UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS[υ]

JUDUL: DEVELOPMENT SCALE MODEL OF STEAM ENGINE WITH STEPHENSON GEARING SYSTEM

SESI PENGAJIAN: 2007/2008

Saya **ZULHELMI BIN ZAINAL**

mengaku membenarkan tesis (PSM/Sarjana/Doktor Falsafah)* ini disimpan di Perpustakaan Universiti Malaysia Pahang dengan syarat-syarat kegunaan seperti berikut:

1. *Tesis adalah hakmilik Universiti Malaysia Pahang.*
2. Perpustakaan Universiti Malaysia Pahang dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh Organisasi/badan dimana penyelidikan dijalankan)

☑ TIDAK TERHAD

NURUL SHAHIDA BINTI MOHD SHALAHIM
LECTURER
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG
LOCKED BAG 12
25000 KUANTAN, PAHANG
TEL : 012-5100420 FAX : 09-549 2244

(TANDATANGAN PENULIS) | (TANDATANGAN PENYELIA)

Alamat Tetap: 150, Batu 15 ½ Air Hitam
84060 Muar , Johor

Nama Penyelia: Nurul Shahida Bte Mohd Shalahim

Tarikh : 21 November 2007

Tarikh : 21 November 2007

CATATAN: * Potong yang tidak berkenaan
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD
υ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM)

DEVELOPMENT SCALE MODEL OF STEAM ENGINE WITH STEPHENSON GEARING SYSTEM

ZULHELMI BIN ZAINAL

A report submitted in partial fulfillment
of the requirements for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
Universiti Malaysia Pahang

NOVEMBER 2007

I declare that this thesis entitled "*Development Scale Model of Steam Engine with Stephenson Gearing System*" is the result of my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Zulhelmi Bin Zainal
Date	:	21 November 2007

Dedicated to my beloved

Father, Zainal Bin Md. Amin

Mother, Maimunah Bte Sukar

Brothers & Sister

Supervisor,

Friends,

And all the person involve to finish this research

ACKNOWLEGDEMENT

In preparing this thesis, I was in contact with many people, lecturers, colleagues and academicians. They have contributed theirs thought, opinions, advisory and supervisory in order to complete this thesis. I would like to give my appreciate the most to my supervisor, Mrs. Nurul Shahida Bt Mohd Shalahim for encourage, guidance, critics and motivation. Without their contribution and support, this thesis would not be complete and presented as here.

My fellow colleagues also deserved best appreciation for their contribution and help while conducting the experiment and also provided assistance at various occasions. I also grateful to my family members especially my parents for their understanding, moral and financial support. Their continues support give me motivation to succeed and completing this thesis.

ABSTRACT

This Final Year Project is about development scale model of steam engine with Stephenson Gearing System. Steam engine is device that use steam power to produce mechanical energy for a variety application. In actual operations, steam engine operates with low efficiency because of the bad management of steam intake and steam exhaust at the engine cylinder. This major problem can be encounter by equipping the Stephenson Gearing System at the steam engine. The objectives of this project are to design the steam engine components base on Mechanical Principles of Steam Engine and to investigate the Stephenson Gearing System operation in order to increase steam engine efficiency. All of the designed components are analyze with the calculation analysis of steam engine and the effectiveness of Stephenson Gearing System is showing in the motion simulation of the steam engine. Then best manufacturing process to fabricate this steam engine is discussed and this will help during fabrication session. So, the scale model of steam engine is ready to fabricate if the analysis and simulation on scale model of steam engine produce the positive results.

ABSTRAK

Projek tahun akhir ini adalah berkaitan dengan pembangunan model engin wap berskala dengan dilengkapi oleh Sistem Sawat Stephenson. Engin wap adalah sejenis alat yang mengunakan kuasa wap untuk menghasilkan tenaga mekanikal untuk perbagai pengunaan. Dalam keadaan sebanar, engin wap berfungsi dengan tidak cekap disebabkan masalah pengurusan masuk dan keluar wap ke dalam silinder engin. Masalah utama ini dapat diatasi dengan melengkapi engin wap ini dengan Sistem Sawat Stephenson. Tujuan projek ini adalah untuk mereka bentuk komponen-komponen enjin wap berdasarkan Prinsip-prinsip Mekanikal bagi Engin Wap dan menyiasat operasi Sistem Sawat Stephenson dalam meningkatkan kecekapan engin wap. Kesemua komponen enjin wap dianalisis dengan mengunakan analisis pengiraan untuk engin wap keberkesanan Sistem Sawat Stephenson dapat dilihat pada simulasi pergerakan enjin wap ini. Proses pembuatan terbaik untuk menghasilkan enjin wap ini akan dibincangkan dan ini akan membantu semasa sesi pembuatan. Dengan ini, engin wap in dapatlah direka bentuk jika analisis dan simulasi terhadap model enjin wap ini menghasilkan keputusan yang baik.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF SYMBOLS

D	-	Bigger diameter
d	-	Smaller diameter
P	-	Boiler pressure
L	-	Length
f	-	Safe fiber stress
t	-	Thickness

LIST OF ABBREVIATION

lb	-	Pounds
inch	-	Inches
rpm	-	Revolution per minutes
hr	-	Hours
ft	-	Feet

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Steam engine is mechanical device used to transfer the energy of steam into mechanical energy for a variety of applications, including propulsion and generating electricity. The basic principle of the steam engine involves transforming the heat energy of steam into mechanical energy by permitting the steam to expand and cool in a cylinder equipped with a movable piston. Steam that is to be used for power or heating purposes is usually generated in a boiler. The simplest form of boiler is a closed vessel containing water, which is heated by a flame so that the water turns to saturated steam. The ordinary household heating system usually has a boiler of this type.

Early industrial steam engines were designed by Thomas Savery in 1698 but it was Thomas Newcomen and his atmospheric engine of 1712 that demonstrated the first operational and practical industrial engine. Together, Newcomen and Savery developed a beam engine that worked on the atmospheric, or vacuum, principle. The first industrial applications of the vacuum engines were in the pumping of water from deep mineshafts. In mineshaft pumps the reciprocating beam was connected to an operating rod that descended the shaft to a pump chamber. The oscillations of the operating rod are transferred to a pump piston that moves the water, through check valves, to the top of the shaft

In 1769 James Watt, another member of the Lunar Society, patented the first significant improvements to the Newcomen type vacuum engine that made it much more fuel efficient. Watt's leap was to separate the condensing phase of the vacuum engine into a separate chamber, while keeping the piston and cylinder at the temperature of the steam. Additionally, unlike the Newcomen engine, the Watt engine operated smoothly enough to be connected to a drive shaft to provide rotary power. In early steam engines the piston is usually connected to a balanced beam, rather than directly to a connecting rod, and these engines are therefore known as beam engines.

Steam engines still develop by scientist and engineer until now because steam engine is one of the potential alternative energy. Since industrial revolution period, steam engine developer was noticed that steam engines have their own advantages where useful to current technology applications and have the tremendous potential to improve their performance for future industrial technology applications. [5]

There are many advantages when using steam engine in high technology and industrial applications. Current technology such as vehicle technology was contribute big percentage of pollutions and results the green house effect. By developing and use steam engines in daily applications, this problem can be dike and our environment will become fresh and safe again. [6]

Steam engines also have the unique advantage and behavior. This engine will run quietly and very environmental friendly comparing with current engine. Today, the petroleum become decrease and the fuels become limited. This phenomenon is very hard situations because, mostly, current engine used gasoline as a fuel and cannot receive another fuel to operate it. But, a good new is, steam engine can run on a choice of fuel and the development of steam engines is the solution of fuel problem. [5]

Another ability of steam engines is, it can run without the transmissions and this special behavior promise long life with low maintenance of steam engines.This tremendous advantage of steam engines was giving inspirations to me to develop the scale model of steam engine model. In this project, steam engine will design and analyze. The basic principles and Mechanical Principles of Steam Engine will apply in the design to make sure the steam engine can operate wisely and successfully at the end.

