that most of the heat generated is dissipated to the disk rotor and a small part goes to the pads. Repetitive braking application of the formula cars and complex aerodynamics causes a sudden rise in temperature of the brake systems. Moreover, for better stability and locking, more torque is applied on the front axle wheels and both the front tires of the formula cars have disk brakes on it. The rear tires have an onboard braking for weight considerations. Other than the problem of brake fluid vaporization with high brake temperature, there exists many risks such as fading of brake pads and bending of components such as rotor at elevated temperature resulting in uneven brake application. The wearing of frictional lining on 3 the brake pads is directly proportional to the applied pressure and wearing of the lining increases exponentially with elevated temperature. To achieve the same, MATLAB will be used to generate a simulation using the governing heat equations and verify the heat generation and temperature of the various components. Validity of the MATLAB model and its stability under noise and other aerodynamics factor will be verified later during the investigation (Newcomb, 1958).

In heating and cooling systems, air bubbles are not only annoying but also extremely costly. It is not always easy to remove such air from systems where large air bubbles can be easier to remove than small ones. Any air within a closed circuit, regardless of whether it is in the form of large air bubbles or microscopic air bubbles, is to be regarded as detrimental. The range of systems that we can provide includes the micro bubble air separator which you can use to remove not only large but also microscopic air bubbles – so-called “micro bubbles” from your system. It is also available with a filter which will then replace the dirt filter normally used. The micro bubble air separator will pay for itself within an extremely short period of time as the efficiency and protection of your whole system will be improved as a result of installing it. When you start using the micro bubble air separator, it will only be a matter of days before your systems are free from air has a

low or insignificant pressure drop as it has full flow through. This is because there is nothing along the flow line that creates pressure drop; no mesh, no “shaving brush”, no metal rings. Traditional separators can have pressure drops of several thousand Pa at a flow rate of 1 m/s. This will bring the energy consumption up to unnecessarily high levels. The use of with a pressure drop of only 50 Pa at a flow rate if 1 m/s, will reduce the need of pump capacity and cost for pump energy (Arindampaul,2013).

The existence of bubbles in working fluids of hydraulic systems exhibits a massive effect on performance lately, a singular device able to effectively eliminating bubbles in hydraulic fluids using swirl flow continues to be developed. This is known as the “Bubble Eliminator”. Within this project, an introduction to the physical concepts involved with bubble elimination inside the Bubble Eliminator during use is going to be provided. A typical hydraulic circuit in which the Bubble Eliminator continues to be effectively utilized in industrial applications is going to be provided. In gear and bearing lube, bubbles might be produced with a churning after effect of the fluid because it flows with the bearing set up. There are specific positions dependent centrifugal forces produced in most areas of the swirl flow, and also the bubbles have a tendency to move toward the central axis from the Eliminator because of the improvement in centrifugal pressure. Small bubbles are trapped making an aura column near central axis from the swirling flow close to the area in which the pressure may be the cheapest(International journal of innovative technology and research, 2017).

The brake fluid is hygroscopic which means it will attract and hold water molecule. The water willbe absorbed right out of the air and as brake fluid ages it will begin to promote corrosion in many of the hydraulic components found in the braking system. The first step to flushing brake fluid is to make sure the entire bleeder screws can be loosened. It is not common to find a rusted shut bleeder screw. It is very important when flushing or replacing Brake fluid to clean the reservoir of the master cylinder. Before bleeding brake it is important to remove old brake fluid from the master cylinder reservoir. This can be easily done with a vacuum brake bleeder. After removing the old /dirty fluid, replace it with fresh cleaner fluid. During the bleeding or flushing process it is critical to not allow the master cylinder to run out of clean brake fluid. The best way to do this when manual, gravity, or vacuum bleeding is to use a bottle that automatically add clean fluid to the master cylinder while you are bleeding out the old dirty fluid during brake repair need to remove a brake line. Wheel cylinder, or calliper and want to be sure that the brake fluid is

not allowed to drain out of the system. This allows air to enter through the top of the system at the master cylinder and may be very difficult to bleed back out.

**Vacuum bleeding**

The way of bleed and flush the brake system to vacuum bleed connects the clean hose to bleeder screw. Connect pressurized shop air to bleeder bottle. As compressed air blows past the top of the bleeder bottle it creates a vacuum inside the bottle. This pulls brake fluid out of the bleeder screw. The problems have found is in experienced technicians will allow the master cylinder to run dry while using the vacuum bleeder. This can cause major problems especially with ABS systems as it can be very difficult to get all the air back out. When vacuum bleed just keep sucking fluid out each bleeder screw until the fluid runs clean. Vacuum bleeding is shown below in figure 2.1.

Figure 2.1. Vacuum bleeding method

**Manual bleeding**

Sometimes is the only way to get air out of the system. This method as it requires 2 people and can cause the master cylinder to fail. The primary disadvantage to this method is having the master cylinder piston moving past minor corrosion that commonly develops in the ends of the master cylinder. This can damage seals and lead to the eventual failure of the master cylinder. The driver will experience the brake pedal slowly as shown figure 2.2 below, sinking as pressure is kept on the pedal.

Figure 2.2. Brake bleeding by manual method

**Gravity bleeding**

This method needs to remove the cover on the master cylinder and open one bleeder screws which bleeder screw open depends up on the bleeding's sequences. The brake fluid should slowly drip out of the bleeder screw add vacuum or gently step on the brake pedal to get the fluid starting to flow out the bleeder screw. Give each bleed plenty of time to drip, and keep the master cylinder reservoir full. It may take 15 or 20 minutes per wheel so plan on doing other task while using this method. Gravity brake bleeding is shown below in figure 2.3.

Figure 2.3. Gravity brake bleeding method

Fluid power is the transmission of forces and motions using a confined, pressurized fluid. In hydraulic fluid power systems the fluid is oil, or less commonly water, while in pneumatic fluid power systems the fluid is air. Fluid power is ideal for high speed, high force, and high power applications. Compared to all other actuation technologies, including electric motors, fluid power is unsurpassed for force and power density and is capable of generating extremely high forces with relatively lightweight cylinder actuators.

Fluid power system have a higher band width than electric motor and can be used in applications that require fast starts, stops and reversals, or that require high frequency oscillations. Because oil has a high bulk modulus, hydraulic systems can be finely controlled for precision motion applications. The brake fluids are classified on the basis of their boiling point. The composition of brake fluids has changed over the years. Previously castor oil based and alcohols (butane or ethanol) were used for making brake fluids prior to DOT 2 category. Come DOT 3, DOT 4 and DOT 2.1, glycol based brake fluids came into existence. (Walkers, 2011). Dot approved brake fluids are given in table 2.1.

Table 2.1. Various grades of DOT approved brake fluids

| | Dry boiling point℃ | Wet boiling point℃ |
|---|---|---|
| DOT 2 | 190 | 140 |
| DOT3 | 205 | 140 |
| DOT 4 | 230 | 155 |
| DOT 5 | 260 | 180 |
| DOT 5.1 | 260 | 180 |

Source: TILTON engineering 2020

Table 2.1 explains that Wet boiling point is defined for liquid having more than 3.7 % of water by volume. Silicone based brake fluids are far less susceptible to hygroscopic effects than ethyl based liquids. The mass of the brake fluids acts as the heat reservoir during the braking application where they gain heat from the pistons in whose contact they come. The convection loss from the fluid is when it comes in contact with the piston and the caliper body. Technically speaking, the aluminum grades of the piston and caliper body are different but for the sake of simplicity of our calculation we will consider them as of the same grades so that we can assume the same convection coefficient value of $h_{\text{fluid}}$ for it. There will not be any radiation losses again as no part of the fluid is exposed to the environment. Let's denote the mass of brake fluid present inside the caliper body as $M_{\text{fluid}}$, $Cp_{\text{fluid}}$ as the specific heat of brake fluid $T_{\text{fluid}}$ the temperature of the fluid to be found out. Considering the aforesaid factors, the heat generation equations will be Analysis. Fluid power is one domain within the field of system dynamics, just as mechanical translational, mechanical rotational and electronic networks are system dynamic domains. Fluid power systems can be analyzed with the same mathematical tools used to describe spring-mass damper or inductor-capacitor-resistor systems. Like the other domains, fluid power has fundamental power variables and system elements connected in networks. Unlike other domains many fluid power elements are nonlinear which makes closed-form analysis somewhat more challenging, but not difficult to simulate. Many concepts from transfer functions and basic closed loop control systems are used to analyze fluid power circuits, for example the response of a servo valve used for precision control of hydraulic pistons. Like all system dynamics domains, fluid power is characterized by two power variables that when multiplied form power, and ideal lumped elements including two energy storing elements, one energy dissipating element, a flow source element and a pressure source element. The earliest hydraulic systems used water for the fluid. The advantage of water is

safe for humans and environment, cheap and readily available, and it has significant disadvantages for hydraulic applications. It provides almost no lubrication, has low viscosity and leaks by seals, easily cavitates when subjected to negative pressures, has a narrow temperature range between freezing and boiling (0 to 100℃), is corrosive to the steels used extensively in hydraulic components and is a friendly environment for bacteria and algae growth, which is why swimming pools are chlorinated. Modern hydraulic system use petroleum based oils, with additives to inhibit foaming and corrosion. Petroleum oils are inexpensive, provide good lubricity and, with additives, have long life. Brake fluid pressure and flop (D V Tretsiak, 2014).

Fluid power is characterized by two main variables, pressure and flow, whose product is power. Pressure *P* is force per unit area and flow *Q* is volume per time. Because pneumatics uses compressible gas as the fluid, mass flow rate Qmis used for the flow variable when analyzing pneumatic systems. For hydraulics, the fluid is generally treated as incompressible, which means ordinary volume flow *Q* can be used. Pressure has several common units that include pounds per square inch and bar as shown in table 2.2.

Table 2.2. Pressure units

| | KPa | Bar | Atm. | Torr. | Psi | MmHg. |
|---|---|---|---|---|---|---|
| KPa | 1 | 0.01 | 0.00987 | 7.5 | 0.146 | 7.5 |
| $cm^3$ | 100 | 1 | 0.987 | 750.06 | 14.504 | 750.06 |
| $m^3$ | 101.325 | 1.013 | 1 | 760 | 14.696 | 760 |
| $in^3$ | 0.133 | 0.00133 | 0.00132 | 1 | 0.0193 | 1 |
| $ft^3$ | 6.895 | 0.o69 | 0.068 | 51.715 | 1 | 51.715 |
| $yd^3$ | 0.133 | 0.0013 | 0.0013 | 1 | 0.0193 | 1 |

Source: (htt//www.sigmaaldrich.com/technical-documents)

For engineering, it is best to do calculations and simulations in SI units, but to report in SI and the conventional engineering unit. Pressure is an across type variable, which means that it is always measured with respect to a reference just like voltage in an electrical system. One can talk about the pressure across a fluid power element such as a pump or a valve, which is the pressure, differential from one side to the other, but when describing the pressure at a point, for example the pressure of fluid at one point in a hose, it is always with respect to a reference pressure. Reporting absolute pressure means that the pressure is

measured with respect to a perfect vacuum. It is more common to measure and report gouge pressure, the pressure relative to ambient atmospheric pressure (0.10132 Mpa, 14.7 psi at sea level). The distinction is critical when analyzing the dynamics of pneumatic systems because the ideal gas law that models the behavior of air is based on absolute pressure. Pressure is measured with a mechanical dial type pressure gage or with an electronic pressure transducer that outputs a voltage proportional to pressure. Almost all pressure transducers report gauge pressure because they expose their reference surface to atmosphere. Volume flow rate is reported in gallons per minute, liters per minute and cubic meters per second. Flow is a through type variable, which means it is volume of fluid flowing through an imaginary plane at one location. Like current in an electrical system, there is no reference point. Flow is measured with a flow meter placed in-line with the fluid circuit. One common type of flow meter contains a turbine, vane or paddle wheel that spins with the flow. Another type has a narrowed passage or an orifice and flow is estimated by measuring the differential pressure across the obstruction. A tube estimates velocity by measuring the dynamic pressure, which is the difference between the stagnation pressure and static pressure. Because flow meters restrict the flow, they are used sparingly in systems where small pressure drops matter. Some common types of flow meter shown in figure 2.4.Brake fluid Power and Efficiency (Rolan Siregar, 2020).

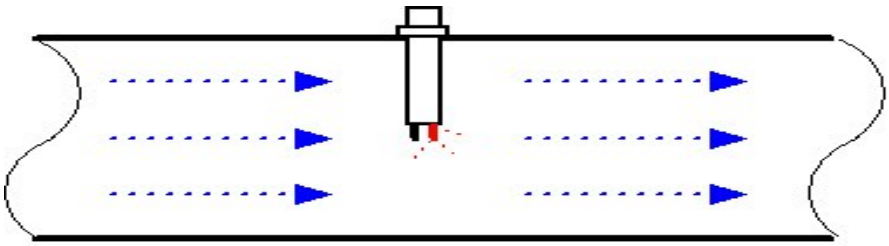


Figure 2.4. Some common types of flow meters (www.engineering toolbox.com)

The power available at any one point in a fluid power system is the pressure times the flow at that point

$$Power = P \times Q \quad (2.1)$$

Where:

P =fluid pressure

Q= fluid flow ret

For the brake power available in a conduit, the pressure relative to the pressure in the system reservoir, this is typically at atmospheric pressure. Components such as cylinders, motors and pumps have input and output powers, which can be used to calculate the efficiency of the component. Pressured fluid flows into a cylinder and the cylinder extends. The input power is the pressure of the fluid times its flow rate while the output power is the compression force in the cylinder rod times the rod extension velocity. Dividing output power by input power yields the efficiency of the component. The same can be done for components such as an orifice. The efficiency of the orifice is the output pressure divided input pressure because the flow rate is the same on either side of the orifice.

All fluids including oil and air have fundamental properties and follow basic fluid mechanics laws. The viscosity of a fluid is its resistance to flow. Some fluids, like water, are thin and have low viscosity while others like honey are thick and have high viscosity. The fluids for hydraulic systems are a compromise. If the viscosity is too low, fluid will leak by internal seals causing a volumetric loss of efficiency. If the viscosity is too high, the fluid is difficult to push through hoses, fittings and valves causing a loss of mechanical efficiency. The dynamic viscosity (also known as the absolute viscosity) is the shearing resistance of the fluid and is measured by placing the fluid between two plates and shearing one plate with respect to the other. The dynamic viscosity of water at 20℃ is 1.00 CP. It is easier to measure and more common to report the kinematic viscosity of a fluid, the ratio of the viscous forces to inertial forces. The symbol for kinematic viscosity is the Greek letter nu (*v*). Kinematic viscosity can be measured by the time it takes a volume of oil to flow through a capillary (Raij put R. K, 2008).

The SI unit for kinematic viscosity is $\frac{m^2}{s}$ but the more common unit is the centistokes which is$\frac{m^2}{s}$

The conversion is$\frac{m^2}{s} = 106\ \text{cSt} = 104\ \text{stokes}$, and

$$\nu = \mu\rho \tag{2.2}$$

Where:

ν = kinematic viscosity

μ = dynamic viscosity

ρ = fluid viscosity

The kinematic viscosity of water over a wide range of temperature is 1 cst while common hydraulic oils at 40℃ are in the range of 20-70 cSt. Sometimes hydraulic oil kinematic viscosity is expressed in Saybolt Universal Seconds (SUS), which comes from the oil properties being measured on a Say bolt viscometer. Viscosity changes with temperature; as fluid warms up it flow more easily. One reason your car is hard to start on a very cold morning is that the engine oil thickened overnight in the cold. The viscosity index express show much viscosity changes with temperature. Fluids with a high viscosity index are desirable because they experience less change in Viscosity with temperature as shown in figure 2.6.

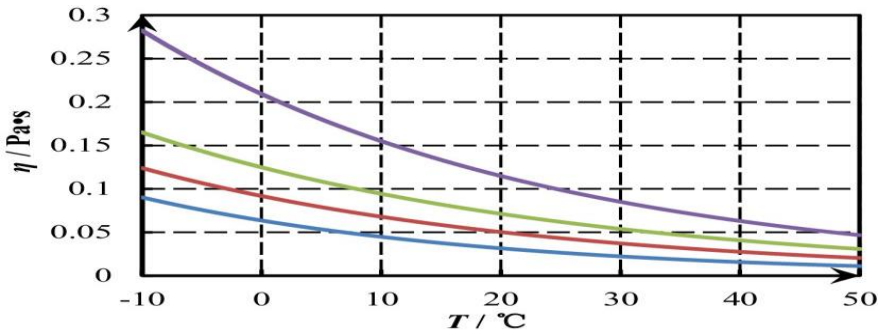



Figure 2.5. Viscosity changes for typical hydraulic fluids

Liquids are assumed to be completely incompressible even though all materials can be compressed to some degree. In some hydraulic applications, the tiny compressibility of oil turns out to be important because the pressures are high, up to 5,000 psi. The bulk modulus of the fluid is the property that indicates the springiness of the fluid and is defined as the pressure needed to cause a given decrease in volume. Typical oil will decrease about 0.5% in volume for every 1000 psi increase in pressure. When the compressibility is significant, it is modeled as a fluid capacitor (spring) and often is lumped in with the fluid capacitance of the accumulator. When air bubbles are entrained in the hydraulic oil, the bulk modulus drops and the fluid becomes springy. You may have experienced this when the brake pedal in your car felt spongy. The solution was to bleed the brake system, which releases the trapped air so that the brake fluid becomes stiff again. Another way that the fluid can change properties is if the pressures fall below the vapor pressure of the liquid causing the formation of vapor bubbles. When the bubbles collapse, a shock wave is produced that can erode nearby surfaces. Cavitations damage can be a problem for propellers and for fluid power pumps with the erosion greatly shortening the lifetime of components (Yu, 2017).

The bulk modulus $\beta$ is defined as

$$2\,\boldsymbol{\beta} = \Delta \mathbf{P}\frac{\Delta \boldsymbol{V}}{\boldsymbol{V}} \quad (2.3)$$

Where:

$V$ = the original volume of liquid

$\Delta V$ = the change in volume of the liquid

$\Delta P$ = when subjected to a pressure change

$\boldsymbol{\beta}$ = the units of pressure

Because $\Delta V/V$ is dimensionless, the units of $\beta$ are pressure.