1.2 Problem Statement

In actual operation, steam engine always produces clearance volume on the cycle and it shown in the indicator diagram of cylinder pressure against cylinder volume. They are different because of the following reasons.

Firstly, the pressure is drop in the steam line and produce the throttling effect of the valves. The result is pressure of the steam at entry is less than the boiler pressure, and falls slightly until cut-off occurs. Then the valve closure is not instantaneous, therefore, cut off is not a definite point.

At release stroke, the valve take time to open, this produces the rounded tip of diagram. The exhaust valves closes before the end of the stroke, trapping a quantity of steam in the cylinder. This steam acts as a cushion thereby relieving stresses in the piston rod. The live steam is admitted before the end of the exhaust stroke.

All the above limitations have the effect of reducing the effective area of the diagram. This means the improvement in steam cycles is desirable to increase the performance and efficiency of steam engine.

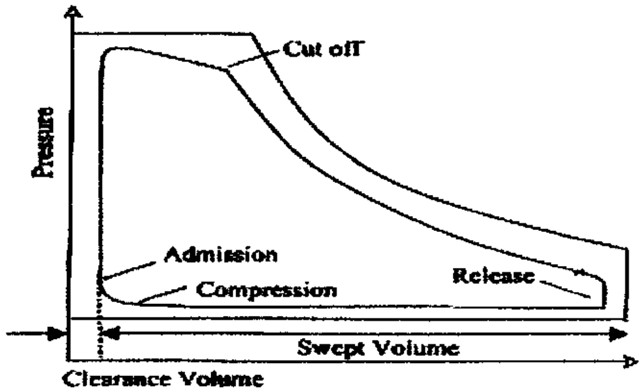


Figure 1.1: Indicator diagram of steam cycle

1.3 Project Objectives

i. To develop the scale model and components of steam engine that can use as a reference for steam engine fabrication.

ii. To incorporate the Stephenson Gearing System in the scale model of steam engine and to proof that this gearing system can increase the cut-off timing performance of sliding valve.

1.4 Project Scopes

i. Literature study and conceptual steam engine.

ii. Modeling the steam engine by using SolidWorks 2005 software.

iii. Calculations analysis on the designed steam engine components.

iv. Investigate the operation of Stephenson Gearing System by applying COSMOS Motion 2003 on steam engine model.

1.5 Thesis Depositions

This project is about the development scale model of steam engine with Stephenson Gearing System. All of the project information is described in this report was divided in six chapters. The purpose of these chapters is to grouping the similar information in the same chapter and also to show the different between the information.

Chapter 1 is explaining about the project introduction, including project background, problem statements, project objectives and project scopes. Chapter 2 is about literature review and this chapter explaining about the main concept in developing scale model of steam engine. This chapter also reviews the existing steam engine and described about their specifications.

Methodology of this project is described in chapter 3. The methodology is summarizing in the flow chart form where the flow chart shows the beginning step until the final step in developing scale model of steam engine. Chapter 4 is about the discussions on theoretical calculation analysis of the designed components of steam engine. This chapter also discuss about the operation of Stephenson Gearing System in order to increase the cut-off timing performance of sliding valve. In this chapter we will know whether the model design of steam engine followed the Mechanical Principles of Steam Engine or not. The manufacturing process to fabricate this engine will be described in this chapter.

The steam engine model can be fabricated when the analysis results proportional with the Mechanical Principles of Steam Engine. Finally, the conclusion and recommendations for developing scale model of steam engine project is described in chapter 6. In this chapter, whole of the project progress and problem will explain details and from this report, the project status will be known.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is purpose to explain about the conceptual and principles on developing scale model of steam engine. The steam engines that exist today also will review in this chapter and the potential concept of steam engine will be select to modeling the steam engine. In the end of this chapter, the desire concept on developing scale model of steam engine will be propose and this concept will be apply in modeling steam engine.

2.2 Steam Engine Definition

A steam engine is an external combustion heat engine that makes use of the heat energy that exists in steam, converting it to mechanical work. Steam engines were used as the prime mover in pumping stations, locomotives, steam ships, traction engines, steam lorries and other road vehicles.

They were essential to the Industrial Revolution and saw widespread commercial use driving machinery in factories and mills, although most have since been superseded by internal combustion engines and electric motors. Steam turbines, technically a type of steam engine, are still widely used for generating electricity. About 86 % of all electric power in the world is generated by use of steam turbines.

A steam engine requires a boiler to heat water into steam. The expansion of steam exerts force upon a piston or turbine blade, whose motion can be harnessed for the work of turning wheels or driving other machinery. One of the advantages of the steam engine is that any heat source can be used to raise steam in the boiler, but the most common is a fire fueled by wood, coal or oil or the heat energy generated in a nuclear reactor. [5]

2.3 Reciprocating Engine

Reciprocating engines use the action of steam to move a piston in a sealed chamber or cylinder. The reciprocating action of the piston can be translated via a mechanical linkage into either linear motion, usually for working water or air pumps, or else into rotary motion to drive the flywheel of a stationary engine, or else the wheels of a vehicle. [5]

2.3.1 Vacuum Engine

Early steam engines, or fire engines as they were at first called such as atmospheric and Watt's condensing engines, worked on the vacuum principle and are thus known as vacuum engines. Such engines operate by admitting low pressure steam into an operating chamber or cylinder. The inlet valve is then closed and the steam cooled, condensing it to a smaller volume and thus creating a vacuum in the cylinder. The upper end of the cylinder being open to the atmospheric pressure operates on the opposite side of a piston, pushing the piston to the bottom of the cylinder. The piston is connected by a chain to the end of a large beam pivoted near its middle. A weighted force pump is connected by a chain to the opposite end of the beam which gives the pumping stroke and returns the piston to the top of the cylinder by force of gravity, the low pressure steam being insufficient to move the piston upwards. [5]

2.3.2 *High Pressure Engine*

In a high pressure engine, steam is raised in a boiler to a high pressure and temperature and then admitted to a working chamber where it expands and acts upon a piston. The importance of raising steam under pressure is that it attains a higher temperature. Thus, any engine using such steam operates at a higher temperature differential than is possible with a low pressure vacuum engine. After displacing the vacuum engine, the high pressure engine became the basis for further development of reciprocating steam technology.

High pressure steam also has the advantage that engines can be much smaller for a given power range, and thus less expensive. There are also the benefits that steam engines then could be developed that were small enough and powerful enough to propel themselves while doing useful work. As a result, steam power for transportation became a practicality, most notably steam locomotives and ships, which revolutionized cargo businesses, travel, military strategy, and essentially every aspect of society at the time. [5]

2.3.2.1 Double Acting Engine

In the double-acting engine, steam is admitted alternately to each side of the piston while the other is exhausting. This requires inlet and exhaust ports at either end of the cylinder with steam flow being controlled by valves. This system increases the speed and smoothness of the reciprocation and allows the cylinder to be mounted horizontally or at an angle.

Power is transmitted from the piston by a sliding rod which in turn drives a connecting rod via a sliding crosshead. This in combination with the connecting rod converts the reciprocating motion to rotary motion. The inlet and exhaust valves have their reciprocating motion derived from the rotary motion by way of an additional crank mounted eccentrically from the drive shaft. The valve gear may include a reversing mechanism to allow reversal of the rotary motion. [5]

2.4 Steam Engine Review

2.4.1 Newcoman Atmospheric Engine

Newcoman atmospheric engine is first truly successful steam engine to drive a pump to remove water from mines. The engine is called an atmospheric engine because the greatest steam pressure used is near atmospheric pressure.

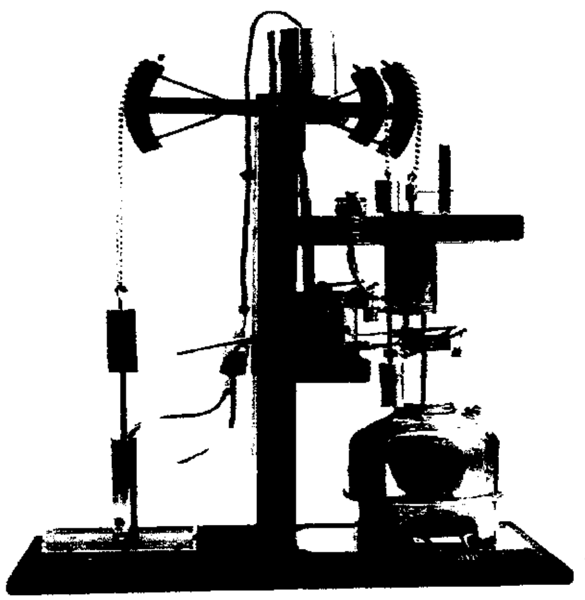


Figure 2.1: Newcoman atmospheric engine

The steam engine consists of a steam piston/cylinder that moves a large wooden beam to drive the water pump. The engine does not use steam pressure to push up the steam piston. Rather, the system is constructed so that the beam is heavier on the main pump side, and gravity pulls down the main pump side of the beam. Weights are added to the main pump side if necessary. The pumps in Figure 2 expel water on upward pump piston stroke, in agreement with the pumps used in the equipment at the time, and the discussion follows that design. In order to draw water into the main pump on the right side of the diagram, consider a cycle that starts with the beam tipped down on the right.

The cylinder below the steam piston is first filled with atmospheric pressure steam and then water is sprayed into the cylinder to condense the steam. The resulting vacuum pulls the steam piston down, pulling the main pump piston upwards, lifting the water above the main pump piston and filling the lower main pump chamber with water. At the bottom of the steam piston stroke, a valve opens to restore the steam cylinder to atmospheric pressure, and the beam tips down on the right by gravity, permitting the main piston to fall. As the main piston falls, the water from below the piston passes to the chamber above the piston as explained later. Atmospheric pressure steam enters the steam cylinder during this step, enabling the process to be repeated. [7]

2.4.2 Green Steam Engine

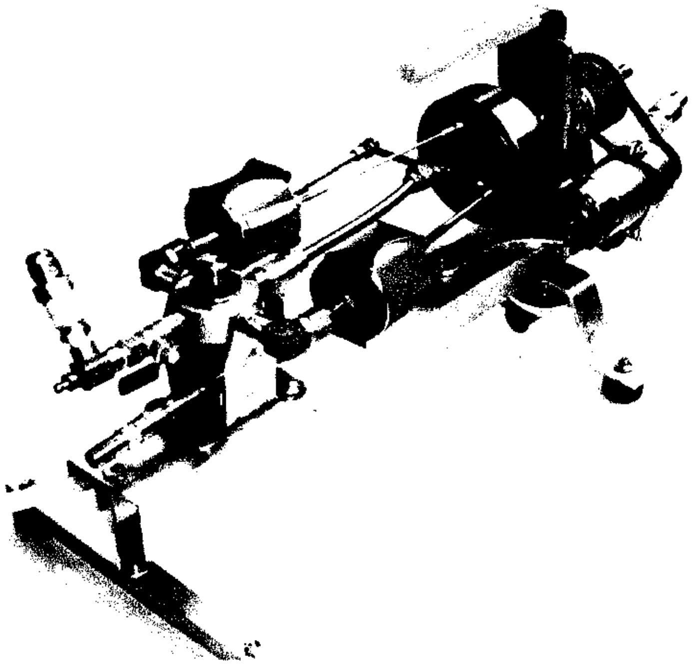


Figure 2.2: Green steam engine

Green steam engine is lightweight and compact alternative power generator exists today. A full size engine such as the one in the picture weighs as little as 5 lb yet produces ample power to run a boat or a generator. Its amazingly small profile allows it to be used in very small spaces.

This steam engine is piston engine type because of converting reciprocating movement into rotary movement. Robert Green used patented crank mechanism called "flexible rod transmission" to provide this engine with the advantage of eliminating the typical crankshaft and cam that requires lubrication and precision machining. It also provides the unique configuration whereby the cylinders are aligned in the same direction as the main shaft. The result is a compact, lightweight and slim engine that is extremely simple to construct and assemble.

The pistons and valves operate off a short piece of flexible shaft. Because the flexible shaft is fixed and cannot rotate, the piston rods and valve push rod are held in position while being reciprocated. The cylinders float, attached to a swivel ball fitting at their base. Much of the structure and weight of a typical steam engine has been eliminated.

The unique feature of the flexible rod transmission is that it produces an intermittent movement whereby the valve movement is stopped in its open and closed position during the power and exhaust strokes. This gives prolonged, fully opened valve timing. In compliment, the pistons are held stationary while the valve moves between phases. The output shaft continues rotation while the pistons stand still. The result is that the efficiency is increased dramatically. The overall friction of the engine is reduced due to the small number of light weight moving parts, and the use of ball bearings throughout. The flex rod is nearly frictionless as the flexing is like a spring in which the energy required to flex it is returned in equal amounts.

This engine may be made in a variety of configurations and sizes. For example, one can change piston size and stroke length in a matter of a couple of minutes. One cylinder may be substituted for an air pump cylinder to provide air or water pumping. It can have one or a plurality of cylinders without increasing the number of bearings. Modern materials and methods have been applied to this steam engine to achieve new results and to bring steam power up to date. [6]

2.4.3 Jensen Steam Engine

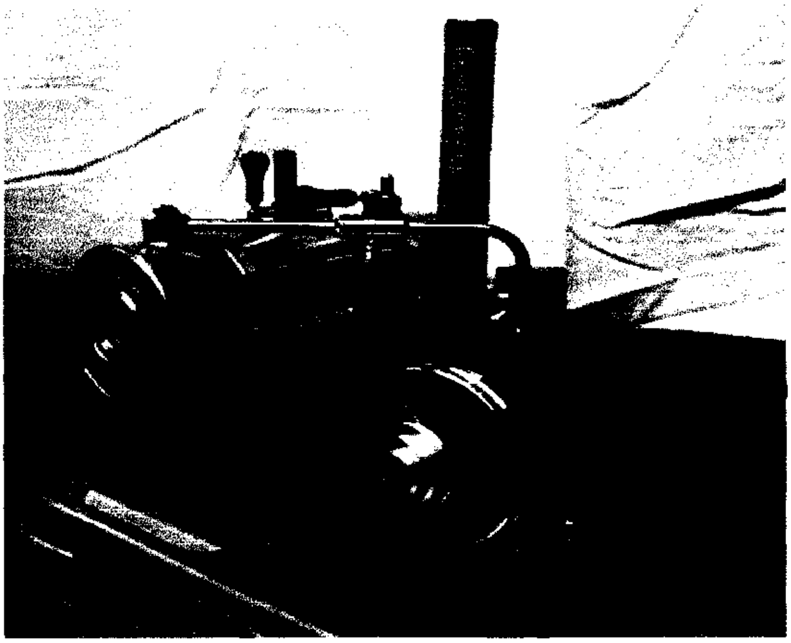


Figure 2.3: Jensen steam engine

The steam engine runs on steam pressure made by heating water in a boiler the same way water is boiled in a tea kettle. The first practical steam engines were built about 1700 and were used to pump water. Over the years steam engines where built to operate many types of equipment from autos, such as the Stanley Steamer, to farm tractors, trains and ships. The steam engine reached its peak use around 1900. [4]