Water has a bulk modulus of $3.12 \times 10^5$ psi (2.15 GPa) while hydraulic oils have a bulk modulus between $2 \times 10^5$ and $3 \times 10^5$ psi (SAE 30 oil is $2.2 \times 10^5$ psi = 1.5 GPa but can drop way down if air is entrained.

**Pascal's Law**

Pascal's Law states that in a confined fluid at rest, pressure acts equally in all directions and acts perpendicular to the confining walls. This means that all chambers, hoses and spaces in a fluid power system that have open passageways between them are at equal pressure so long as the fluid is not moving. Pascal's Law makes it easy to understand the operation of a simple hydraulic amplifier. The piston on the right is 25 times the area of the piston on the left. Pushing down with 10 lbs on the left piston will lift a 250 lb load on the right because the pressure of 10 psi is the same everywhere. The pressure losses in straight pipe and hoses contribute to the overall efficiency of a fluid power system. The losses can be estimated using the Energy losses in pipes used for the transportation of fluids (water, petroleum, gas, etc.) are essentially due to friction, as well as to the diverse singularities encountered. These losses are usually converted into head reductions in the direction of the flow (James Van De Ven, 2015). (Zhao Xiangyang, 2020)

$$\Delta P = f\frac{PL}{2D}V^2 \quad (2.4)$$

Where:

$\Delta$P = the pressure drop

f = friction factor.

L = pipe length.

D = pipe inside diameter.

$V^2$= average flow velocity.

Bends and Fittings Flow through long straight pipes is not common in practical fluid power system as typically flow goes through right-angle fittings and short sections of bent, flexible hose. The pressure drops in these pathways can be significant and must be estimated to analyze system efficiency. While fluid mechanics theory and computational fluid dynamics simulations can be used to generate precise values of pressure loss, the fluid power engineer generally uses tabulated values of dimensionless loss coefficients K for each component. The pressure drop across the component is where *A* is the area of the fitting. Note that the pressure drop is proportional to the flow squared. The flow as a function of pressure Loss coefficients can be found in vendor catalogue (Belhocine, 2013).
Fluid resistors are any component that resists flow. Another way of looking at fluid resistors is any component that causes a pressure drop when fluid flows through the component. Fluid resistors include valves, filters, hoses, pipes and fittings. A generalized linear fluid resistor relates flow and pressure (R. K $R_{ajput}$, 2008).
Fluid capacitors are one of two types of energy storing elements in fluid power systems. Capacitance in a fluid power circuit comes from discrete accumulators but also from the fluid itself if it is compliant. Fluid compliance is essential to consider in pneumatic systems, but generally does not play a significant role in dynamic models of hydraulic systems unless there is significant trapped air causing spongy behavior. The idea of capacitance of fluid trapped in a cylinder can be expanded to estimate the capacitance of a plug of fluid in a hose or pipe, which in turn can be used in a dynamic model. One application of a dynamic model involving fluid compression is to understand water hammer, which is impact loading cause by sudden changes in flow, such as when a valve is switched from on to off (R. K Raj put, 2008).

Fluid is the medium in which energy is transmitted through in a hydraulic system and the type e of fluid used will have an impact on a number of different system properties. The fluid itself might be synthetic or non-synthetic and important properties and issues that need to be considered when selecting a hydraulic fluid are lubricate, viscosity, protection against corrosion, tendency to foam, fire resistance and environmental impact. The properties of a fluid medium are apart from the type of fluid used also dependent on temperature, pressure and entrained air. Understanding how these various parameters affect the behaviour and control of a hydraulic system constitutes the fundamentals of hydraulic system theory and is therefore presented in the following (Douglas W. Harwood, 1208).

The ARI line of automatic air release valves and the automatic air release components of ARS. Combination air valve are based on the rolling seal technology. The ARI patented sealing mechanism replaces tradition configurations that incorporate a ball float closing against around orifice. While the system is under pressure the ARI rolling seal mechanism, with its aerodynamically designed float. Releases air in large quantities, often greater than in traditional valves. They also provide for the soft dynamic closure of the valve. This concept of rolling seal mechanisms enable A. R.I. to develop. The self cleaning feature of rolling seal mechanism greatly reduces the possibility of clogging, leaking and the adhesion of suspended particles to the rolling seal surface. The valve body and interior components are made of corrosion resistant material. This ensures years of corrosion free and maintenance free operation even under extreme environmental conditions. The A.R.I.line of production also includes a wide variety of air and vacuum and combination air valves. They are made of the same quality materials as the automatic air release valves and provide the same level of quality and assurances. These valves are offered in dimensions of ½ to 1(automatic air release valves). They provide solutions for various applications in all industrial fields. These products are light weight, have a compact profile and are offered at competitive prices (Karan C. Prajapati, 2014).

An important factor in brake is the stopping distance. This is the distance between the point the driver actually applies the brakes, and the point when the vehicle rolls to a fully stop from any steady road speed. It depends up on a number of factors. The time a driver takes to stop depends on the time it takes him/her to react. As well as the time it takes the brake to half the vehicle. During this reaction the time is about two third of a second for most drivers. The vehicle travels for what is called the thinking distance for a given efficiency the stopping distance is proportional to the square of speed braking from 120 km/h requires nine times the distance needed from 40 km/h. Brakes are designed to stop the vehicle within the distance indicated in while it is carrying its rated driver reaction time poor road conditions or an over loaded vehicle will increase the stopping distance. Warn or glozed brake shoe lining worn drums also increase stopping distance by decreasing the coefficient of friction (Sulakshan Rajendran, 2006).

As mentioned before, the function of the brake is to reduce the vehicle kinetic energy. For distance brake this kinetic energy is mainly transformed into heat through a frictional sliding contact between the disc and pads. This resisting torque initially transforms the rotational inertial energy of the wheel in to heat which slow down the wheel rotation with

respect to the vehicle translation motion. This reduce wheel rotational speed generates in turn a frictional force at the wheel ground contact patch which reduces the vehicle translation velocity. During the transient phase of the braking phase, elastic energy is being built up in the tire while it is deforming in order to build up the friction force at the tire ground contact patch. Next to this, some of the heat is absorbed by elastic deformations in the chassis and suspension. Therefore, the initial part of the heat generation process does not translate immediately into vehicle deceleration. On top of this at high deceleration braking there is a significance amount of slip at the tire ground contact patch which generates heat well (Xu Wen-bo, 2020).

Air bubbles entrained in the hydraulic fluid can create many problems in the hydraulic system, such as the acceleration of oil degradation due to oxidation, a decrease in lubricant caused by air emulsion, the reduction of fluid viscosity, a reduction in thermal conductivity, an increase heat load, cavitations erosion, higher noise emissions, an increase in compressibility, a reduction in bulk modulus resulting in spongy operation, poor control system response, and a decrease in system efficiency. Air entrainment in working hydraulic fluids has greatly detrimental effects on the function and lifetime of the hydraulic fluids, components, and systems. It is important to eliminate air bubbles from hydraulic fluid in order to preserve oil quality and system performance and to avoid possible damage to the components of the hydraulic system (Mr. Harshal Salvi, 2017).

The dissolved air in the oil is eliminated through bubbles extracted at the pump's suction side under negative pressure. Using a pump-motor unit and the bubble eliminator, a changing ratio of dissolved oxygen in oil is measured during the pump circulation. Sampling and time-consuming methods had been conventionally used to determine the bubble content of the oil. One is to introduce sample oil into a vertical glass pipe or a syringe, and finally measure the volumes of the air and the liquid. Another method is to let the oil with the bubbles flow through a small separation of two glass plates. Verify a reduction of thermal conductivity of oil by eliminating bubbles in the oil, oil temperature rise in a hydraulic line is measured with and without the bubble eliminator. The bubbles in the oil are considered as some kind of a heat insulator, so the existence of the air bubbles causes reduction of the thermal conductivity of the oil. The oil temperature rise in the condition becomes lower than in the case, but it remains higher than that in the cases. In the case only a cavitation air at the restrictor has much influence on the temperature rise of the oil. If the bubble eliminator is used, the infused bubbles from the suction side of the

pump are perfectly eliminated, and the temperature rise can be prevented comparing to the no operating the bubble eliminator. It can be explained that the bubble in the oil causes the oil temperature rise (Mahmood Hasan Dakhil, 2015).

Simulation using the straight type bubble eliminator without the tapered tube to clarify the relationship between sizes of the device and bubble. Working oils with bubbles tangentially flow into the device from the inlet ports and form a swirl flow that circulates the fluid through the flow passage. The swirl Flow accelerates downstream. Bubbles are trapped in the vicinity of the central axis because of the difference between the specific gravity of the oil and the bubbles; they are collected near the range of the vent port, where the pressure is the least. When back pressure is applied by a check valve or an orifice located on the downstream side of the bubble eliminator, the bubbles are pushed out through the vent port (Shrikant Jambhale, 2019).

Particularly entrained air in hydraulic systems results in a reduction in stiffness and a modified static and dynamic behavior. This influence of entrained air in hydraulic systems is complex as air can be dissolved into the hydraulic fluid. The amount depends on the static pressure. There with, the amount of entrained air inside the fluid changes with a change in pressure. To model the most important parameter in hydraulic systems, the pressure build-up and release, first a mass transfer model between entrained and dissolved air was developed and presented in this paper. This model not only considers the static pressure but also the pressure change velocity as it was found to be an influencing parameter as well. This physical diffusion process is in reality very complex and depends on much more factors than the pressure and the pressure change rate, e.g. the radius of the individual bubbles, the surface tension, viscosity etc. Finally, the model to calculate the pressure change including the pressure-dependent change in fluids composition was presented and validated by measurements (W. A. Akpan, 2012).

The changes in volume and pressure of the sampled hydraulic fluid as functions of time for both conditions. The volume change was calculated from the displacement of the piston cylinder and shown as the relative value against the initial volume of the pressure vessel. The relative volume change was as small as 0.2%. The volume change is the same with the bubble eliminator turned on and off. The pressure with the bubble eliminator turned on increased up to 3MPa according to the volume change, but the pressure with the bubble eliminator turned off increased up to less than 1MPa to the entrained air. A significant

amount of the fluid volume change was consumed to compress the entrained air. The secant bulk modulus with the bubble eliminator turned on and turned off was calculated to be 1.37 and 0.26GPa, respectively. The entrained air greatly influenced the effective secant bulk modulus in the low-pressure range. To compare the bulk modulus changes with and without air bubbles in detail when the pressure applied to the oil changed from low to high, we pressurized the sampled oil up to 45MPa and measured the pressure and volume changes of the oil. Moreover, we measured them during not only the pressurized process but also the depressurized process, and we confirmed the differences of the bulk modulus changes in the pressurized and depressurized processes (Hiroyuki (Goo, 2018).

Volume fraction is defined as the volume of a constituent divided by the volume of all the constituents in the mixture. In end of cycle 1, it was observed that there are air bubbles gathering at specific locations in the upper region of the cavity, thread gap and the narrow space between the spindle and nut-spindle in particular, where the air bubbles are compressed and expanded, and finally trapped. It is clear that the air with a high concentration was trapped in the thread gap and gap space due to the effect of fluid resistance to complex geometry. However, the air bubbles in the upper region are inconsequential since they are located in an relatively open space close to the bleeding port. Despite more cycles, it is to be noted that the trapped air expands and remains in the same location without escaping, particularly in the thread gap and the space. Hence, once the air is trapped, it remains, even if the number of cycles increases. Thus, the fundamental cause of the reduction in the brake bleeding performance is the trapped air (LUNDIN, 2015).

Cavitation is the formation, oscillation and decay of cavities in liquids. Accordingly, vapor cavitation is the evaporation and re-condensation of liquid to vapor due to local pressure variations which go below the vapor pressure. In contrast, gas cavitation is the desorption, oscillation and dissolving of gas bubbles in a liquid as a result of local pressure variations going below the saturation pressure of the liquid. During the operation of hydraulic systems, the occurrence of cavitations is usually unavoidable. Vapor and gas cavitations' are based on two completely different physical processes and work on different physical time scales. Vapor cavitation is a phase transition and gas cavitation is a diffusion process. In nano –or microseconds vapor bubbles re-condensate and collapse in regions of higher pressure which can cause erosive micro jet. Air bubbles do not re-condensate but diffusively resolve in the liquid, which takes seconds or minutes. Therefore, air bubbles

usually do not collapse and cause no micro jet. The effect of cavitation's fundamentally limits the operating range, the lifespan and performance of hydraulic components and systems (Bako Sunday, 2019).

Master cylinder is a central pressure pump. It uses force generated by mechanical advantage of the brake pedal which is further converted into hydraulic pressure by compressing brake fluid inside the brake lines. The brake lines are connected to a master cylinder for transportation of pressurized fluid from master cylinder to the brake calliper where it pushes calliper piston and thus brake pads against the brake rotor which causes friction and vehicle stops. It has fluid inlet and compensating port connected to a brake fluid reservoir which supplies brake fluid into the cylinder when vacuum gets created inside the master cylinder. When the brake pedal is applied by the driver, the brake fluid in system gets compressed and brakes are applied. Further when brake pedal is released the piston moves backward due to the compression spring (NEYS, 2012).

The consequence of which is the decrease of the pressure of brake fluid in brake calliper piston of the right front wheel with the same pressure force on the brake pedal was the reason why obtained peak values of braking delay were half lower. In such conditions, due to the occurring differences of the developing braking force in the right and left wheel of the vehicle, pressure hydraulic valves were started by anti-lock braking system, what is very clearly visible on the courses presented. The constraint of the possibility of increasing pressure in hydraulic calliper cylinder of one of the wheels resulting from the presence of air bubbles was the reason for the occurrence of the tendency of blocking and skidding the second wheel, the anti-lock braking system needed to counteract. However, its consequence was considerable decrease of the obtained braking delay in maximum values up to $4m/s$.Also in this case, the presence of vapor bubbles of the hydraulic calliper cylinder caused lowering the maximum obtainable braking delay by 50 %, and additionally it can be noticed that in the initial braking phase. in the phase of the increase of longitudinal delay, the increase of the value of parallel acceleration of the vehicle is also recorded. Such a course of parallel acceleration can be explained with the increasing difference of braking forces on the wheels on the right and left side of the vehicle, not corrected by the operation of anti-block system. The changes of the braking force on the vehicle wheels are visible on all acceleration courses recorded by the sensor in parallel axis of thevehicle. The lack of the possibility of correcting braking forces on the remaining wheels after turning off anti-lock braking system was the reason for even larger decrease of

the obtained perpendicular delays. This was when the difference exceeded 10 %. Higher values of maximum parallel acceleration can also be observed during these tests. The values of parallel acceleration were more than 50 % higher. Fully blocked flow of brake fluid to the brake calliper cylinder of the right front wheel of the vehicle caused even larger difficulties with the maintenance of the track of vehicle movement.

The average values of delay obtained in the same road conditions in the vehicle with the diminished braking force, resulting from the air pocket of brake calliper piston, reached similar values both in case of the operation of anti-lock system and with the lack of it. However, anti-lock braking system influences the restriction of the acceleration fluctuations registered in the parallel axis of the vehicle. During rectilinear braking with fully efficient braking system, maximum acceleration registered in parallel axis reached 1.5 m/s, whereas in case of the lack of anti-lock system it was 20% higher. Also in case of fully blocked brake calliper cylinder of one of the wheels of the vehicle, anti-lock braking system can considerably influence the course of parallel acceleration of car body (Cornák, 2008).

### 2.2. Summary for related Literature

The reviewed literature shows that, Hydraulic technology with braking systems was another leap in the technology of brakes. This earliest hydraulic system concept used a single pedal to transfer force from the main cylinder through a series of tubes and cylinders to the brake shoes, thus reducing the amount of force needed by the operator to slow the vehicle and increasing system reliability. This was to present hydro mechanical braking system for the passenger car to reduce the road accident by developing the additional braking force with boosting the master cylinder hydraulic pressure. In hydraulic brake components and operational factors influencing the hysteresis losses. These parts have analysis of the factors influencing the hysteresis pressure losses in a hydraulic brake system. The investigation is the brake pedal stroke velocity, the gaps between the brake pads and the brake disc, and the configuration of the brake system. Automotive brake pipes characteristics and their effects on brake performance; the distribution of the brake fluid pressure between axle wheels is one element that has a large effect on braking performance and vehicle dynamic behavior during braking. Fitting improves brake efficiently for the vehicle in its straight motion and in its cornering motion depending on the variation of load distribution, road curvature and moving speed. According to the characteristics and required braking function of front and rear dual motor driven hybrid electric vehicle,

braking control strategy for an electro hydraulic braking system with conventional braking and regenerative braking is proposed. Electromagnetically braking system is an electromagnetic braking system uses magnetic force to engage the brake, but the power required for braking is transmitted manually. Brake Fluids have unique and district properties that enable its application in Engineering. It assists the braking system to bring a moving mass to rest. Most of the brake fluids that are in use are glycol ether based, though mineral oil and silicon-based fluids also exist. The glycol based fluids normally have low compressibility but are hygroscopic in nature. The dry boiling point of glycol based fluid seldom exceeds 304°C. The second classification which is ester-based has higher dry and wet boiling points. Failure of a brake system is more as a result of brake fluid vaporization under intense braking as per the designated track of the vehicle. The existence of bubbles in working fluids of hydraulic systems exhibits a massive effect on performance. The brake fluid is hygroscopic which means it will attract and hold water molecule. The water will be absorbed right out of the air and as brake fluid ages it will begin to promote corrosion in many of the hydraulic components found in the braking system. An important factor in brake is the stopping distance. This is the distance between the point the driver actually applies the brakes, and the point when the vehicle rolls to a fully stop from any steady road speed.

### 2.3. Research gap

These literatures showed that automotive brake performance, reliability, active safety such advanced systems. Antilock braking systems (ABS), electronic stability program, Anti slip control system and assisting a driver in ensure driving safety.