2.4.4 Watt Steam Engine

Figure 2.4: Watt steam engine

Watt steam engine was used separated condenser in their steam engine. This invention was save much energy when to heat the cylinder. The Watt engine, like the Newcomen engine, operated on the principle of a vacuum pulling the steam piston down. However, Watt's steam cylinder remained hot at all times. Valves permitted the steam to be sucked into a separate condenser and then pumped along with any gases using the air pump. [5]

2.4.5 Stuart Steam Engine

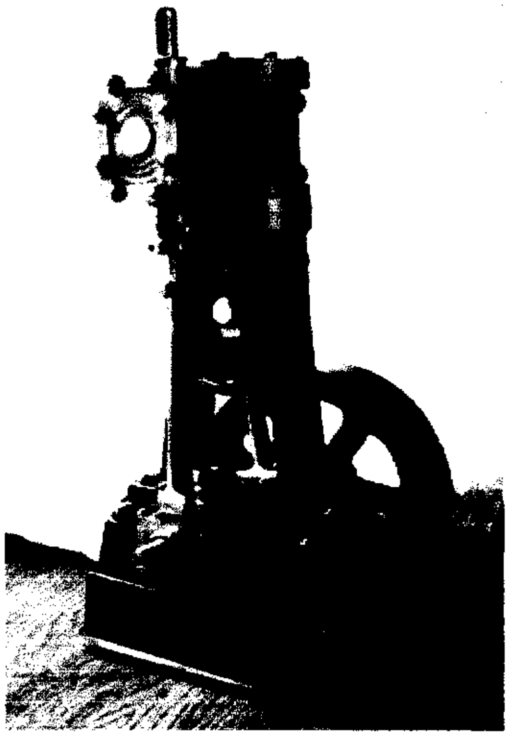


Figure 2.5: Stuart steam engine

The Stuart 10V has for many years been the most popular engine in our range. It is powerful enough to drive a 48 inch model steam boat. As with all Stuart Models finished engines it is supplied ready to run complete with a hand numbered certificate of authentication. The Stuart 10V is 6 inch height and operates with 3/4 inches cylinder bore and stroke. The flywheel is 3 inches in diameter.

The box bed, soleplate, standard, cylinder, valve chest and cover, top and bottom cylinder covers and flywheel are made from cast iron. The slide valve, piston, connecting rod, eccentric rod, valve operating block, glands, crosshead, crankshaft bearings, oil cups and drain cocks are made from brass. Steel is used in making the crankshaft, crank-webs, eccentric sheave, crosshead pin, piston and valve rods. [12]

2.5 Steam Engine Components and Materials

2.5.1 Valve Gear

The valve gear of a steam engine is the mechanism that operates the inlet and exhaust valves to admit steam into the cylinder and allow exhaust steam to escape, respectively, at the correct points in the cycle.

2.5.1.1 Stephenson Valve Gear

The Stephenson gear consists of the reverse lever, reach rod, lifting shaft, link hanger, link, eccentric, and rocker arm. The reversing lever is given a variety of forms, a good design of gearing system. This makes it possible to use very fine graduations of the quadrant and by making the latch as shown, the cut-off can be regulated by practically what amounts to all notches.

The reach rod, or reversing rod, is fastened to the reversing lever and consists of a simple piece of flat iron having a jaw at one end by which it serves to connect the reversing lever and the lifting shaft. The lifting shaft consists of a shaft held in brackets usually bolted to the engine frames to which are connected three arms, one being vertical and to which is attached the reach rod, and two horizontal ones from which the links are suspended.

The link hanger is a flat bar with a boss on each end. It carries the link by means of a pin attached to the link saddle. The link is an open device held by the saddle and fitted with connections for the eccentric rod. The eccentrics, usually of cast iron, are fitted to the main driving axle. The rocker arm consists of a shaft to which two arms are connected, the lower one of which is attached to the link block and the upper to the valve stem. [6]

Figure 2.6: Stephenson Valve Gear

2.5.1.2 Walschaert Valve Gear

The Walschaert valve gearing system produce the motion of the valve is obtained from the crosshead and an eccentric crank attached to the main crank pin. In some designs, the eccentric pin is replaced by the usual form of eccentric attached to the main driving axle. The crosshead connection imparts a movement to the valve which in amount equals the lap plus the lead when the crosshead is at the extremities of the stroke, in which position the eccentric crank is in its mid-position.

The lead of the valve is constant and can only be changed by altering the leverage relation of the combination lever. The eccentric crank actuates the eccentric rod which, in turn, moves the link to and fro very much the same as does the eccentric blade in the Stephenson gear. There is a radius bar, which connects the link block with the valve stem. It is evident, therefore, that the valve obtains a motion from the eccentric crank, link, radius bar, and valve rod in a manner similar to the Stephenson, the main difference being in the crosshead connection which results in giving the valve a constant lead.

It is to be noted that in a valve having internal admission, the radius bar connects with a combination lever above the valve rod connection and that in a valve having external admission. The connection is made below the valve rod. Also, in a valve having internal admission, the eccentric crank follows the main crank, while in a case where the valve has external admission, it precedes the main crank. Theoretically, the eccentric crank is 90° from the main crank but because of the angularity of the eccentric rod, it is usually two or three degrees more. [6]

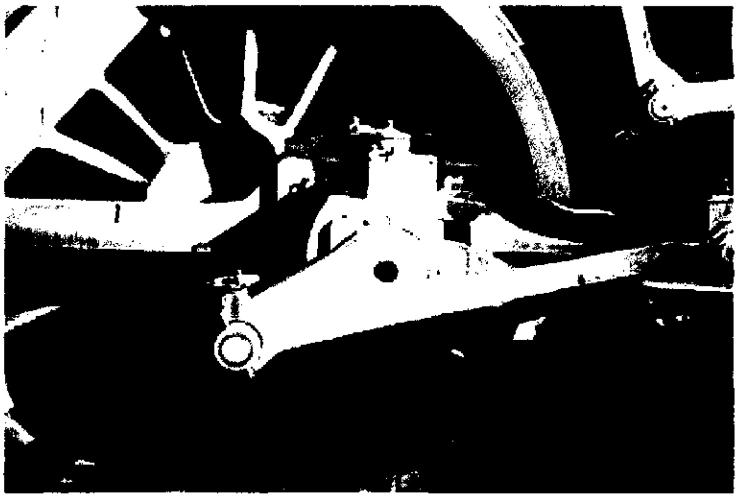


Figure 2.7: Walschaert Valve Gear

2.5.2 Flywheel

A flywheel is a rotating disk used as a storage device for kinetic energy. Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft when a fluctuating torque is exerted on it by its power source such as a piston engine, or when the load placed on it is intermittent. Flywheels can be used to produce very high power pulses as needed for some experiments, where drawing the power from the public network would produce unacceptable spikes. A small motor can accelerate the flywheel between the pulses. Recently, flywheels have become the subject of extensive research as power storage devices for uses in vehicles. [6]

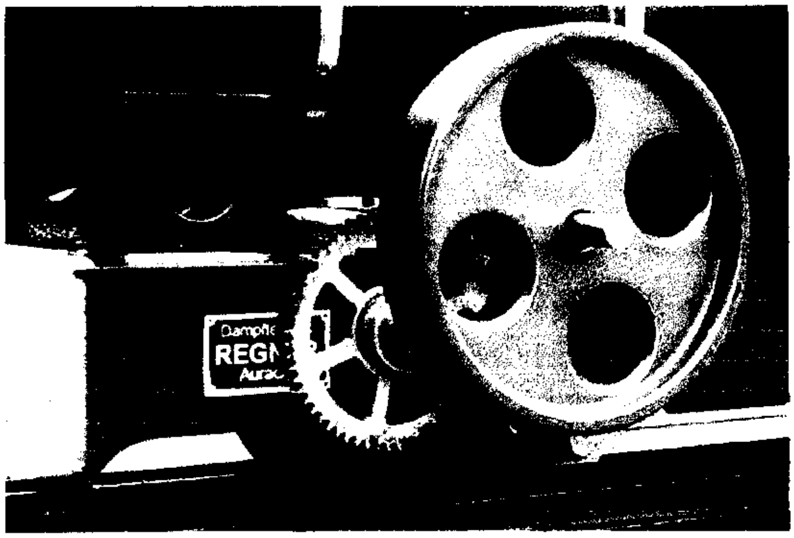


Figure 2.8: Flywheel

2.5.3 Sliding Valve

The D Slide Valve was a form of rectilinear slide valve for use in rotational steam engines invented by William Murdoch and patented in 1799. It was named for the hollow central piston and was in the shape of a D.