Many kinds of brake system are more reliable and effective. But most of the hydraulic brake system which are available; now need high brake fluid boiling temperature. And there is no brake fluid temperature sensors, brake fluid pressure regulator, brake fluid evaporator, brake fluid pressure measuring device, which is not on light vehicle in our country. And some of them have only signal to reduce the speed on dash board and even traffic police call, some acts are shutting the engine which can cause unexpected accident since there will be no movement until the vehicle stalls and starts again. Some driver increasing the force on the accelerator pedal but the driver can push the pedal with a greater force and run the vehicle with fast speed.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1. Introduction

For achieving the set target, proper materials are to be used and step by step methodology to be followed. The materials used and methodology followed are given in this chapter.

## 3.2. Materials

The materials used in this thesis work are listed in Table 3.1.the system is developed based on TOYOTA 3K car model. The dimensions of brake system of TOYOTA 3K are taken from Toyota manual.

SOLID WORKS: used to construct the baseline and modified model of bus.

ANSYS FLUENT: used to simulate the flow fluid around the model of automatic brake bleeding.

Table 3.1. Materials used

| I.NO | Component name | Specification | Quantity |
|---|---|---|---|
| 1 | Brake fluid | DOT3 | 1 bottle |
| 2 | Brake pad | 6.4mm thick | 1 set |
| 3 | Brake line(hose) | 4.8mm in diameter Steel tube | 2m |
| 4 | Rotor | 1.7 mm thick | 1pc |
| 5 | Wheel cylinder | Two piston | 1pc |
| 6 | Brake booster | 10 Pascal | 1set |
| 7 | Brake fluid reservoir | 0.5 litre | 1pc |
| 8 | Brake calliper | 38.20mm in diameter,38.18mm bore | 1pc |
| 9 | Master cylinder | 13.84mmout diameter,0.55 mm in diameter | 1set |
| 10 | Return spring | 30 cm length | 1pc |
| 11 | Wood plate | $1m^2$ 4cm thick | 1 |
| 12 | Aluminum sheet | 1.5 m length and 3cm thick | 1 |
| 13 | Aluminum shaft | 25 cm diameter,0.5 m long rigged | 1 |
| 14 | Metal washer | 17mm outer D, 25 in D | 2 |
| 15 | Filter material | 20 $cm^2$ area, 1cm thick | 1 |
| 16 | O ring seal | 25cm outer D, 23cm in D | 2 |
| 17 | O ring seal | 27cm outer D ,25 cm in D | 1 |

### 3.3. Methodology

The methodology followed in the execution of this thesis work includes various steps. The steps involved in the methodology followed are shown in the form of flow chart in figure 3.1.

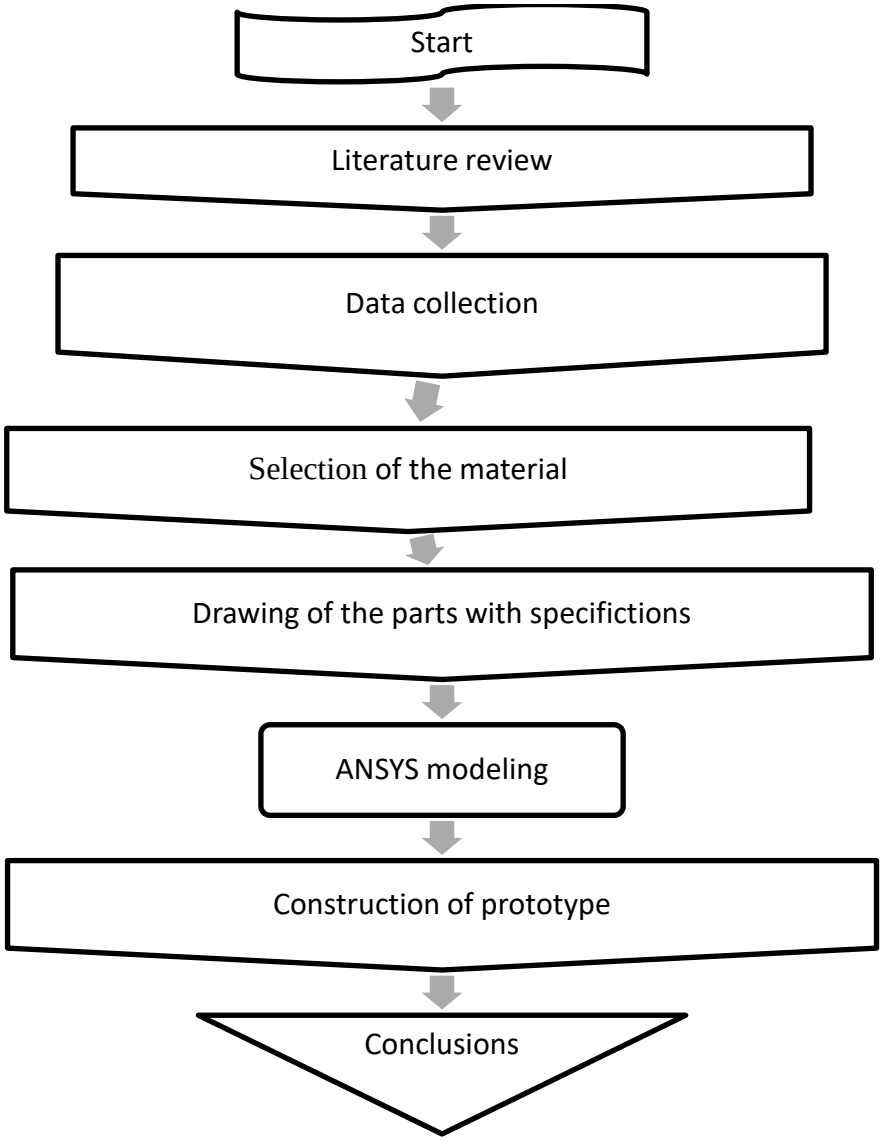



Figure 3.1. Flow chart of thesis work methodology

#### 3.3.1. Literature review

Various literature related to this work are collected and reviewed to gain the necessary knowledge related hydraulic brake system, its functionality and air bleeding.

### 3.3.2. Data collection

The data related to TOYOTA 3K model car was collected from the manual and direct measurement. The data related to hydraulic brake system and its air bleeding was also gathered. Information on effect of air bubble in working fluid on performance of light vehicle brake system was also gathered. The specifications of TOYOTA 3K light vehicle are given in Table 3.2.

Table 3.2. Basic vehicle specification of Toyota 3k model

| Brake component | Unit measurement | Measurement |
|---|---|---|
| Inside diameter of the disc | mm | 33 |
| Outside diameter of the disc | mm | 262 |
| Disc thickness | mm | 29 |
| Disc height | mm | 51 |
| Wheel diameter | m | 0.686 |
| Brake drum diameter | m | 0.318 |
| Lining area per drum | $m^2$ | 0.0321 |
| Initial velocity | m/s | 28 |
| Deceleration a | $m/s^2$ | 8 |
| Rate distribution of the braking force | lb | 20 |
| Initial speed | Kmph | 28 |
| Deceleration | $m/s^2$ | 8 |
| Tire radius | mm | 314 |
| Vehicle mass | kg | 1480 |

### 3.3.3. Selection of the materials

The properties which are important for the materials are:

- ✓ Strength
- ✓ Durability
- ✓ Machinability and

- ✓ Workability

The best material is one which serves the desired objective. The following factors are considered while selecting the materials. These factors are:

- ➢ Availability of the material
- ➢ Suitability of the materials for the working conditions and
- ➢ The cost of the material.

**A. Polyethylene plastic tube**

Polyethylene is a lightweight, durable thermoplastic with variable crystalline structure. It is one of the most common plastic tubes in use today. The kinds of polyethylene are known, with most having the chemical formula $(C2H4)_n$ for common commercial grades of medium and density polyethylene tube the melting point is typically in the range 120℃ to 130℃. The specifications of the tube are given in table 3.3.

Table 3.3. Specification of polyethylene tube

| Material Name | Size | | | Working pressure | | Working temperature | |
|---|---|---|---|---|---|---|---|
| Polyethylene plastic tube | OD Mm | ID mm | Wall thick mm | Min MPa | Max MPa | Min ℃ | Max ℃ |
| | 21.33 | 12.70 | 3.17 | 1.38 | 27.58 | 26.7 | 93 |

Figure 3.2. Polyethylene plastic Tube

**B. Plastic O-ring**

An O-ring, also known as a packing or toric joint, is a mechanical gasket in the shape of a torus, it is a loop of elastomer with a round cross- section, designed to be seated in groove and compressed during assembly between two or more parts, creating a seal at the interface with dimensions. The dimensions of o-ring are given in table 3.4. it is shown in figure 3.3.

Table 3.4. O-ring Specification

| O-ring | Size | | |
|---|---|---|---|
| | ID<br>Mm | OD<br>mm | Cross section<br>mm |
| | 12.42 | 15.98 | 2 |

Figure 3.3. O-ring

**C. Aluminum piston**

Aluminum alloys are the preferred material for piston due to their specific characteristics like low density, high thermal conductivity, simple net shape fabrication techniques, easy machinability, high reliability and very good recycling characteristics.

Figure 3.4 shows the material used for fabrication of piston.

Figure 3.4. Aluminum material for piston

**3.4. Automatic brake bleeding working principle**

Series automatic brake bleed valve is normally open valve. Until the system is pressurized, the valve is simply open and air is present. As pressure builds within the system, unwanted air is forced to the highest point in the system. The normal open air releases the system, when pressure within the system high pressure, air is expelled. As liquid rises, the piston becomes buoyant and eventually closes. It is possible that trace amounts of air will remain in the system, depending on the rapidity with which the valve closes. It is also likely that some trace amounts of process liquid will be emitted. At system pressure of 10 psi the piston will seal bubble tight against the orifice. When pressure and liquid level drop, the valve will automatically re open. The piston is guided by a series of hydraulic pressure

within the piston seat. The piston is a unique design by aluminum material. That is designed to provide a balance of buoyancy and seal ability. This balanced piston is the key to the superior performance of this system. It is dense enough to permit maximum emission of unwanted system air. Yet buoyant enough to affect quick seal and minimize emission of the process liquid.

### 3.4.1 Basic calculation and consideration for hydraulic brake system

Kinetic energy is the force that keeps the vehicle moving. This energy is provided by the engine in order to accelerate the vehicle from a standstill to desired speed. Kinetic energy is dissipated as heat by the brakes during application of brakes. The kinetic energy of a vehicle during braking is given. Thus, the kinetic energy doubles as the weight doubles, but it increases four times as speed doubles.

$$KE = \frac{1}{2}\left(\frac{W}{g}\right)(u^2 - v^2) = \frac{1}{2}m(u^2 - v^2) \quad (3.1)$$

Where, w = vehicle gross weight, N

u = initial velocity $^{m}/_{s}$

v= final velocity $^{m}/_{s}$

m= mass of the vehicle kg

g = acceleration due to gravity $^{m}/_{s^2}$

### 3.4.2. Stopping distance

Stopping distance is extremely important for emergency braking. The stopping distance is based on the deceleration rate. Also, it is affected by the tyre deflection, air resistance, braking efforts and the inertia of the driveline. Distance travelled by the vehicle during application of brake can be obtained from the following equations of motion assuming the brake efficiency as 100%.

S =ut -$\left(\frac{1}{2}\right) ft^2$ and $u^2 - v^2$ = -2fs (3.2)

S =$\frac{u^2}{2g}$

Where; s =distance moved by vehicle, m

u = initial velocity of vehicle m/s

v= final velocity of vehicle, m/s

t= duration of application of brake's

g= deceleration of the vehicle, m/$s^2$

If the vehicle comes to stand still due to application of brake, the final velocity, v = 0 in the above equations, then stopping distance, S is given by the relations, S = u/2f. The stopping distance remains same with the same tyre and road conditions, when the wheels are locked and skidding, regardless of the weight, number of wheels or vehicle load. Maximum braking force occurs when the wheels are brake just before the locking point or point of impending skid.

The stopping distance for a vehicle travelling at 60 km/hr with a deceleration equal to the acceleration due to gravity

S =$\frac{u^2}{2g}$ , u= 60km/hr = $\frac{60}{3.6}$ m/s

g= 9.81m/$s^2$, s = $\left[\frac{60}{3.6}\right]^2 \times \frac{1}{2\times9.81} = \frac{60\times60}{3.6\times3.6\times2\times9.81}$ = 14.4m

### 3.4.3. Brake fluid volume requirements

When a hydraulic brake is applied, fluid is required to move through the pipes. If the fluid source is a master cylinder it has a finite capacity. Brake fluid is required to take up running clearance.

$$V_{f1} = \frac{A \times R_C}{1000} \quad (3.4)$$

Where:

$V_{f1}$= fluid volume to take up running clearance

A = total piston area

$R_c$= running clearance

It is also needed to compensate for lack of stiffness of the brake housing. For a disk brake the flowing approximation can be used.

$$V_{F2} = p \times ( 0.007db - 0.2365 )$$

Where:

$V_{f2}$ = fluid volume to take up disc brake housing stiffness

P = pressure in brake system

dp = brake piston diameter

Pads compressibility: pad compressibility varies between hot and cold conditions. The number is 2% cold and 5% hot at pressure of 16Mpa. The fluid required is given by

$$V_{F3} = \frac{C_3 \times t \times db \times 2\pi}{6400} \quad (3.5)$$

Where:

$Vf3$ = fluid volume due to pad compression

$C_3$ = pad compressibility

t = sum of pad twitchiness

p = pressure in brake system

Pd = brake piston diameter

Rubber hose expansion: the rubber hose expansion coefficient is usually take as

$$V_{f4} = C_h \times l_h \times p \quad (3.5)$$

Where: $V_{f4}$ = fluid volume due to rubber hose expansion

$c_h$= house expansion cost

$l_h$ = length of hose

p = system pressure

b = hose bore diameter

Steel pipe expansion: pipe expansion is very small and unlikely to be of interest however it should be noted that it is proportional to the cube of the diameter, so using bigger pipe than

necessary on a system with affixed fluid volume will cause longer travel for two reasons, the stiffness of the pipe and more important the additional fluid compression losses

$$V_{f5} = \frac{Dp^3 \times l_3 \times p}{1266t \times E} \quad (3.6)$$

Where: $V_{f5}$ = fluid volume due to steel pipe expansion

Dp = outer side diameter of steel pipe

$l_3$ = length of steel pipe

P = system pressure

T = wall thickness of steel pipe

E = young modulus

Master cylinder losses: Fluid losses in master cylinders increase with bore size and pressure. A reasonable assumption can be found by using the following

$$V_{F6} = p \times 1o^{(0.025DM-23)} \quad (3.7)$$

Where:

$V_{f6}$= lessees in the master cylinder

P = system pressure

DM = diameter of master cylinder bore

Fluid compression: Fluid compression varies with temperature and the type of fluid used. The fluid needed take account of compression is calculated

$$V_{f7} = p \times V_A \times C_{fl} \quad (3.8)$$

Where: $V_{f7}$ = lost volume due to fluid compression

P = system pressure

$V_A$ = maximum active fluid in the system with worn lining

$C_{fl}$ = fluid compressibility factor

It is usually to allow about 3% for trapped air in the circuits that can't be removed by bleeding. This air is squashed totally flat during braking.

Dry disc temperature rise: In order to approximate the temperature, rise of the disc an assumption at to where the energy is going has to be made. Initially most of the heating take place in the disc, however this can then be rapidly cooled by surrounding components and the air stream.

The calculation assumes 80% goes to the disc.

$$q = \frac{4p}{\pi \times (D^2 - d^2)} \quad (3.9)$$

Where: $\boldsymbol{q}$ = heat flux

P = average power

D = disc use able outside

d = disc useable inside diameter

3k motor car has a wheel base of 2.64m, the height of its c.g. above the ground is 0.61m and it is 1.12m in front of the rear axle. If the car is travelling at $40km/hr$,$60km/hr$, $80km/hr$,$100km/hr$ on level track, determine the minimum distance in which the car may be stopped.

(a) The rear wheels are brake

(b) The front wheels are braked

(c) All wheels are braked

The coefficient of friction between tyre and road may be taken as 0.6. Prove any formula if assumed.

b = 2.64m

l = 1.12m

h = 0.61m

(a) $\frac{f}{g} = \frac{\mu (b-l)}{b+\mu h} = \frac{0.6 (2.64-1.12)}{2.64+0.6 \times 0.61}$

$$\text{Retardation} = \frac{0.6 \times 1.52 \times 9.81}{3.006} = 2.98\, m/s^2$$

Stopping distance will

$$S_1 = \frac{v^2}{2f} = \frac{11.1^2}{2 \times 2.98} = \frac{123.21}{2 \times 2.98} = 20.55\text{m}$$

$$S_2 = \frac{v^2}{2f} = \frac{16.66^2}{2 \times 2.98} = 46.60\text{m}$$

$$S_3 = \frac{v^2}{2f} = \frac{22.22^2}{2 \times 2.98} = 82.85\text{m}$$

$$S_4 = \frac{v^2}{2f} = \frac{27.77^2}{2 \times 2.98} = 129.4\text{m}$$

(b) $\frac{f}{g} = \frac{\mu l}{b - \mu h} = \frac{0.6 \times 1.12}{2.64 - 0.6 \times 0.6 \times 0.61} = \frac{0.6 \times 1.12}{2.274}$

$$f = \frac{0.6 \times 1.12 \times 9.81}{2.274} = 2.9 m/s^2$$

Required distance:

$$S_1 = \frac{v^2}{2f} = \frac{(11.1)^2}{2 \times 2.9} = \frac{123.21}{2 \times 2.9} = 21.25\text{m}$$

$$S_2 = \frac{v^2}{2f} = \frac{16.66^2}{2 \times 2.9} = 47.85\text{m}$$

$$S_3 = \frac{v^2}{2f} = \frac{22.22^2}{2 \times 2.9} = 85.12\text{m}$$

$$S_4 = \frac{v^2}{2f} = \frac{27.77^2}{2 \times 2.9} = 132.96\text{m}$$

(c) $\frac{f}{g} = \mu$

$$f = \mu g = 0.6 \times 9.81 = 5.88 m/s^2$$

Hence required distance:

$$s_1 = \frac{v^2}{2f} = \frac{123.21}{2 \times 5.886} = 10.5\text{m}$$

$$s_2 = \frac{v^2}{2f} = \frac{16.66^2}{2 \times 5.886} = 23.577\text{m}$$

$$s_3 = \frac{v^2}{2f} = \frac{22.22^2}{2\times5.886} = 41.94\text{m}$$

$$s_4 = \frac{v^2}{2f} = \frac{27.77^2}{2\times5.886} = 65\text{m}$$

### 3.4.4. Mean lining pressure and heat generation during braking operation

Wi and wt are the actuating forces for leading and trailing shoes respectively. Pi and pt are the normal forces between the shoe and the drum for leading and trailing shoes respectively air sing due to actuating force and act at an angle 0 to the vertical. Pi and Pt produce frictional force respectively on the shoes. These forces act perpendicular to the normal forces and at a radius k called the effective radius. The effective radius, k, is found to be greater than the drum radius, a. $\mu$ stands for the coefficient of friction between the drum and shoe. Figure 3.23 shows internal expanding shoe layout.

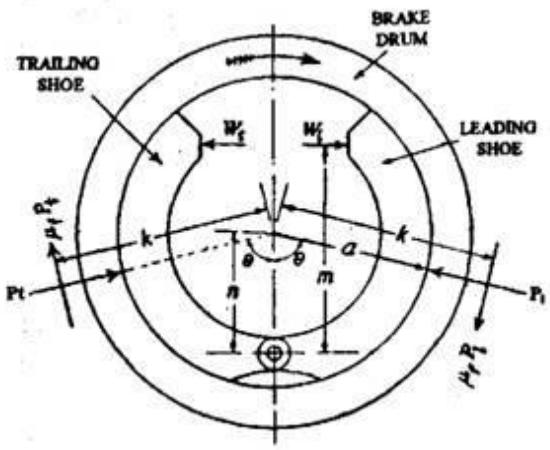



Figure 3.5. Internal expanding shoe layout

$P_t$ = normal force between the shoe and drum for trilling.

$\mu$ = coefficient of friction between shoe and drum.

$\mu$pl = frictional force due to pl

$\mu$Pt = frictional force due to pt

r = effective wheel radius in cm.

d = brake drum radios in kg.

$\propto$ = contact angle of angle each lining in degree.

w = width of brake lining in cm.

W = weight of vehicle in kg.

U = initial speed of the vehicle in$km/h$.

V = reduced velocity of the vehicle in$km/h$.

S = distance of retardation in meter.

f = rate of retardation in $\frac{m}{sec^2}$.

(a) Mean lining pressure.

$$f = \frac{(\frac{u}{3.6})^2 - (\frac{v}{3.6})^2}{2 \times s} \frac{m}{s^2} \quad (3.10)$$

Therefore; braking force when the vehicle move on a level road

$$F = \frac{W}{g} \times f$$

Braking torque on each wheel

$$= \frac{F \times r}{4} \text{ kg.cm.}$$

We have,

Braking torque on each drum = ($\mu$pl + $\mu$pt) d

$$= 2\mu \times p \times d$$

Let, pl = pt = p

Equating two value of braking torque from equation above

$$2\mu \times p \times d = \frac{F \times r}{4}$$

$$P = \frac{F \times r}{8\mu d} \text{ kg.}$$

Area of a braking lining = lining width × length of lining arc.

$$= \frac{w \times d \times \alpha\pi}{180} cm^2$$

Mean lining pressure = $\frac{p}{area\ of\ a\ linlig}$

$$= \frac{F \times r}{8\pi \times \alpha} \times \frac{180}{w \times \alpha \times d\pi}$$

$$= \frac{180 \times F \times r}{8\pi \times \mu \times \alpha^2 \times w \times \alpha} {}^{kg}/_{cm^2}$$

(b) Heat generation during braking.

Work done in braking = braking force × distance moved by vehicle.

$= F \times S$ kg.cm.

Heat equivalent to this work done.

$.= \frac{F \times 8}{427}$ kcal

Heat generated to each wheel

$= \frac{F \times 8}{4 \times 427}$ kcal

Heat generated in one minute at each wheel

$= \frac{F \times speed\ per\ minute}{4 \times 427}\ kcal/_{min}$

3k car weight 1480 kg is fitted with four-wheel brakes and slowed uniformly from $90^{km}/_{hr}$. In a distance of 150 m while running down an incline of 1 in 15.the amount of heat generate in kcal. During this operation and mention the methods employed to transfer this heat to the atmosphere. If the front wheels share 55% of the braking forces, calculate the mean lining pressure in $^{kg}/_{cm^2}$.

On the front wheel brake from the following data

With brake line width = 5cm

With effective wheel diameter = 70cm

With drum diameter = 32 cm

Lining area per drum =322 $cm^2$

Coefficient of friction between drum and lining = 0.4

What is the lining contact angle in each drum?

Solution:

We have, retardation of the vehicle,

$f = \frac{u^2 - v^2}{2s}$

$$= \frac{(\frac{90}{3.6})^2 - (\frac{50}{3.6})^2}{2 \times 150}$$

$$= \frac{624.8 - 193.0}{300} = \frac{431.8}{300}$$

$$= 1.439 {}^{m}/_{sec^2}$$

Total braking force when vehicle runs down a gradient of 1 in 15,

$$F = W \times \sin\theta + \frac{W}{g} f$$

$$= \frac{1480}{10} + \frac{1480 \times 1.439}{9.81}$$

$$= 98.666 + 217.3$$

$$= 315.766 \text{ kg.}$$

Therefore, the work done in braking the vehicle

$$= 315.766 \times 150 \text{ m.kg.}$$

Heat equivalent to this work

$$= \frac{315.766 \times 150}{427}$$

$$= 110.9 \text{J}$$

As the front wheels share 55% of the braking force, therefore braking force on each of the front wheel,

$$= \frac{315.766 \times 0.55}{2} \text{ kg}$$

Therefore: braking torque on each from wheel

$$= \frac{315.766 \times 0.55 \times 0.35}{2}$$

$$= 30.4 \text{ kg.m.}$$

Equating this torque to the braking torque on the drum, we have,

$$2\mu f \times p \times \alpha = 30.4$$

$$P = \frac{30.4}{2\mu f \times \alpha}$$

$$= \frac{30.4}{2 \times 0.4 \times 0.16}$$

$$= 237.5 \text{ kg.}$$

Half area of the lining of a drum

$$= \frac{322}{2} = 161 \text{ cm}^2$$

Therefore: average lining pressure = $\frac{237.5}{161}$

$$= 1.475\ kg/cm^2 \text{ ans.}$$

Area of lining = width × radius × arc subtended at the centre

$$161 = 5 \times 16 \times \frac{\propto \pi}{180}$$

$$\propto = \frac{161 \times 180}{5 \times 16 \times \pi} = 115.3$$

The total lining contact in each drum

$$= 115.3 \times 2$$

$$= 230.6° \text{ ans.}$$

3k car with all wheel brake weighting 1480 kg, Make an emergency stop at $90\frac{km}{hr}$. The total rolling and air resistance at 90 $km/hr$ Is 80 kg the coefficient of adhesion is 0.6.

(a) The retarding forces if the brake is applied to lock.

(b) Heat flow per minute at each wheel at the beginning of braking.

(a) With all the four wheel brake, the braking

$$= \mu R_R + \mu R_F$$

$$= \mu W$$

$$= 0.6 \times 1480$$

$$= 888\text{kg.}$$

The total resistance given,

R = 80 kg.

Total retarding force

= 888+ 80

= 968 kg

(b) Let distribution of force is equal on each wheel.

Therefore: velocity of the vehicle in beginning,

$V = \frac{90}{3.6} m/_{sec}$

$= 25\ m/_{sec}$

Hence work per sec. due to braking on each wheel at beginning

$= \frac{\mu W \times v}{4}$

$= \frac{0.6 \times 1400 \times 25}{4}$ m. $kg/_{sec.}$

Heat flow = $\frac{0.6 \times 1480 \times 25\ 60}{4 \times 427} kcal./_{min.}$

= 779.86k. $cal/_{min}$

$= \frac{(2.247 - 1.34) \times 1350}{2.247}$

= 544.9 kg.

Heat flow in brake system by indifferent speed 40 $km/hr$ ,60 $km/hr$ ,80 $km/hr$ ,100 $km/hr$ respectively.

When the front wheel are braked at 40 $km/hr$ ,60 $km/hr$ ,80 $km/hr$ ,100 $km/hr$.

Heat flow under front wheel for 40 $km/hr$ $= \frac{\mu \times w\ v}{4 \times 427}$

$= \frac{0.6 \times 1480 \times 11.11 \times 60}{4 \times 427}$ = 346.57kcal.

Heat flow under front wheel for 60 $km/hr$ $= \frac{0.6 \times 1480 \times 16.11 \times 60}{4 \times 427}$ = 519.7kcal.

Heat flow under front wheel for 80 $km/hr$ $= \frac{0.6 \times 1480 \times 22.22 \times 60}{4 \times 427}$ = 693.14kcal.

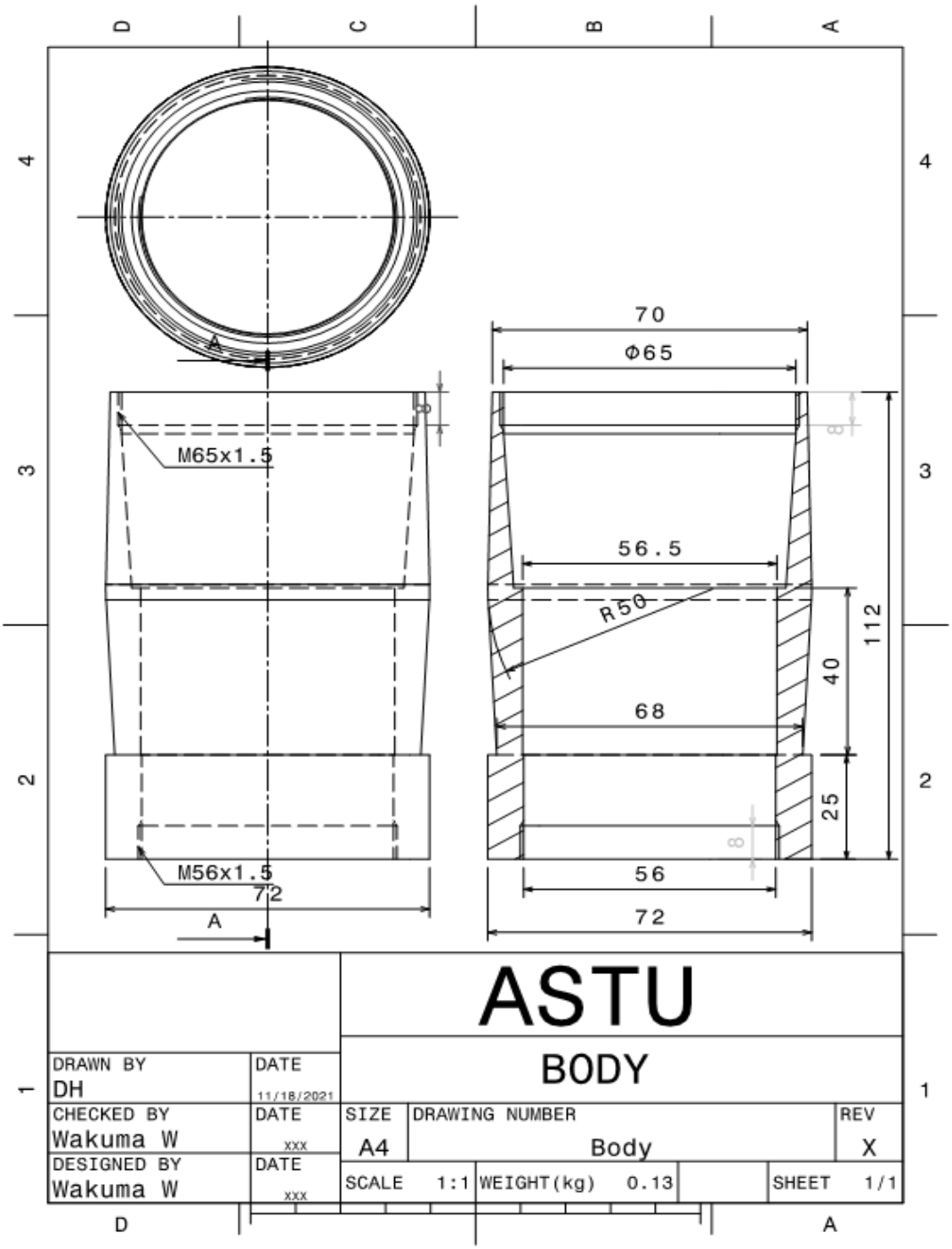
Heat flow under front wheel for 100 $km/hr$ $= \frac{0.6 \times 1480 \times 27.78 \times 60}{4 \times 427}$ = 866.58kca

### 3.4.5. Part drawing and 3D modeling

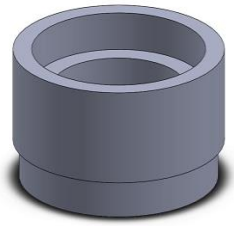
The detailed drawings of the parts are prepared using AUTO CAD software. The drawings of piston holder, upper house, piston, sleeve, seal, adapter bolt, adaptor nut are prepared and 3D models are also prepared. 3D model is prepared using solid works software.

### A. Piston holder

It is a cylindrical shape holding the internal part. Piston holder is a geometric solid that is drilled in different internal diameter. It has two ends, called bases that are usually used for connecting the components. The purpose of piston holder is holding piston and internal parts. The part drawing of the piston holder is shown in figure 3.9.




(a). part drawing



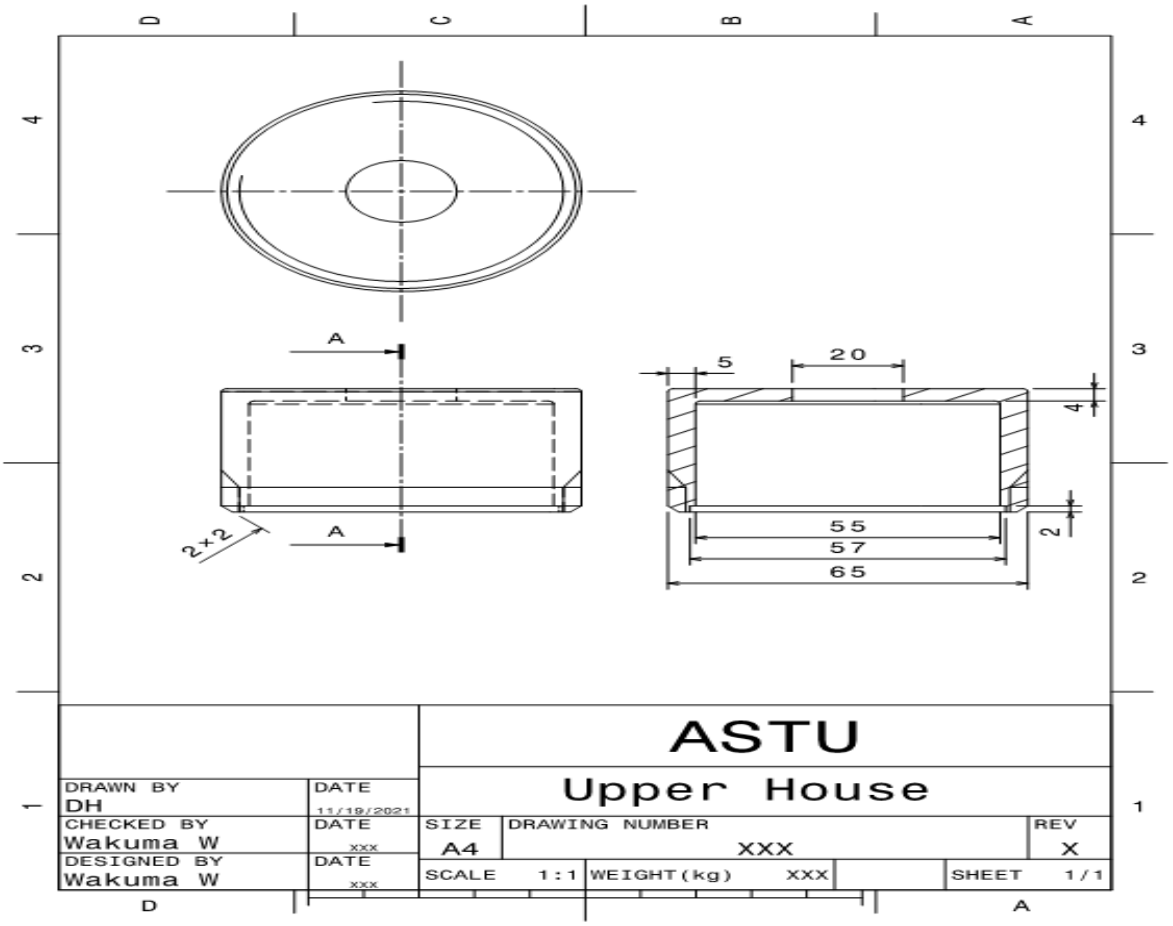
(b) 3D modeling

Figure 3. 6. Piston holder(a). Part drawing and (b).3D model

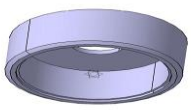
**B. Upper house**

The upper house helps in protecting the system from contaminants and maintaining the pressure in brake system. It gives the space for vapor to separate and accumulate.

Upper house with specification shown in figure 3.10.