This valve worked by connecting the upper and lower valves so as to be worked by one rod or spindle, and in making the stem or tube which connects them hollow, so as to serve for an induction pipe to the upper end of the cylinder. This allowed two valves to do the work of four. [6]

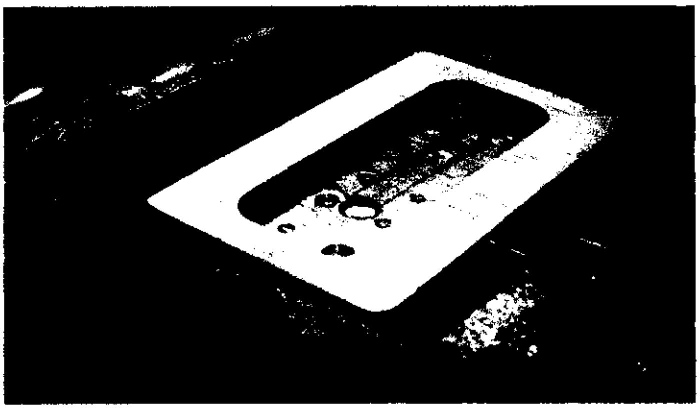


Figure 2.9: Sliding valve

2.5.4 Piston and Piston Rod

The pistons of locomotives vary greatly in details of construction but the general idea is the same in all cases. Since the pistons receive all the power the locomotive delivers, they must be strongly constructed and steam tight. All pistons consist of a metal disk mounted on a piston rod which has grooves on the outer edges for properly holding the packing rings. The pistons are commonly made of cast iron, but where great strength is required, steel is now being used. The cylindrical plate is made of cast-steel and the packing rings, two in number, are made of cast iron. The packing rings are of the snap ring type and are free to move in the grooves.

The piston rod is made of steel and has a tapered end which fits into the crosshead where it is secured by a tapered key. The crosshead fit is made accurate by careful grinding. The crosshead key should likewise be carefully fitted. [6]

Figure 2.10: Piston and piston rod

2.5.5 Crosshead

In the design of the crosshead, the wearing surface must be made large enough to prevent heating. In practice it has been found that for passenger locomotives the maximum pressure between the cross-head and guides should be about 40 lb/inch^2 while for freight locomotives it may be as high as 50 lb/inch^2.

For crosshead pins, the allowable pressure per square inch of projected area is usually assumed at 4,800 lb, the load on the pin to be considered as follows: For simple engines, the total pressure on the pin is taken to be equal to the area of the piston in square inches multiplied by the boiler pressure in pounds per square inch. [6]

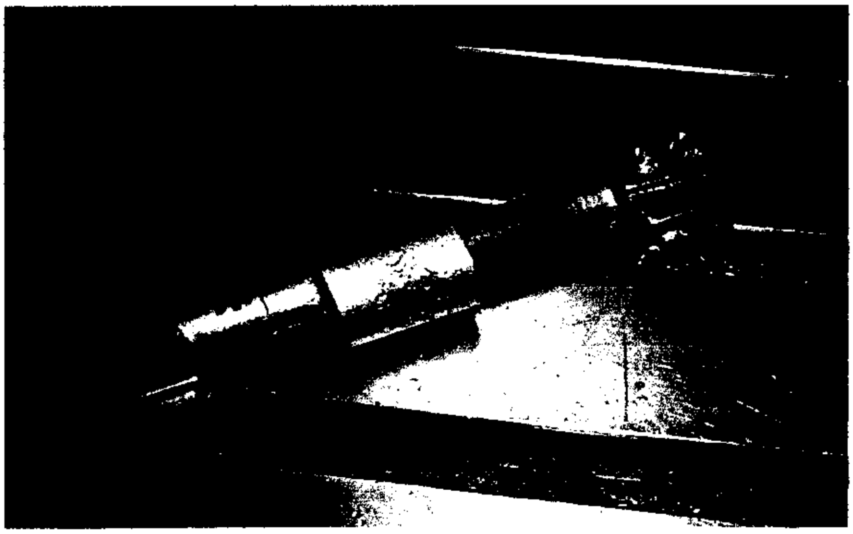


Figure 2.11: Crosshead

2.6 Conclusion

After reviewed some of steam engine and learned about the principles and concepts, we can see that many steam engines were applying high pressure steam in order to move their piston. It is because, the high pressure of steam engine can applied in many light and heavy application such as moving the boat and supply the rotational movement to the generator.

To develop steam engine, the simple operation of engine should be applied to reach the high performance of steam engine. Beside that, the steam engine is not equipped with the complicated component and steam engine will be operating wisely, just by applying the basic concept in developing this engine.

Because of that, this project will develop the scale model of beam steam engine. The steam engine is reciprocating engine with double-acting of sliding valve. The Stephenson Gearing System is applied in this steam engine to increase the cut-off steam performance in the intake and exhaust port of steam engine cylinder.

All of this component will be design by using the SolidWork 2005 software and it will be analyze by the COSMOS Motion 2003 software. The steam engine model design is based on Mechanical Principles of Steam Engine and this method will produce the good performance of steam engine.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of this chapter is to explain the steps in methodology in order to develop the scale model of steam engine. Every method is planning according to the finding on literature review where it is simplify in the flow chart. There are described in different subchapter and every subchapter will be explaining detail about the method to run this project.