(a) Upper house part drawing

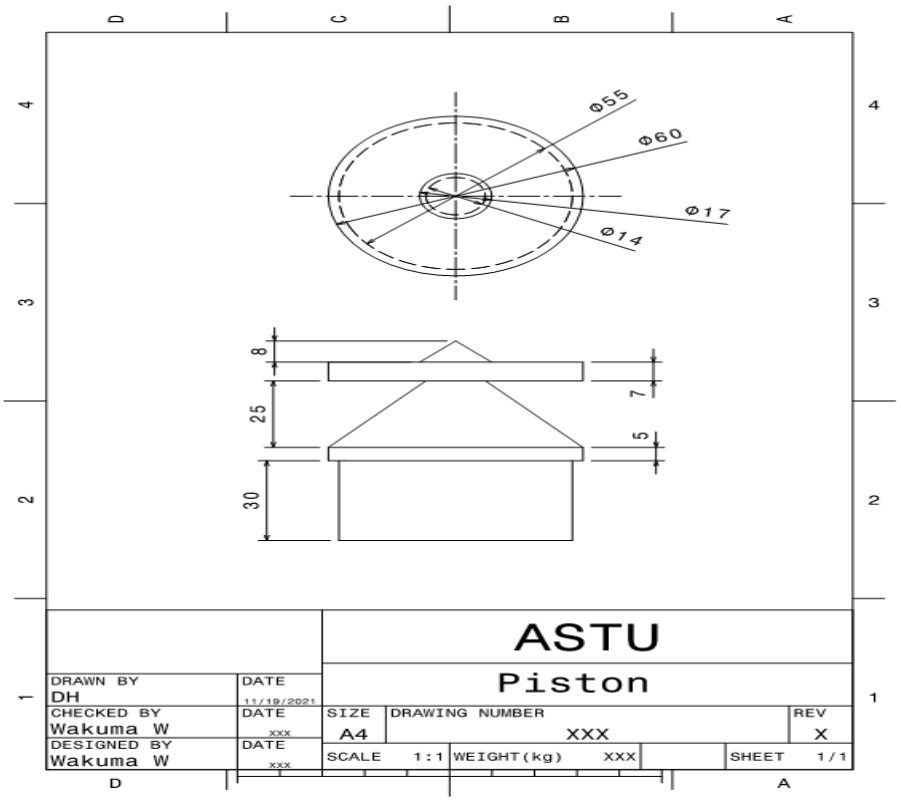


(b) 3D model

Figure 3.7. Upper house (a) part drawing and (b).3D model

## C. Piston

This piston can be used in pneumatic and hydraulic systems. It can be set to be either normally closed in energized state open in de-energized state, but it is free to reciprocate in the piston holder. Piston drawing with specification and solid works shown in figure 3.11.



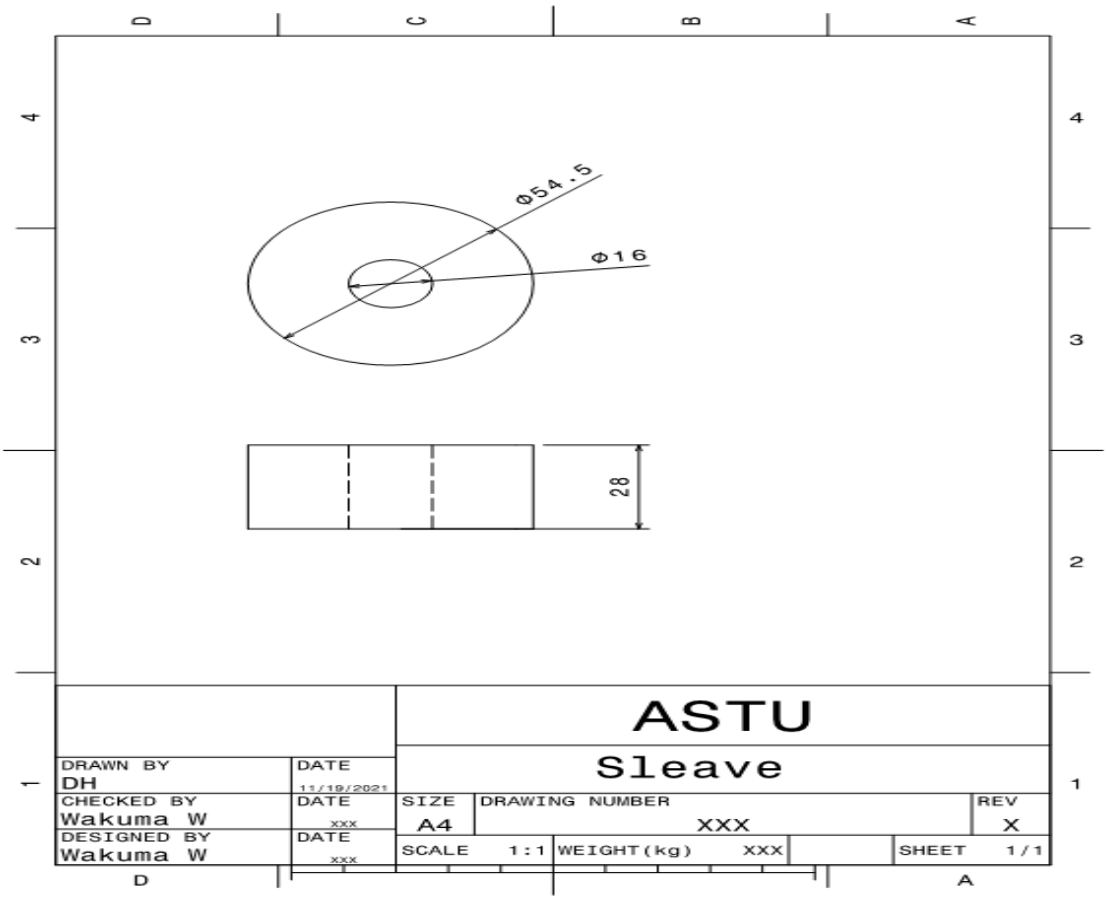

(a). part drawing

(b).3D model

Figure 3.8. Piston (a).part drawing(b).3D model

## D. Sleave

The main purpos of sleave is to utilize hydraulic brake pressure system, control runout and vibration dampenig characteristics. Sleave shown in figure 3.12.



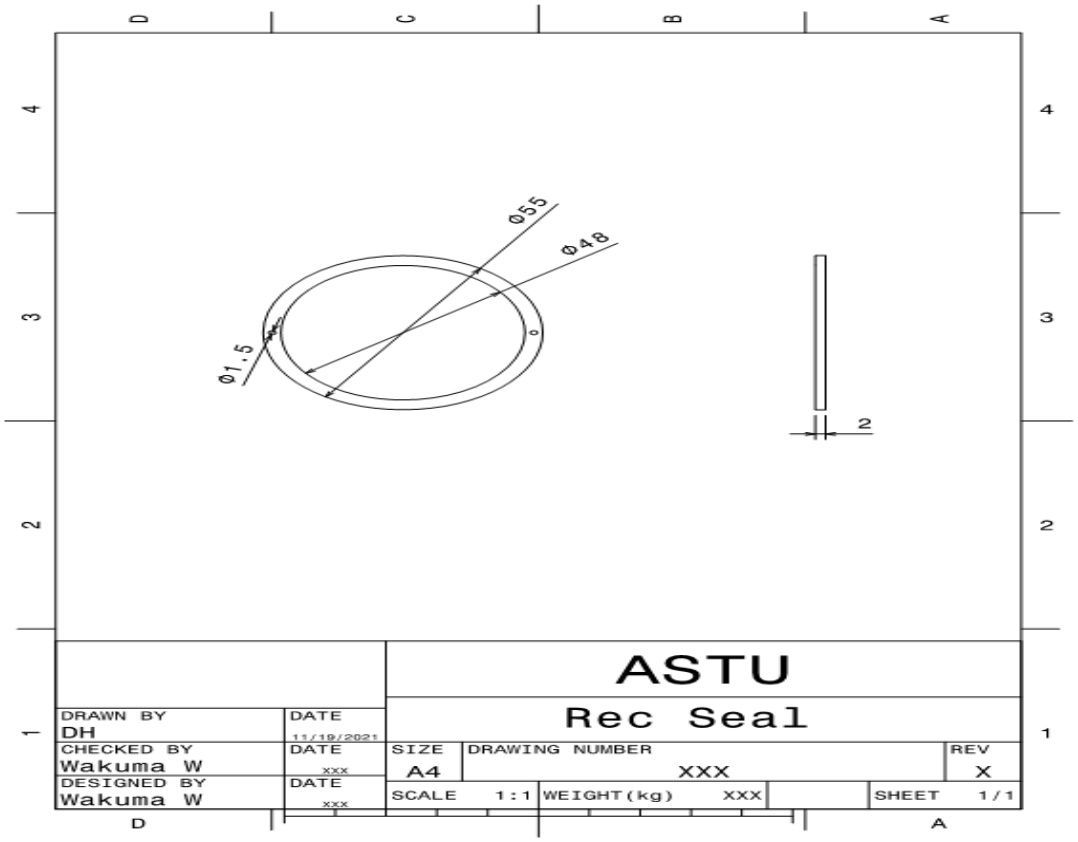

a. Part drawing

B.3D model

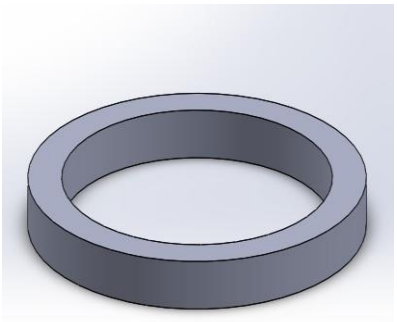
Figure 3.9.sleavea. Part drawing and b. 3D modeling

## E. Seal

This seals are generally relatively soft, non metallic ring cuptured in fixed in combination of rings, forming a seal assembly to block or separete fluid in resciprocating motion applictions. Sleave shown in figure 3.13.




(a).part drawing

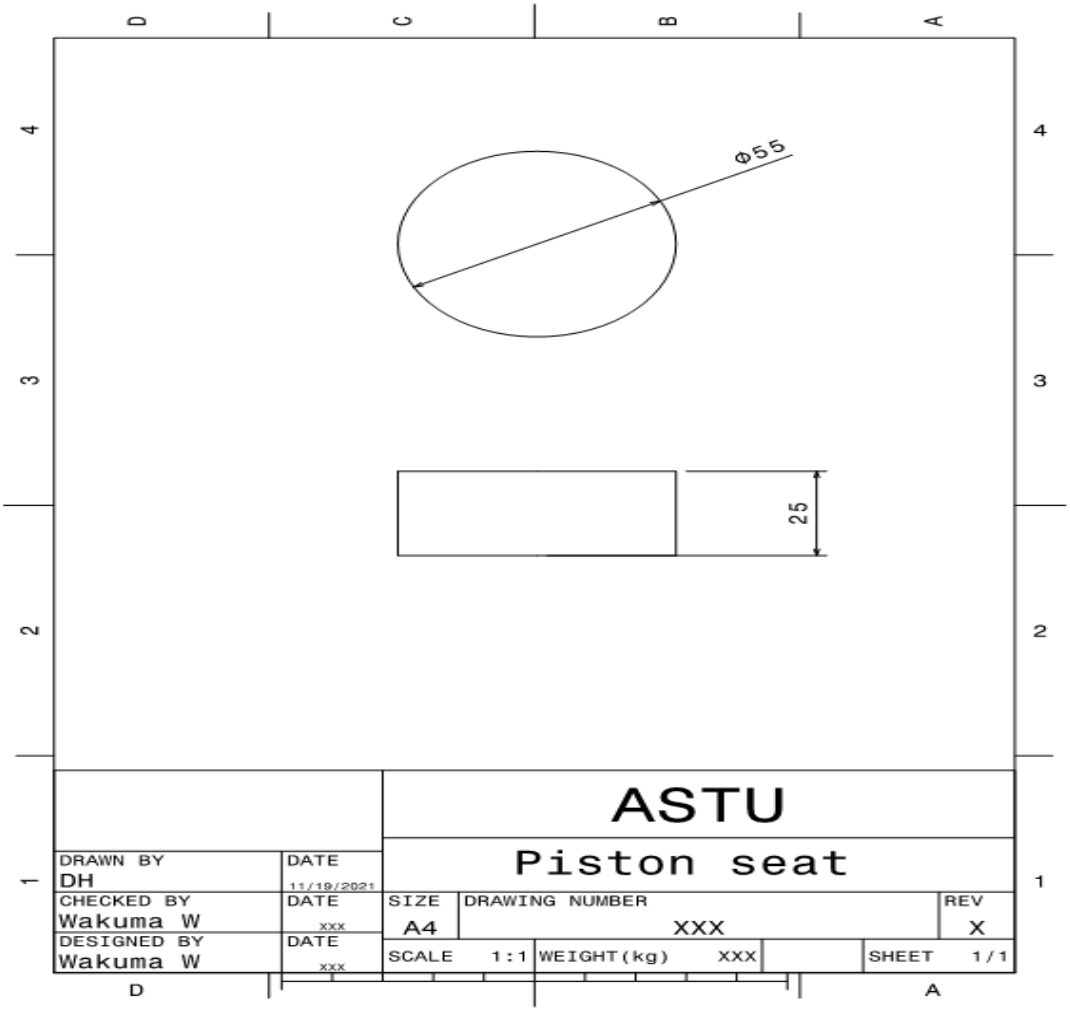


(b). 3D model

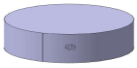
Figure 3.10. Seal (a) part drawing (3D) model

**F. Piston seat**

Piston seat is made of cast iron. It helps in proper seating of the piston during reciprocating motion of the piston. It is shown in Figure 3.14.




a. Part drawing

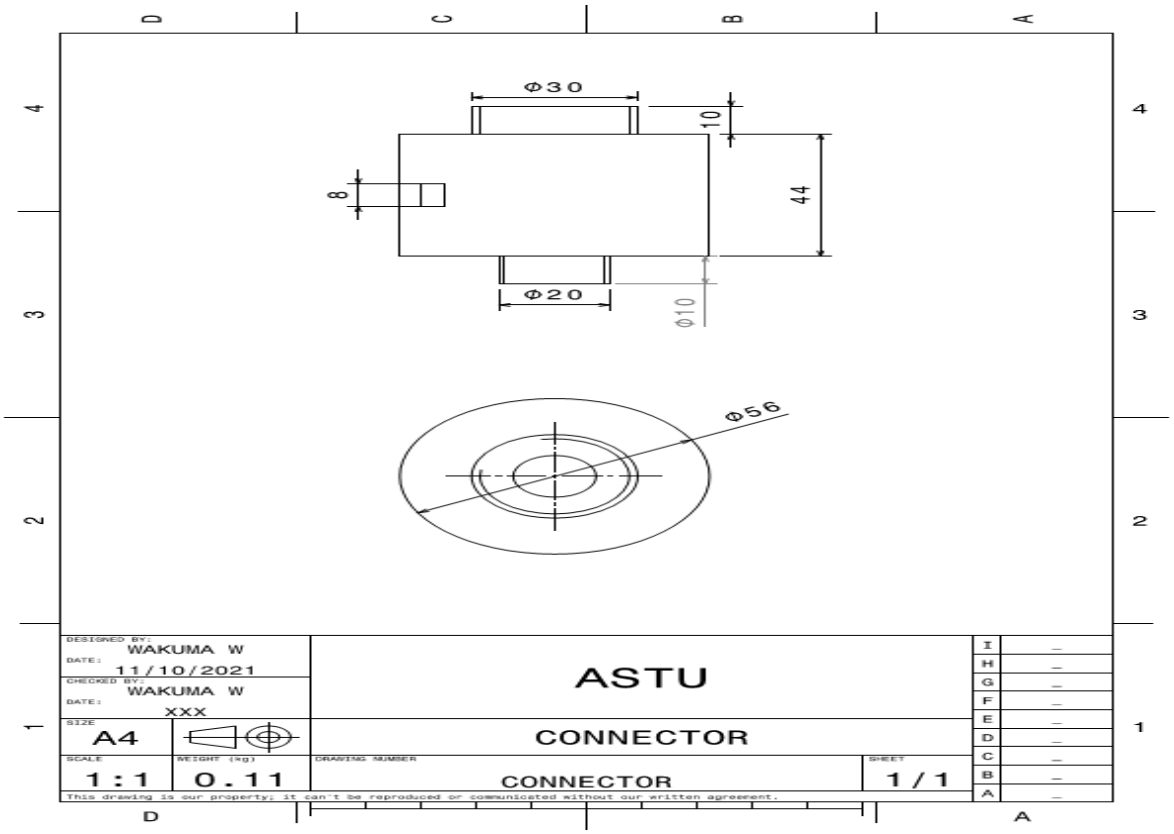


b. 3D model

Figure 3.11.piston seat a. Part drawing and b.3D modeling

**G. connector bolt**

A connector bolt is fixed to the hydraulic line instead of the threaded column. This allows brake fluid to flow and preventing leakage in the system. These fittings are widely used in hydraulic system. Adapter bolt is shown in figure 3.15.