3.2 Flow Chart

3.2.1 Project Flow Chart

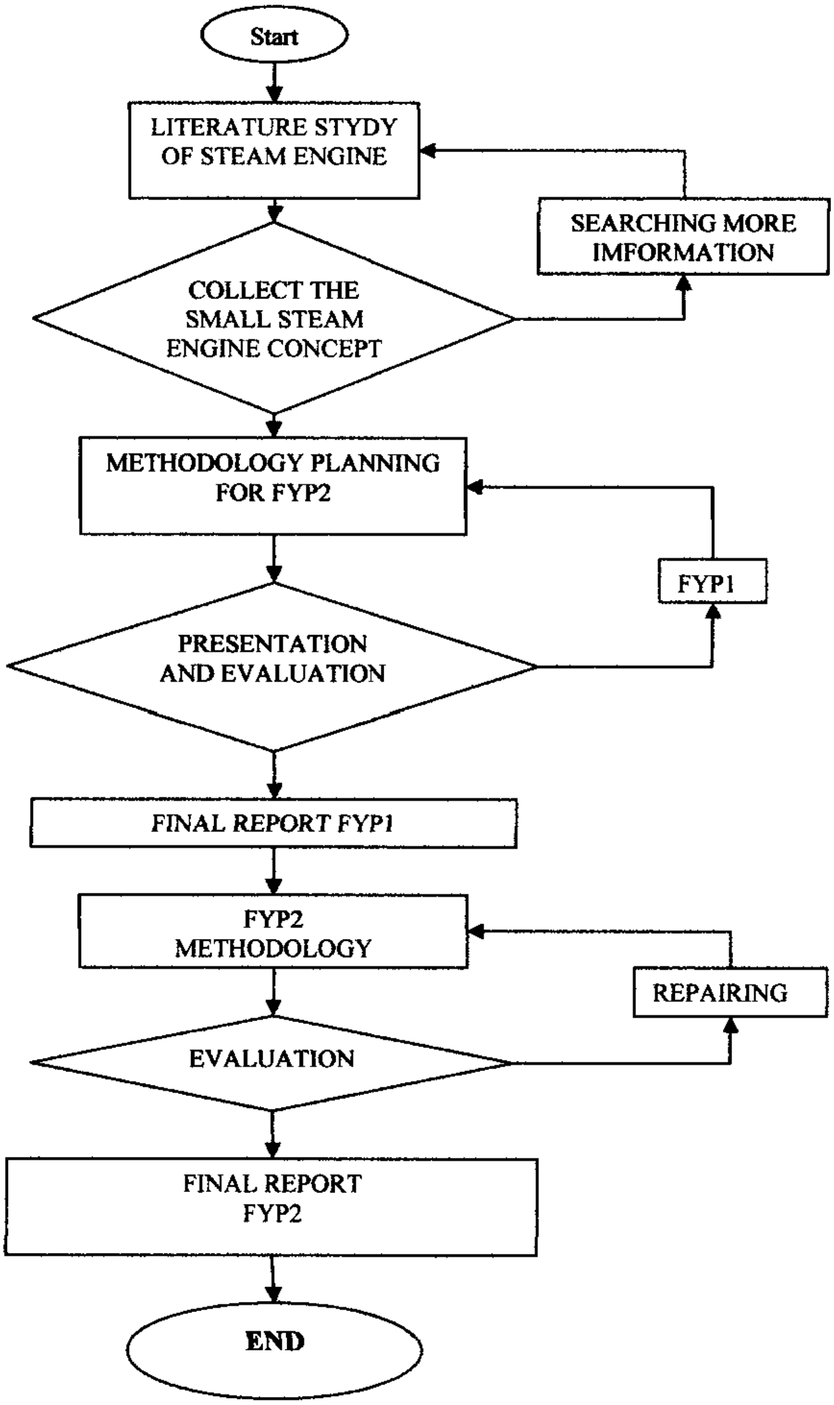


Figure 3.1: Project flow chart

3.2.2 Methodology Chart

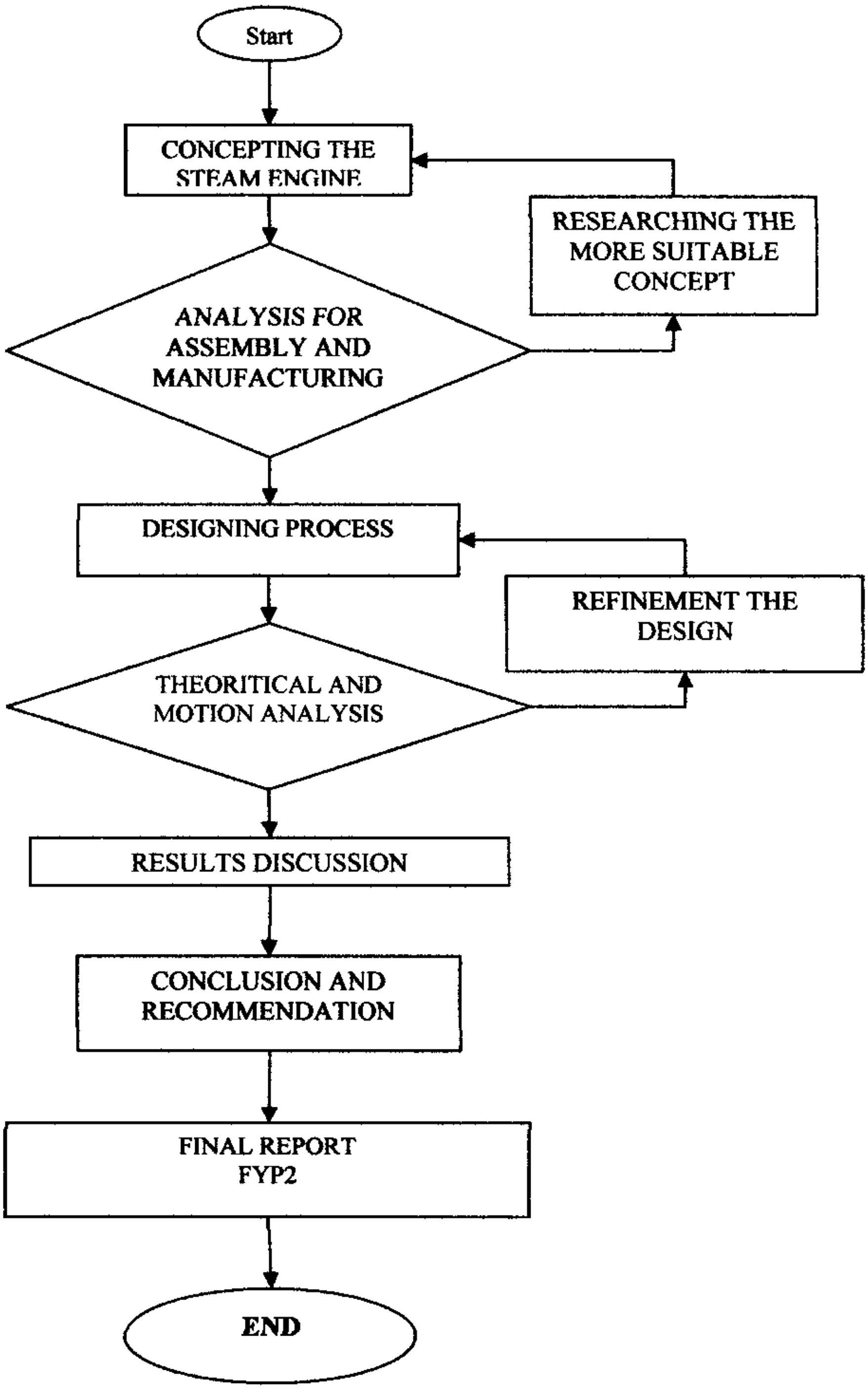


Figure 3.2: Methodology flow chart

3.3 Planning of Methodology

3.3.1 Proposed the potential concept and principles on developing steam engine

Developing some product is very challenging field and it required the developer to understand and expert about the concept and principles before developing some product. The required information will be finding in literature study where this method is continuous along the project progress.

Studying the concept of steam engine is very important to make sure that the project will be success and only the true concept applied can operates the steam engine successfully. When studying the concept of steam engine, we can see different concept and principles applied in different steam engine. This different should be compared and the potential concept is selected. Combination of the concept also can be doing if the tremendous outcome will present.

After getting enough information, new or combination of concept will proposed based on the literature study information. This selected concept will guide whole of the project design and guide in selecting the material use.

3.3.2 Manufacturing and assembling analysis

Using suitable materials and components are needed when developing steam engine. The materials will give the big influence to the steam engine and also the performance of the steam engine. The materials and components should be choosing based on the proposed concept.

Material reviewing can help in designing method by giving the real shape and dimension of the materials or components of steam engine. The designed steam engine model will be analyzed and this method required the material information to make the analysis.

The manufacturing and assembling analysis is important to help the developer to find the best design of steam engine. The good result of analysis will helping in assembly process. T his will reduce the cost and manufacturing process time.

3.3.3 Designing

Designing is important method in developing steam engine and it used to give the view of the final product. Basically, this steam engine equipped by the available materials and components in market. Because of that, the design almost referred to this material and components dimensions where this materials and components was review and listed in previous method.

The design is started by scaling the entire steam engine component. This design is based on proposed concept and used in understanding the steam engine working. After that, the draft will design by the SolidWork 2005 software to give the proper view of the steam engine.