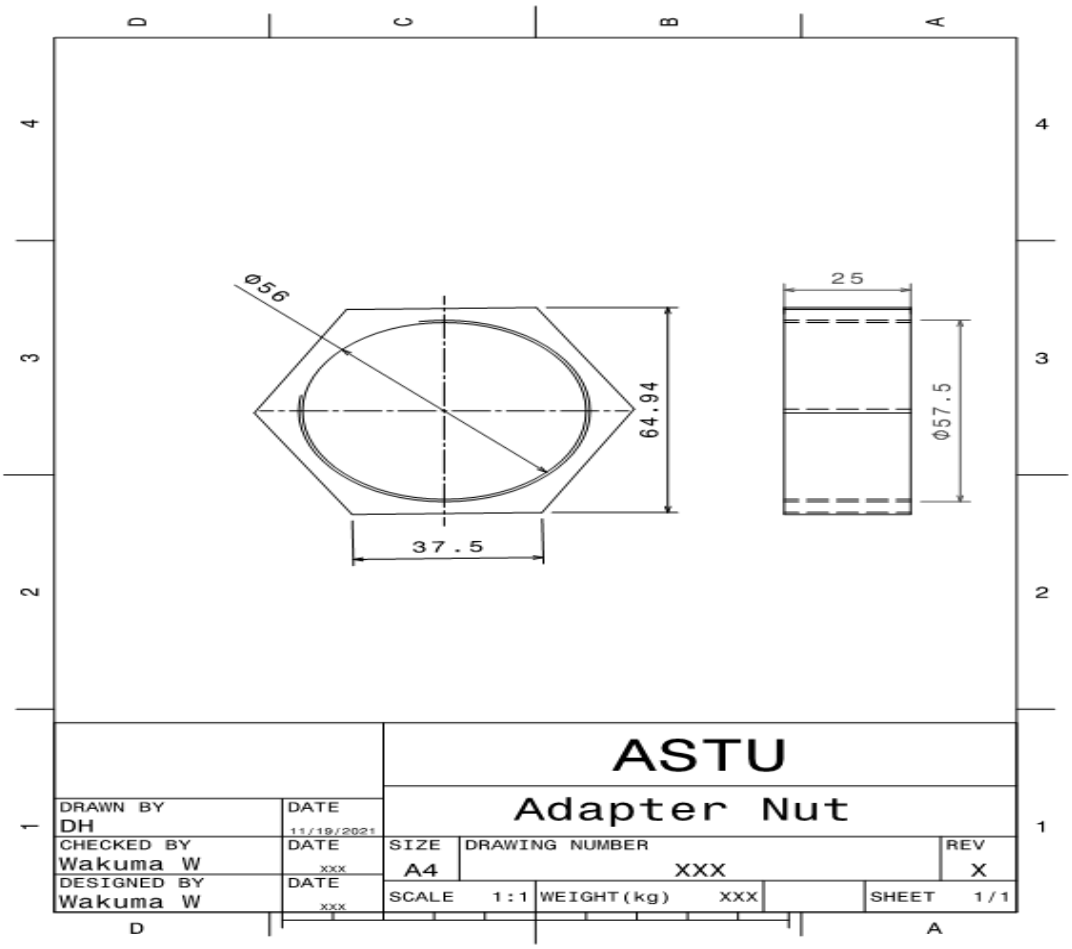

a. Part drawing of connector bolt

b.3D model

Figure 3.12. Connector bolt (a). Part drawing and (b). 3D modeling

## H. Adapter nut

It is used to connect hoses, pipes and tubes in a hydraulic system. Most fittings havea male and female component that joins to form a connection. These connections help contain and direct the flow of hydraulic fluid,while preventing leakage. Adapter nut is shown in figure 3.16.




a. Part drawing

B.3D model

Figure 3.13. Adapter nut a. Part drawing and 3D modeling

**I. Assembling**

The assembly of the automatic brake bleed system is shown in figure 3.17. Sectional views are used in technical drawing to expose internal surfaces. It serves to present additional orthographic views of surfaces that appear as hidden line in the standard front. Where solid material has been cut in a sectional view lines are evenly spaced at any inclined angle that is not parallel to any existing edge line. Sectional view of the assembled automatic brake bleed system is shown in figure 3.17.

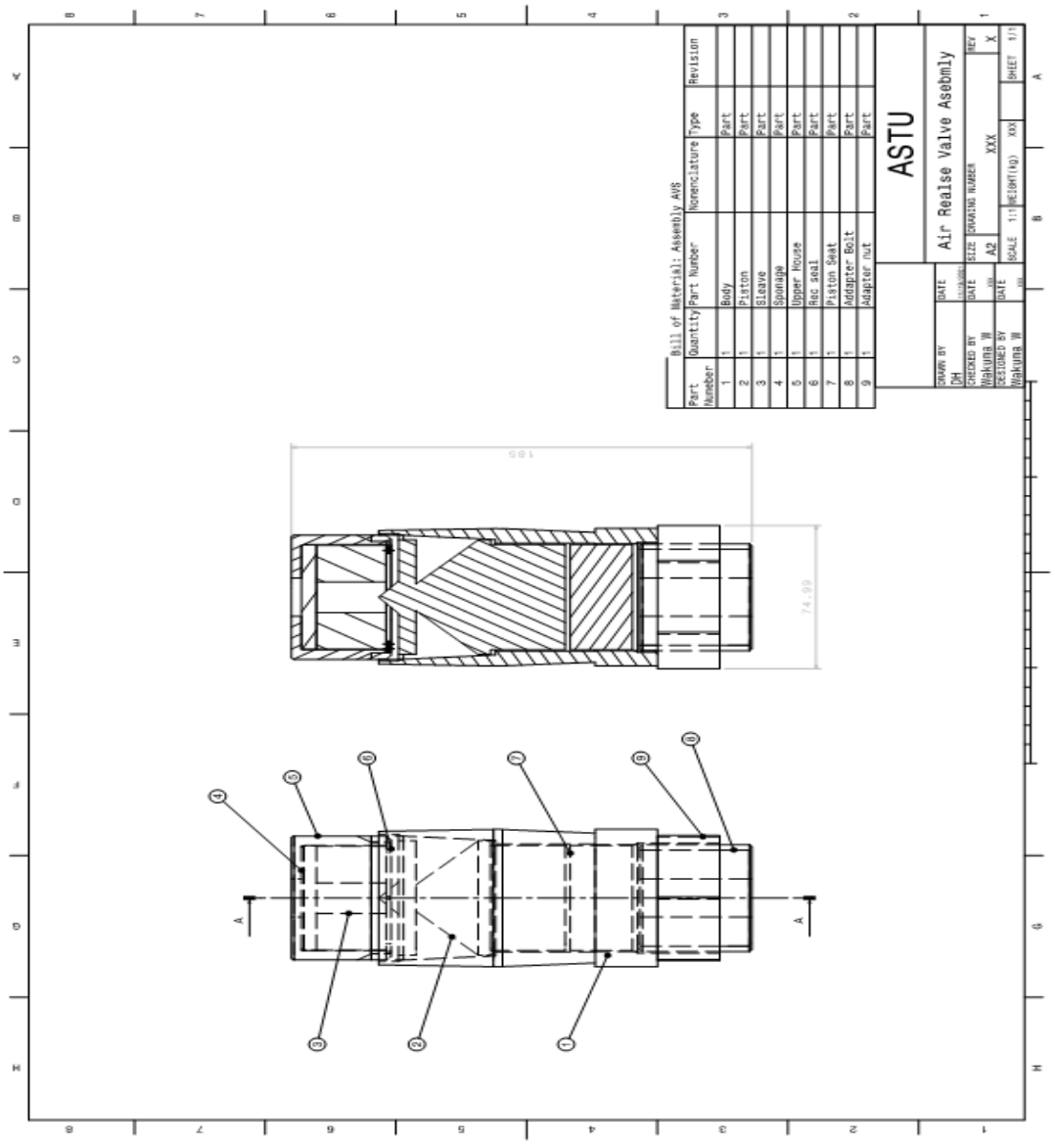



Figure 3.14. Sectional view of assembled automatic brake bleeds system.

**J. Exploded view**

Exploded drawing shows the relationship between different components and how they fit together to form the final product and helps understand the order of assembly of the different parts. Exploded view is shown in figure 3.18.

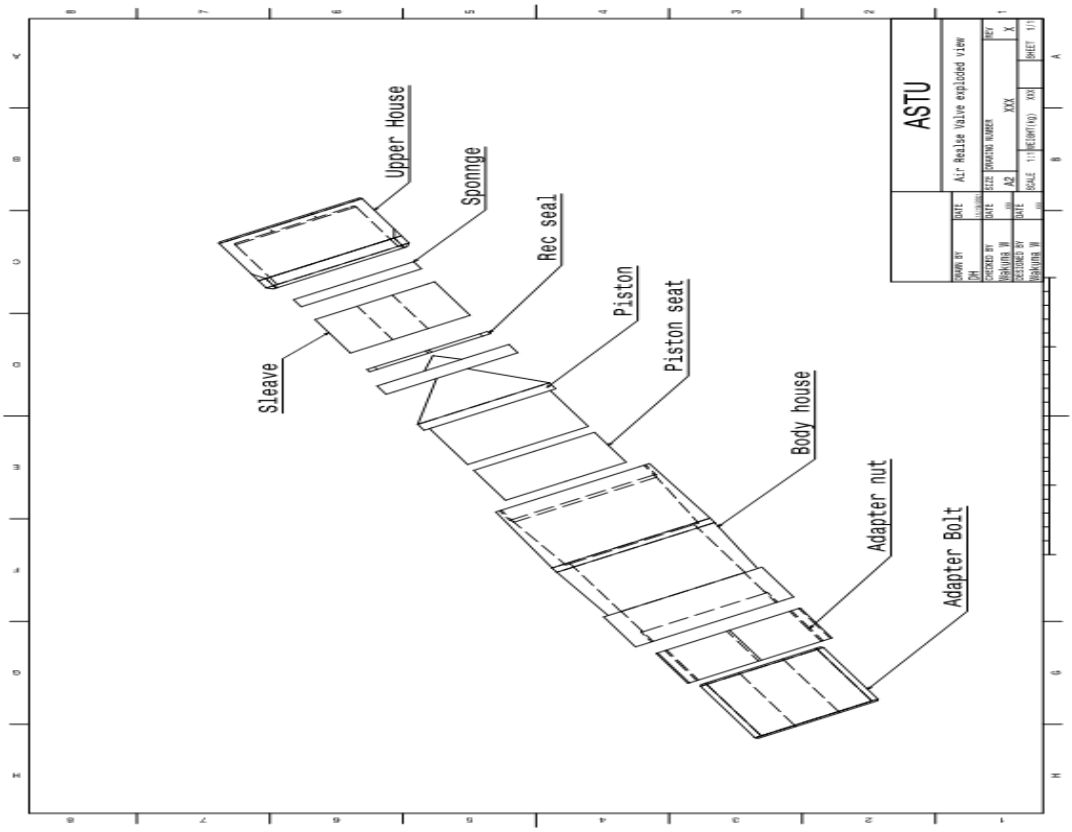



Figure 3.15. Exploded view of automatic air bleed system.

**3.4.6. Prototype construction**

The parts produced are shown in Figure 3.19. The instruments used for the production are shown in figure 3.21. A metallic frame using angle iron is prepared for mounting the automatic bleed system for demonstration purpose. Automatic brake bleed system mounted on frame is shown in figure 3.20. The brake system parts like brake pedal, booster, master cylinder, brake disk etc, which are collected from TOYOTA 3K vehicle are used our construction of the prototype.

Figure 3.16. Components produced with specifications before assembling

Figure 3.17. Constructed the whole components of prototype

Figure 3.18. The instruments used in the construction of the prototype.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

Integral results of force on the brake pedal are crucial parameters for the technical design of valves. Furthermore, the spatial distribution of velocity pressure and temperature are items of interest. The liquid is not allowed to become gaseous if the static pressure falls below the saturation vapor pressure. Due to the high bulk modulus the pure liquid cannot expand enough to capture the space itself as well in reality, even above the saturation pressure gas cavitations or pseudo cavitations occurs. Dissolving air and expanding air bubbles increase to volume fraction of the gas phase which influences the flow in the rear area. Considering cavitations in hydraulic oil is complex and relies highly on fluid parameters or empirical constants.

## 4.1. Performance parameters without self-bleeding hydraulic brake system

### 4.1.1. Loss of horsepower

When an air pocket is present in an actuator, it is alternately compressed and relaxed as the actuator is cycled. Since the air bubble must first be compressed before the fluid can cause the actuator is cycled. Since the air bubble must first be compressed before the fluid can cause the actuator to move, power is consumed. Up on relaxation, the air pocket expands and drives fluid out. The stored power, therefore, is expended in driving fluid back into the reservoir and not in moving the actuator.

### 4.1.2. Loss of bulk modulus

Free or entrained air in the hydraulic system reduces substantially the effective bulk modulus of the system. That is, an air oil mixture appears to increase the compressibility of the fluid, making the system spongy. To reduce the effect of dissolved air on bulk modulus, providing the air bleeding system is required.

### 4.1.3. Free air

That trapped in a system, but not totally in contact with a fluid. It is neither entrained nor dissolved; it is entrapped. Free air is an air pocket in a system; it can be removed by bleeding.

### 4.1.4. Dissolved air

It can be removed by two methods: subjecting the fluid to a reduced pressure and/or raising the fluid temperature. Its presence or absence does not affect fluid volume. Even if all the air bubbles and pockets were removed from a hydraulic system and the system totally

enclosed, after a short run-in period, air bubbles would begin to reappear. The source of these bubbles is the working fluid itself because all fluids contain dissolved air. It is this dissolved air that, under certain conditions, comes out of solution and plagues the system.

### 4.2. Ansys modeling

The objective of FFA is to investigate fluid stresses and problem area experience by automatic brake bleed. Since this hydraulic brake bleed is also used to optimization. Fluid mechanical analysis is used for analysis of this work. Therefore, material properties of aluminum alloy are tabulated.

#### A. geometric setting

Geometric model can be built for objective of any dimension in any geometric space. 3D geometric model is extensively used in computer graphic and models central to computer aided design.

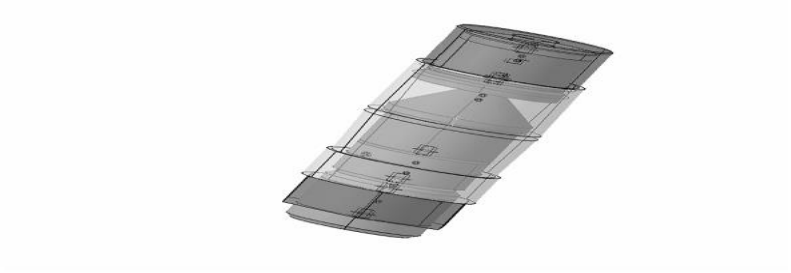


Figure3. 19.Shows CATIA geometric set up**.**

#### B. mesh

Figure3. 20 shows meshed model of automatic brake bleed in ANSYS designed model. A tetrahedral element was used for the solid mesh. Table3.5. shows meshing properties of existing piston. Once the created geometry set up was completed in the meshing. It was stated polyhedral mesh type develop in this study.

**Mesh**

Subject:
Author:
Prepared For:
Date Monday, July 18, 2022
Comments:

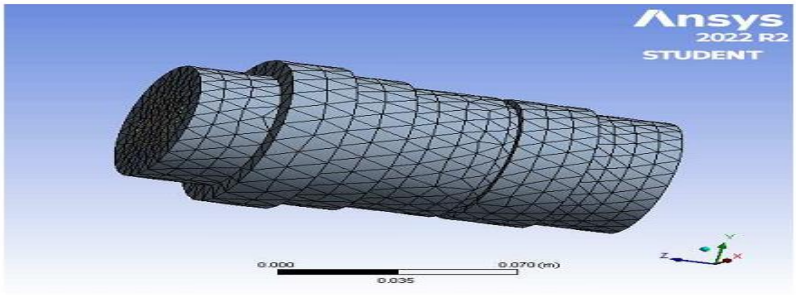





Figure 3.20. meshed model of automatic brake bleeding in ANSYS designed modular

Table 4. 1. Meshed model of piston in ANSYS designed modular.

| Number of nodes | Number of elements | Size of element |
|---|---|---|
| 6465 | 24107 | 0.1m |

Cutting plane ANSYS design modular

Model
Subject:
Date Monday, July 18, 2022
Comments:

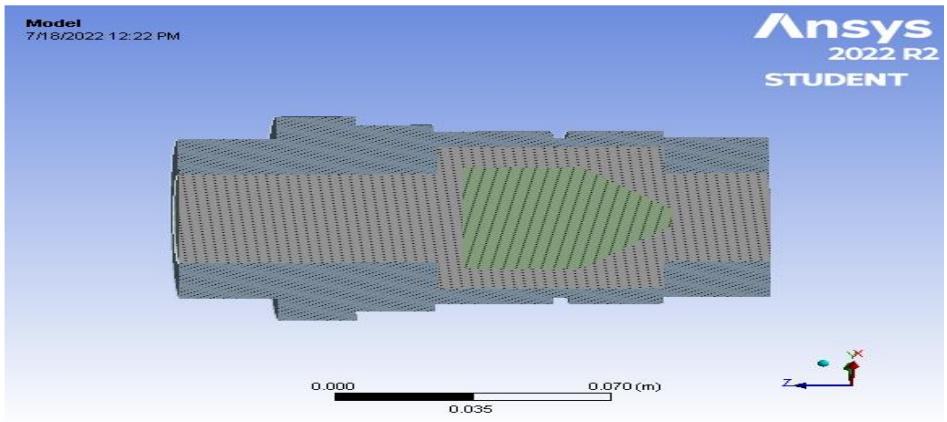



Figure 3.21 automatic brake bleed cutting plane

**C. Fluid mechanics analysis in ANSYS of automatic brake bleeding**

Velocity counter

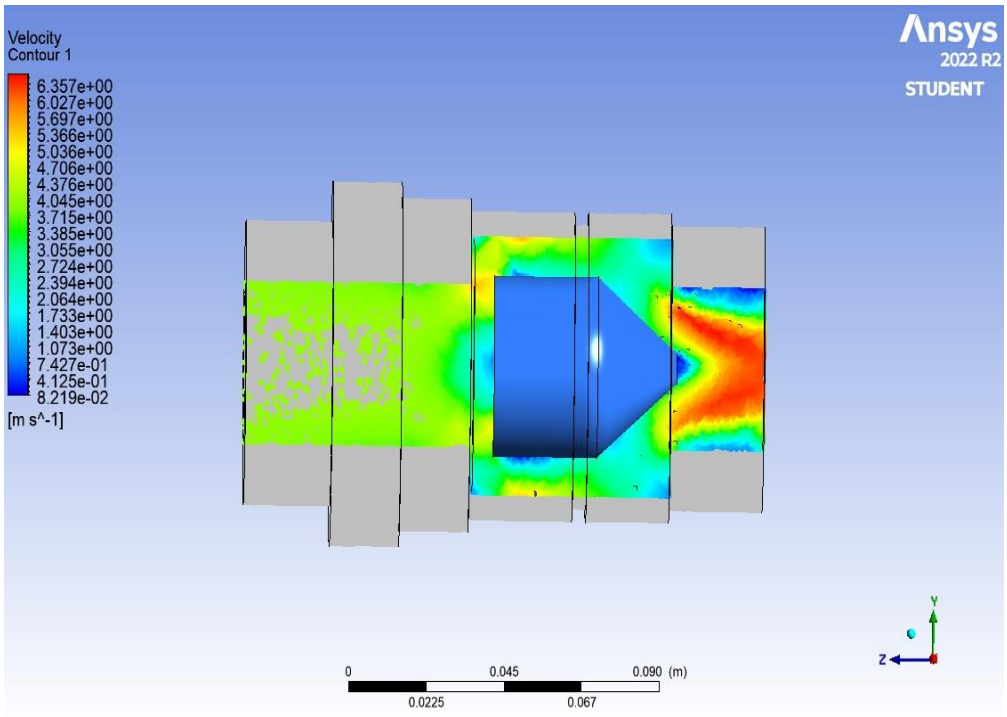



Figure3.22. velocity counter in ANSYS design module

Temperature counter

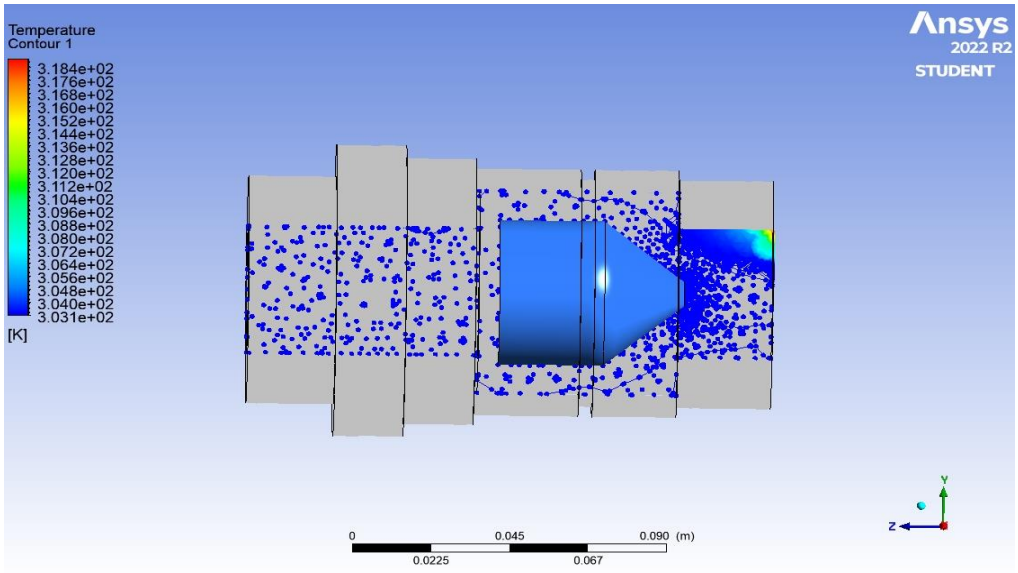



Figure 3.23. Temperature country in ANSYS design model

Velocity stream line

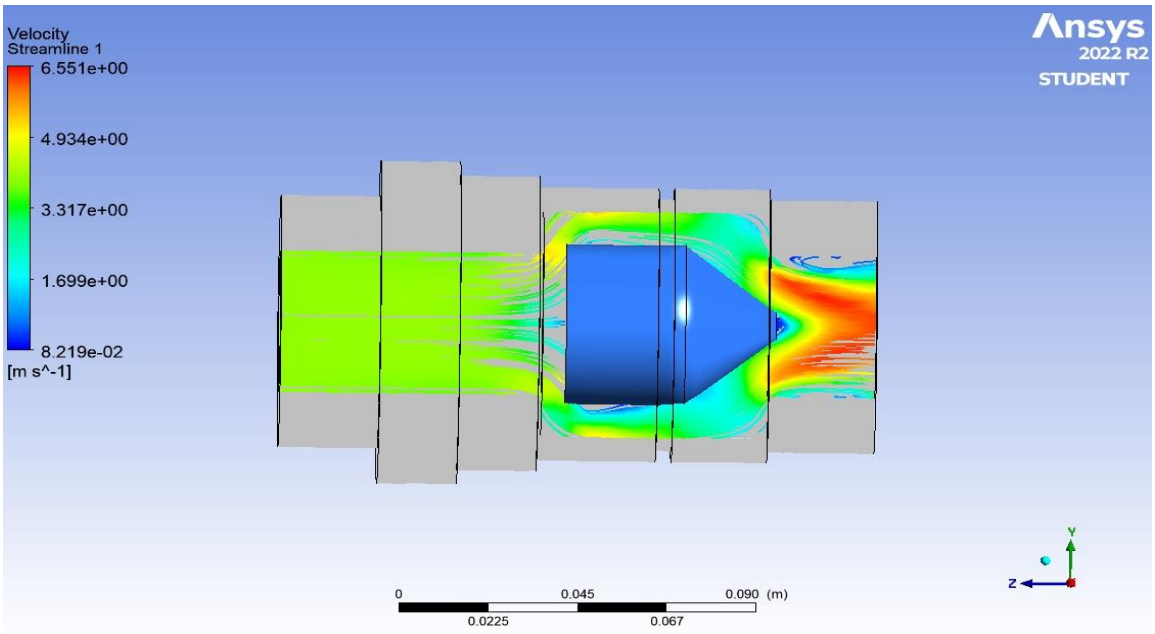



Figure 3.24. Velocity stream line in ANSYS design model

### 4.3. Development of model

- ❖ Automatic air bleeding system is developed for TOYOTA 3K light vehicle.
- ❖ The part drawings of each and every part of the system are prepared.
- ❖ The material are selected as per the criteria of availability, durability etc.
- ❖ The prototype was constructed to demonstration of the working principle.
- ❖ The functionality is successfully demonstrated.

### 4.4. The raise in heat on Each Wheel and vehicle speed

The heat difference on each wheel is used as a reference for the balance of brake performance. The temperature difference will be below or equal to the temperature difference based on the results of calculations carried out on the specifications of the vehicle if the brakes work normally. In braking on a straight road, the temperature difference between one of the rear wheel brakes and one of the brakes on the front wheel can be shown in Table 4.2 shows variation of the brake heat in the rear with the front.

Table 4.2 the relationship between vehicle speed and heat generates

| V($km/hr$) | Heat generated kcal | Selected wheel |
|---|---|---|
| 40 | 346.57 | Front wheel |
| 60 | 519.7 | Front wheel |
| 80 | 693.14 | Front wheel |
| 100 | 866.58 | Front wheel |

# CHAPTER FIVE
# CONCLUSION AND RECOMMENDATION

## 5.1. Summary

The entrapped air bubble in hydraulic brake system if not bleed properly, effects the efficiency of the brake system. Due to this, the vehicle cannot be stopped within the intended distance and may meet collision, which causes property damage, injuries etc. To solve the problem of air bleeding, an automatic air bleeding system is designed and developed which helps in automatic bleeding of air and improving the efficiency.

## 5.2. Conclusions

The entrained air in hydraulic systems is complex as air can be dissolved into the hydraulic fluid. The amount depends on the static pressure. There with, the amount of entrained air inside the fluid changes with a change in pressure. The most important parameter in hydraulic systems, the pressure build-up and release, first a mass transfer between entrained and dissolved air was developed and presented in this thesis. The bulk modulus of the fluid is the property that indicates the springiness of the fluid and is defined as the pressure needed to cause a given decrease in volume. Typical oil will decrease in volume for every increase in pressure. When air bubbles are entrained in the hydraulic oil, the bulk modulus drops and the fluid becomes springy. The solution was to bleed the brake system, which releases the trapped air so that the brake fluid becomes stiff again. Another way that the fluid can change properties if the pressures fall below the vapor pressure of the fluid causing the formation of vapor bubbles.

## 5.3. Recommendation

- ✓ It is recommended to implement on the light vehicles.
- ✓ It is recommended to use the system for demonstration of the working principle.
- ✓ Interested research can manufacture and assemble the automatic brake bleeding to the light vehicle.

## 5.4. Future work

Simulation of the bleeding system is to be done for understanding the behaviour of the fluid under different operating conditions of the brake system. Detailed design and analysis of the components are to be done further.