3.3.4 Analysis

Analysis is use to know the behavior of the steam engine during operate in real condition. The Stephenson Gearing System is tuned to get the best timing of steam engine. The best timing of steam engine can be observed at the movement of sliding valve. The timing also can be determined by the motion graph of the sliding valve.

The analysis by compare the designed parameter with the theoretical parameter use to know the limitation of the steam engine. The designed parts are acceptable when the parameter of parts is obeyed to the Mechanical Principles of Steam Engine. The best manufacturing process to fabricate this steam engine also will be described.

3.4 Conclusion

The development steam engine can be determined as a success project if the final designed model show the good result in analysis method. The successful designed model is ready to fabricate by following the fabrication step and the tremendous steam engine will be produced.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will introduce the main operating principle of steam engine that applied in the designed model of steam engine. The designed part of steam engine will analyze by the theoretical calculation for identified the limitation of steam engine during operation. The motion simulation result of Stephenson Gearing System will discuss in this chapter by comparing the good cut-off timing and bad cut-off timing of sliding valve. The theoretical specifications of steam engine will list in this chapter.

4.2 Steam Engine Theory

Steam engine is function to convert the heat energy contained in the steam into rotational energy at the shaft. The steam expands in the engine cylinder and doing work on the engine piston. The engine is double acting where steam is admitted to either side of the piston. Steam admission is controlled by a slide valve which covers and uncovers the ports opening.

4.2.1 Cycle Operations of Steam Engine Model

Movement of the valve uncovers the inlet port A and exhaust port B. steam is admitted on top of the piston pushing the piston down the cylinder. Further movement of the valve closes the inlet port, cutting off the steam supply. The steam in the cylinder expands, pushing the piston down the cylinder with a resulting drop of pressure. Steam in the cylinder on the underside of the piston is forced out to exhaust.

Near the end of the stroke, the exhaust port is closed, trapping a quantity of steam in the cylinder. This steam is compressed to provide a cushioning effect for the reciprocating motion. When the piston reaches the extremity of its stroke, movement of the valve uncovers the inlet port C and exhaust port D.

All the events described are repeated, but with the steam acting on the crank end of the piston.

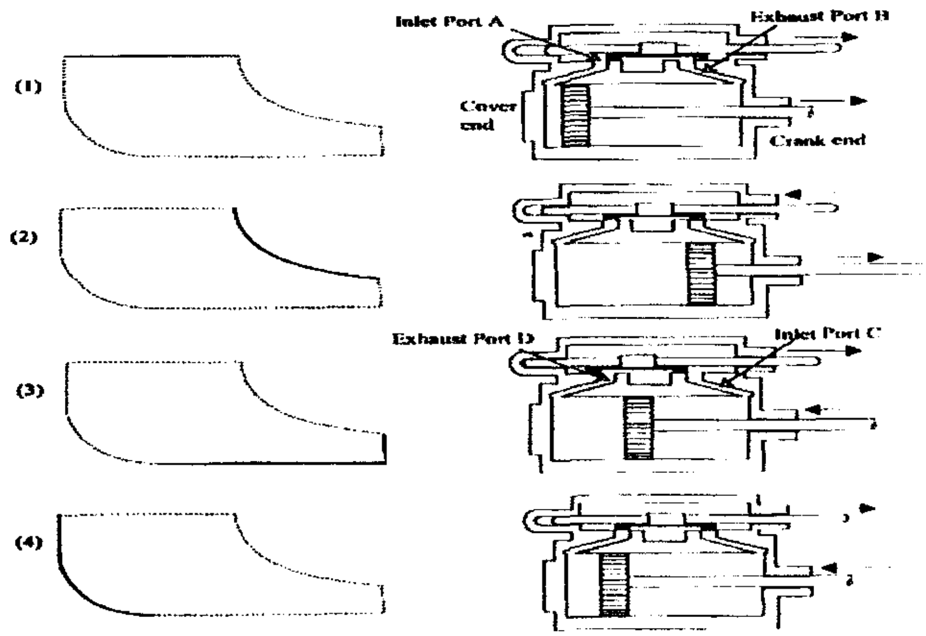


Figure 4.1: Steam engine cycle operation

4.2.2 Steam Engine Model Specification Prediction Power

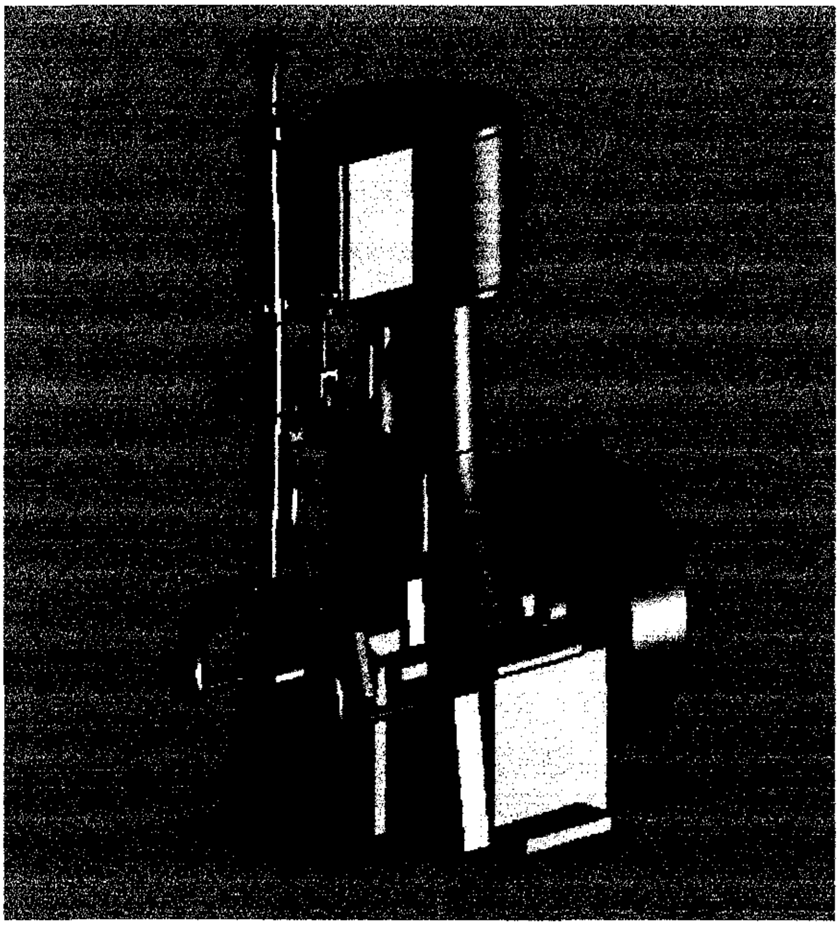


Figure 4.2: Steam engine scale model

Bore	= 1 ¼ inch
Stroke	= 1 inch
Cylinder volume	= 1.2272 $inch^3$
Speed	= 1500 rpm
Maximum steam pressure	= 6.9 bar (100 $lb/inch^2$)
Steam consumption	= 80 lb/hr
	= 5.5 bar (80 $lb/inch^2$)

4.3 Analysis Parts of Steam Engine

Designing steam engine is not a simple job. The designs should consider the actual service of the steam engine and these designs are the result of a gradual development of the proper proportions based upon the tests of each part of steam engine. The specifications for materials and workmanship are rigidly drawn and as carefully lived up to, for in daily service the chances for failure of any part of the engine, because of the excessive vibration, are many, and the destructive effect of such failure is out of all proportion to the original manufacturing expense. These conditions, therefore, make perfect action and excessive reliability prime necessities in engine designs. Because of that, the component should be design by following the mechanical principle of designing steam engine. [6]