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# APPENDIXES

## Appendix A. Part Drawing

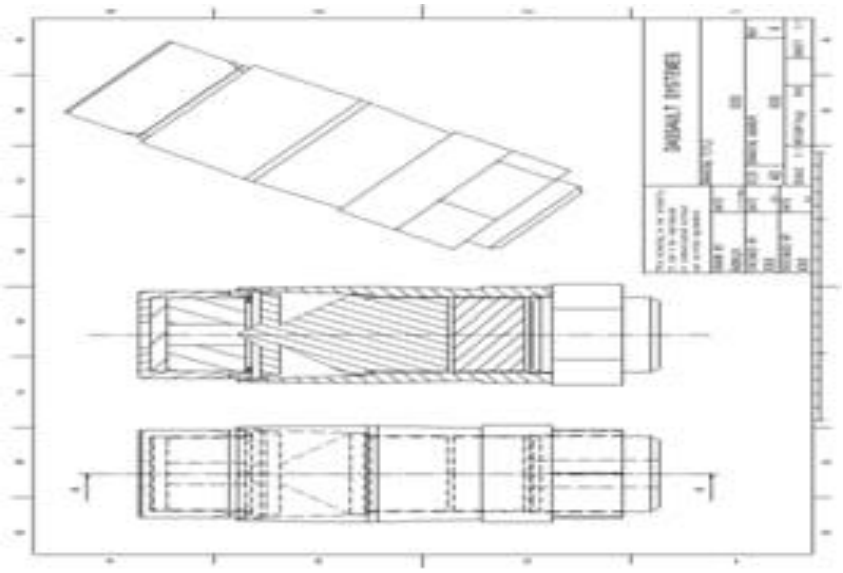


Figure A.1. Section view

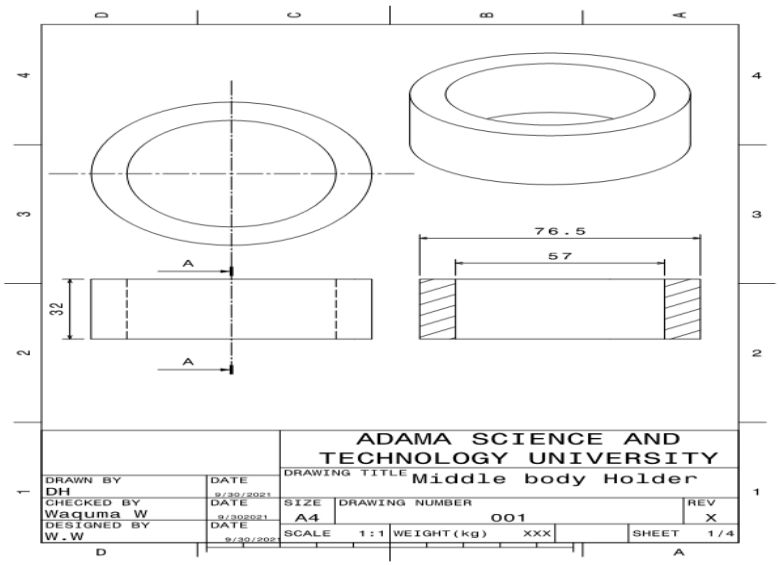



Figure A.2. Midle part drawing

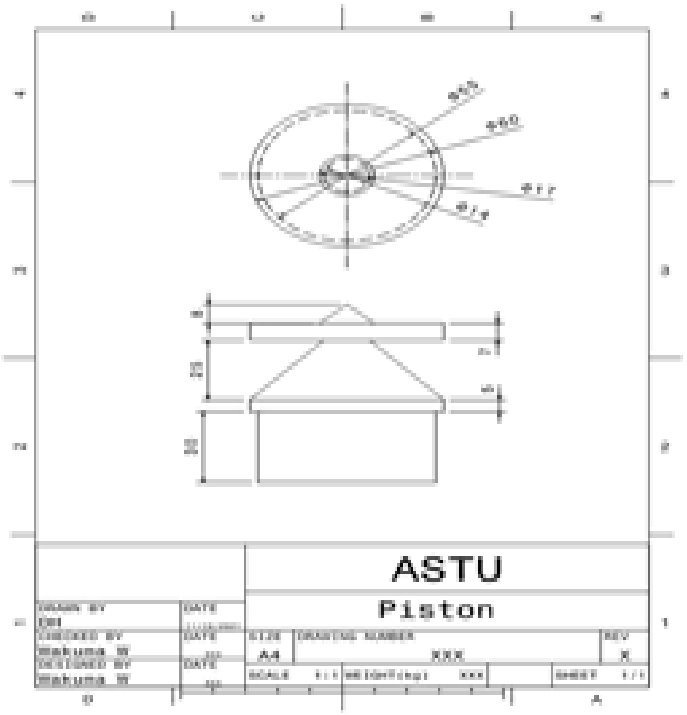



Figure A.3.Piston drawing

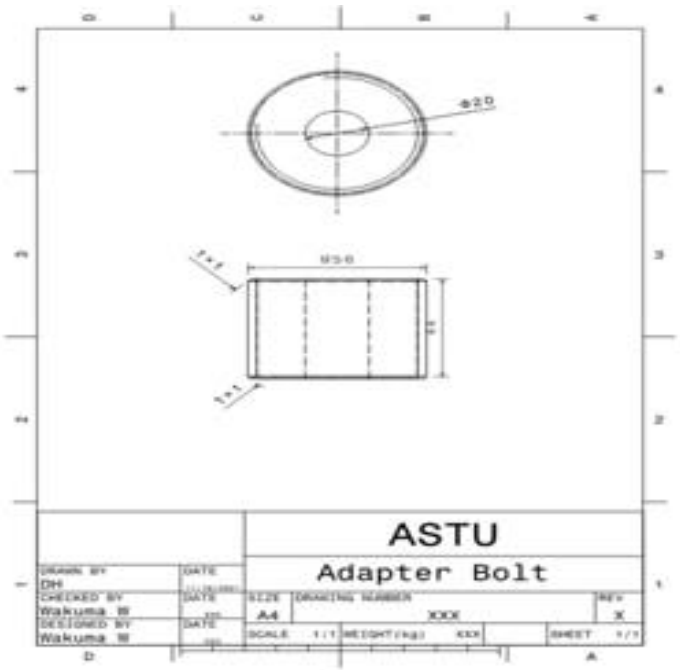



Figure A.4. Adapter drawing

## Appendix B. Model of The Parts

Figure B.1. Piston

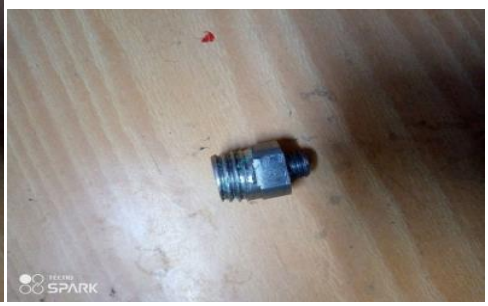


Figure B.2. Adaptor Connector

Figure B.3. Upper Vent Hole

Figure B.4.Sleav

Figure B.5.Top view of hole

Figure B.6.Cap

Figure B.7.side view of hose

Figure B.8.Piston site

## Appendix C. Assemble Picture of Prototype

A / measuring length

B / measuring diameter

C / measuring angle

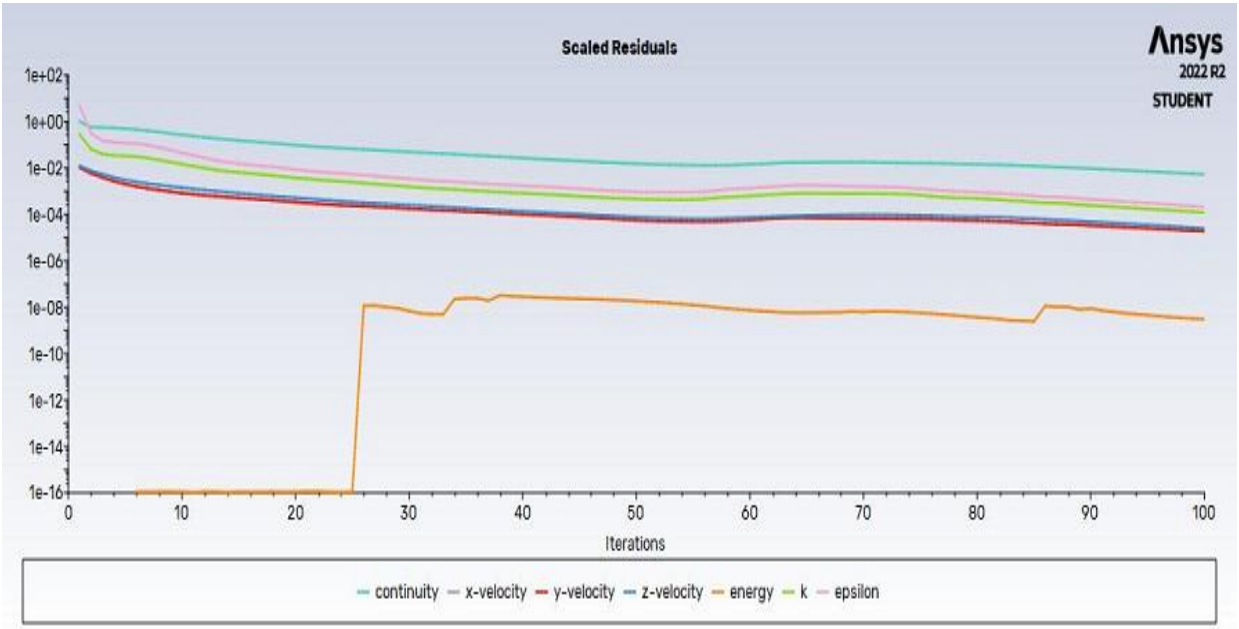
D / milling head

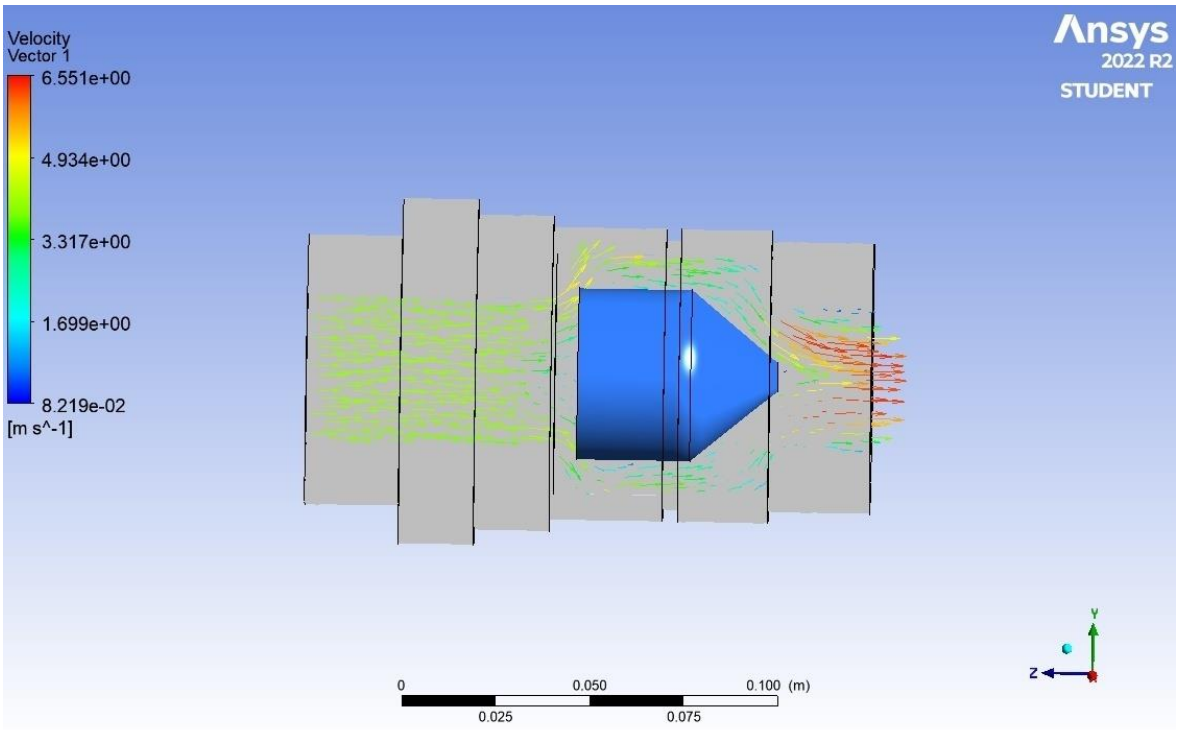
E / Turning

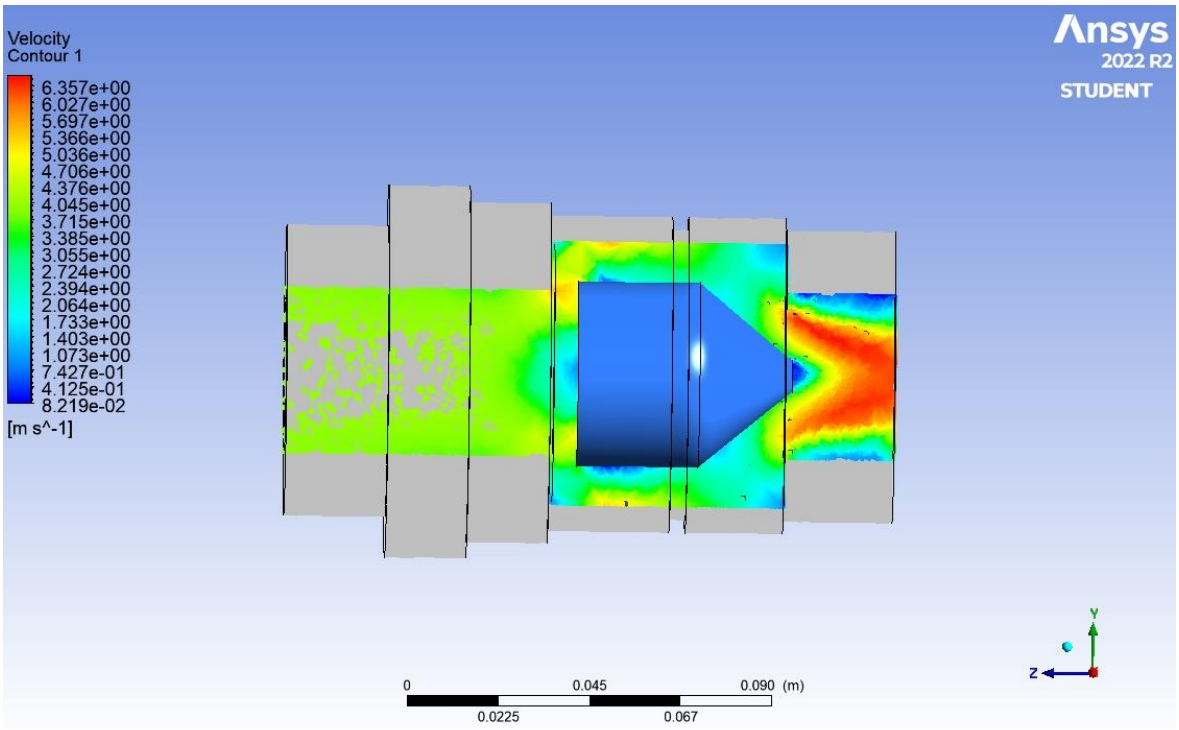
F / Grinding

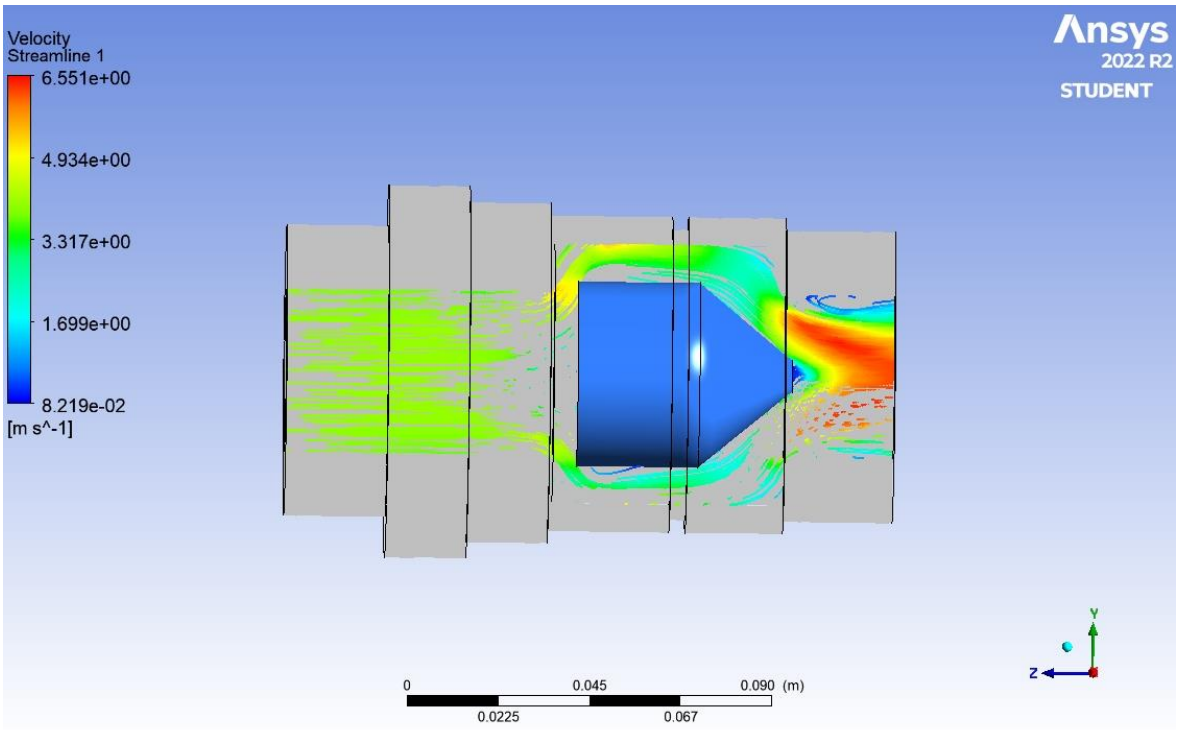
G / Assembled prototype H / final product of prototype

## Appendix D. Software results




Velocity
Vector 1
6.551e+00
4.934e+00
3.317e+00
1.699e+00
8.219e-02
[m s^-1]
Ansys
2022 R2
STUDENT
0
0.050
0.100 (m)
0.025
0.075
Y
Z


Velocity
Contour 1
6.357e+00
6.027e+00
5.697e+00
5.366e+00
5.036e+00
4.706e+00
4.376e+00
4.045e+00
3.715e+00
3.385e+00
3.055e+00
2.724e+00
2.394e+00
2.064e+00
1.733e+00
1.403e+00
1.073e+00
7.427e-01
4.125e-01
8.219e-02
[m s^-1]
Ansys
2022 R2
STUDENT
0
0.045
0.090 (m)
0.0225
0.067
Y
Z




| | |
|---|---|
| Unit System | Metric (m, kg, N, s, V, A) Degrees rad/s Celsius |
| Angle | Degrees |
| Rotational Velocity | rad/s |
| Temperature | Celsius |

Model (A3)

**TABLE 2**
**Model (A3) > Geometry Imports**

| Object Name | *Geometry Imports* |
|---|---|
| State | Solved |

**TABLE 3**
**Model (A3) > Geometry Imports > Geometry Import (A2)**

| | |
|---|---|
| Object Name | *Geometry Import (A2)* |
| State | Solved |
| **Definition** | |
| Source | C:\Users\pc\Desktop\ANSYS SW S VERSION\excerci\Design3.scdoc |
| Type | Space Claim |
| **Basic Geometry Options** | |
| Parameters | Independent |
| Parameter Key | |
| **Advanced Geometry Options** | |
| Compare Parts On Update | No |
| Analysis Type | 3-D |

Geometry

**TABLE 4**
**Model (A3) > Geometry**

| | |
|---|---|
| Object Name | *Geometry* |
| State | Fully Defined |
| **Definition** | |
| Source | C:\Users\pc\Desktop\ANSYS SW S VERSION\excerci\Design3.scdoc |
| Type | Space Claim |
| Length Unit | Meters |
| **Bounding Box** | |
| Length X | 9.2e-002 m |
| Length Y | 9.2e-002 m |

| | |
|---|---|
| Length Z | 0.15 m |
| **Properties** | |
| Volume | 7.2981e-004 m³ |
| Scale Factor Value | 1. |
| **Statistics** | |
| Bodies | 3 |
| Active Bodies | 3 |
| Nodes | 6465 |
| Elements | 24107 |
| Mesh Metric | None |
| **Update Options** | |
| Assign Default Material | No |
| **Basic Geometry Options** | |
| Solid Bodies | Yes |
| Surface Bodies | Yes |
| Line Bodies | Yes |
| Parameters | Independent |
| Parameter Key | |
| Attributes | Yes |
| Attribute Key | |
| Named Selections | Yes |
| Named Selection Key | |
| Material Properties | Yes |
| **Advanced Geometry Options** | |

| | |
|---|---|
| Use Associativity | Yes |
| Coordinate Systems | Yes |
| Coordinate System Key | |
| Reader Mode Saves Updated File | No |
| Use Instances | Yes |
| Smart CAD Update | Yes |
| Compare Parts On Update | No |
| Analysis Type | 3-D |
| Mixed Import Resolution | None |
| Import Facet Quality | Source |
| Clean Bodies On Import | No |
| Stitch Surfaces On Import | None |
| Decompose Disjoint Geometry | Yes |
| Enclosure and Symmetry Processing | No |

**TABLE 5**
**Model (A3) > Geometry > Parts**

| Object Name | *Volume\Volume* | *Design3\Solid* | *Design3\Solid* |
|---|---|---|---|
| State | Meshed | | |
| **Graphics Properties** | | | |
| Visible | Yes | | |
| Transparency | 1 | | |
| **Definition** | | | |
| Suppressed | No | | |

| | | | |
|---|---|---|---|
| Coordinate System | Default Coordinate System | | |
| Treatment | None | | |
| Reference Frame | Lagrange | | |
| **Material** | | | |
| Assignment | | | |
| Fluid/Solid | Defined By Geometry (Solid) | | |
| **Bounding Box** | | | |
| Length X | 6.4e-002 m | 9.2e-002 m | 4.6e-002 m |
| Length Y | 6.4e-002 m | 9.2e-002 m | 4.6e-002 m |
| Length Z | 0.15 m | | 5.3e-002 m |
| **Properties** | | | |
| Volume | 2.3503e-004 m³ | 4.2958e-004 m³ | 6.5199e-005 m³ |
| Centroid X | 1.8195e-018 m | 4.521e-019 m | -6.165e-009 m |
| Centroid Y | 3.0449e-007 m | -1.4673e-006 m | -1.1169e-007 m |
| Centroid Z | -2.1529e-002 m | -7.4313e-003 m | -3.4143e-002 m |
| **Statistics** | | | |
| Nodes | 3026 | 2179 | 1260 |
| Elements | 14295 | 8776 | 1036 |
| Mesh Metric | None | | |
| **CAD Attributes** | | | |
| PartTolerance: | 0.00000001 | | |
| Color:143.143.175 | | | |
| Color:143.175.143 | | | |

**TABLE 6**
**Model (A3) > Materials**

| | |
|---|---|
| Object Name | *Materials* |
| State | Fully Defined |
| **Statistics** | |
| Materials | 0 |
| Material Assignments | 0 |

Coordinate Systems

**TABLE 7**
**Model (A3) > Coordinate Systems > Coordinate System**

| | |
|---|---|
| Object Name | *Global Coordinate System* |
| State | Fully Defined |
| **Definition** | |
| Type | Cartesian |
| Coordinate System ID | 0. |
| **Origin** | |
| Origin X | 0. m |
| Origin Y | 0. m |
| Origin Z | 0. m |
| **Directional Vectors** | |
| X Axis Data | [ 1. 0. 0. ] |
| Y Axis Data | [ 0. 1. 0. ] |
| Z Axis Data | [ 0. 0. 1. ] |

Connections

**TABLE 8**
**Model (A3) > Connections**

| | |
|---|---|
| Object Name | *Connections* |
| State | Fully Defined |
| **Auto Detection** | |
| Generate Automatic Connection On Refresh | Yes |
| **Transparency** | |
| Enabled | Yes |

**TABLE 9**
**Model (A3) > Connections > Contacts**

| | |
|---|---|
| Object Name | *Contacts* |
| State | Fully Defined |
| **Definition** | |
| Connection Type | Contact |
| **Scope** | |
| Scoping Method | Geometry Selection |
| Geometry | All Bodies |
| **Auto Detection** | |
| Tolerance Type | Slider |
| Tolerance Slider | 0. |
| Tolerance Value | 4.9641e-004 m |
| Use Range | No |
| Face/Face | Yes |
| Face-Face Angle Tolerance | 75. ° |

| | |
|---|---|
| Face Overlap Tolerance | Off |
| Cylindrical Faces | Include |
| Face/Edge | No |
| Edge/Edge | No |
| Priority | Include All |
| Group By | Bodies |
| Search Across | Bodies |
| **Statistics** | |
| Connections | 2 |
| Active Connections | 2 |

**TABLE 10**
**Model (A3) >Connections > Contacts > Contact Regions**

| Object Name | *Contact Region* | *Contact Region 2* |
|---|---|---|
| State | Fully Defined | |
| **Scope** | | |
| Scoping Method | Geometry Selection | |
| Contact | 5 Faces | 4 Faces |
| Target | 5 Faces | 4 Faces |
| Contact Bodies | Volume\Volume | |
| Target Bodies | Design3\Solid | |
| Protected | No | |
| **Display** | | |
| Element Normals | No | |
| **Advanced** | | |

| | |
|---|---|
| Small Sliding | Program Controlled |

Mesh

**TABLE 11**
**Model (A3) > Mesh**

| | |
|---|---|
| Object Name | *Mesh* |
| State | Solved |
| **Display** | |
| Display Style | Use Geometry Setting |
| **Defaults** | |
| Physics Preference | CFD |
| Solver Preference | Fluent |
| Element Order | Linear |
| Element Size | 0.1 m |
| Export Format | Standard |
| Export Preview Surface Mesh | No |
| **Sizing** | |
| Use Adaptive Sizing | No |
| Growth Rate | Default (1.2) |
| Max Size | Default (0.2 m) |
| Mesh Defeaturing | Yes |
| Defeature Size | Default (5.e-004 m) |
| Capture Curvature | Yes |
| Curvature Min Size | Default (1.e-003 m) |
| Curvature Normal Angle | Default (18.0°) |
| Capture Proximity | No |

| | |
|---|---|
| Bounding Box Diagonal | 0.19856 m |
| Average Surface Area | 3.5061e-003 m² |
| Minimum Edge Length | 2.5133e-002 m |
| **Quality** | |
| Check Mesh Quality | Yes, Errors |
| Target Skewness | Default (0.9) |
| Smoothing | Medium |
| Mesh Metric | None |
| **Inflation** | |
| Use Automatic Inflation | None |
| Inflation Option | Smooth Transition |
| Transition Ratio | 0.272 |
| Maximum Layers | 5 |
| Growth Rate | 1.2 |
| Inflation Algorithm | Pre |
| View Advanced Options | No |
| **Advanced** | |
| Number of CPUs for Parallel Part Meshing | Program Controlled |
| Straight Sided Elements | |
| Rigid Body Behavior | Dimensionally Reduced |
| Triangle Surface Mesher | Program Controlled |
| Topology Checking | Yes |
| Pinch Tolerance | Default (9.e-004 m) |
| Generate Pinch on Refresh | No |

| Statistics | |
|---|---|
| Nodes | 6465 |
| Elements | 24107 |

Named Selections

**TABLE 12**
**Model (A3) > Named Selections > Named Selections**

| Object Name | *INLET* | *OUTLET* | *CYLINDER WALL* | *PISTON* |
|---|---|---|---|---|
| State | Fully Defined | | | |
| **Scope** | | | | |
| Scoping Method | Geometry Selection | | | |
| Geometry | 1 Face | | 1 Body | |
| **Definition** | | | | |
| Send to Solver | Yes | | | |
| Protected | Program Controlled | | | |
| Visible | Yes | | | |
| Program Controlled Inflation | Exclude | | | |
| **Statistics** | | | | |
| Type | Manual | | | |
| Total Selection | 1 Face | | 1 Body | |
| Surface Area | 1.2468e-003 m² | | | |
| Suppressed | 0 | | | |
| Used by Mesh Worksheet | No | | | |