4.3.1 Connecting Rod

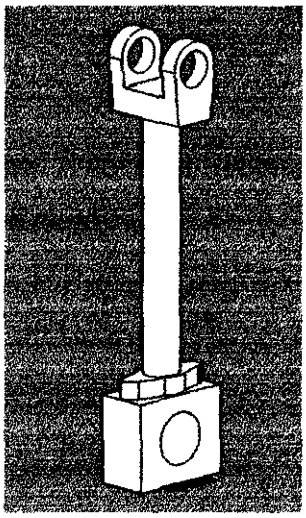


Figure 4.3: Connecting rod

Because of the peculiar conditions of stress and loading of a piston rod, a very high factor of safety must be used in its design. It is subjected to both tensional and compressional stresses and must be capable of resisting buckling when in compression. Reuleaux formula for determining the diameter of connecting rod is

$d = 0.0108 \times D \times \sqrt{P}$

where

D = diameter of cylinder in inches

d = smallest diameter of connecting rod in inches

L = length of the piston rod in inches

P = the boiler pressure in pounds per square inches

D = 1.25 inch

P = 80 lb/inch^2

$d = 0.0108 \times 1.25 \times \sqrt{80}$

= 0.12074 inch

Piston rod designed diameter= 0.25 inch

Base on Reuleaux formula, the smaller diameter of connecting rod should be in 0.12074 inches for withstand with 80 lb/inch^2 pressure of steam from the boiler. Then, the designed connecting rod was 0.25 inches in diameter. T his larger diameter will make the connecting rod become more strength and the possibility for this connecting rod fracture during operations is low. After that, the ability of this connecting rod for withstands with higher pressure can be trust because, the connecting rod is making from 1040 steel. This steel has greater properties in strength, hardness and wears resistance.

4.3.2 Cylinder

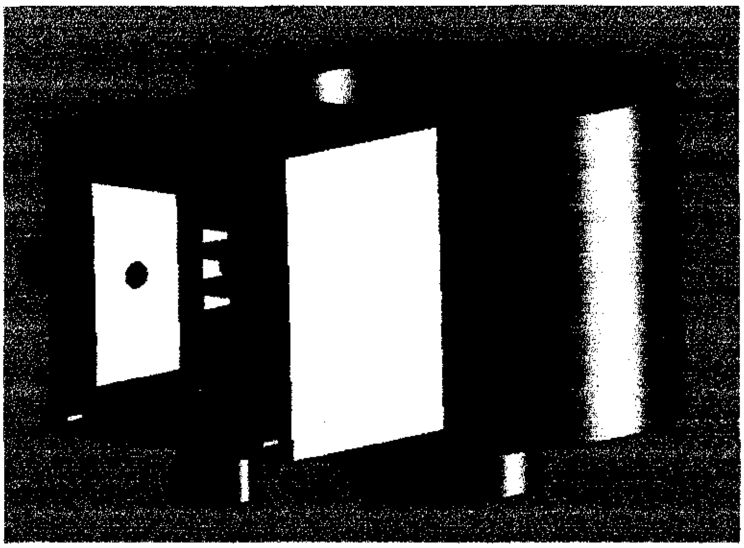


Figure 4.4: Cylinder

The steam engine cylinder contribute big factor in the steam engine performance. Because of that, the mechanical principles in designing steam engine cylinder should be follow to get the efficient cylinder shape. The formula commonly used in determining the thickness of boiler shells, circular tanks, and cylinders is

t= pd/2f

where

t = thickness of cylinder wall in inches

p = pressure in pounds per square inches

d = diameter of cylinder in inches

f = safe fiber stress which for cast iron is usually taken at 1500 pounds per square inch

t = thickness of cylinder wall in inches

p = 80 lb/inch^2

d = 1.25 inch

f = safe fiber stress which for cast iron is usually taken at 1500 pounds per square inch

t= (80 x 1.25) / (2 x 1500)

=<u>0.033 inch</u>

Cylinder designed thickness= <u>0.0625 inch</u>

Based on mechanical principles of steam engine, the minimum thickness of cylinder for this steam engine is 0.033 inches. This minimum thickness can withstand with 80 $lb/inch^2$ pressure of steam without fracture. The designed thickness of cylinder was 0.0625 inches and this value is bigger than theoretical value. It is because, the cylinder was design by considering the assembling and manufacturing factor and with this thickness, steam engine cylinder become ease in assembling process.

4.3.3 Cylinder Head

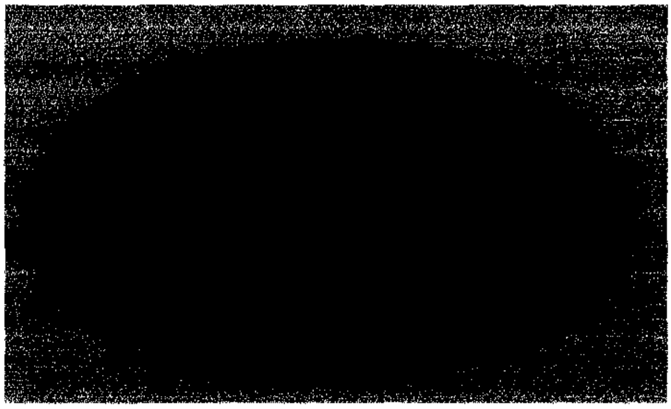


Figure 4.5: Cylinder head

In designing the cylinder head, the safety factor should be considered. The material selections also give the big influence to the safety factor and the performance of steam engine. Because of that, this empirical formula was used in calculating the thickness of cylinder head.

$T = 0.00439\, d \sqrt{p}$

where

T = the thickness of the cylinder head in inches

p = pressure in pounds per square inches

d = stud diameter in inches

T = the thickness of the cylinder head in inches

p = 80 lb/inch^2

d = 0.0625 inch

T= 0.00439 x o.0625 $\sqrt{80}$

= 0.002454 inch

Cylinder head designed thickness= 0.125 inch

Cylinder head is made from gray cast iron; pearlitic in type. This material has 275 MPa of ultimate tensile strength and 140 MPa of yield strength. With this behavior, the cylinder head can withstand with 80 lb/inch^2 steam pressure without fracture. The designed cylinder head thickness should be larger compared to theoretical value because, the smaller thickness of cylinder head can be damage during drilling process and this will decrease the strength of the cylinder head.

4.3.4 Flywheel

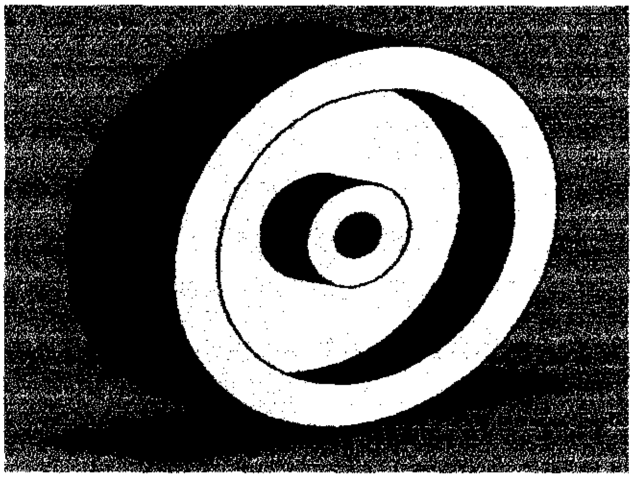


Figure 4.6: Flywheel

Boulton and Watt's rule for finding the dimension of flywheel is

A= 4400 x L x d^2 / v^2 x d

where

L= stroke in feet

d= flywheel diameter in inches

v= speed in revolutions per minutes

A= sectional area of flywheel in inches square

L= 0.13 ft

d= 3.25 inch

v= 1500 rpm

$A = 4400 \times 0.13 \times 3.25^2 / 1500^2 \times 0.2708^3$

$= \underline{0.135\ \text{inch}^2}$

Flywheel cross sectional area = $\underline{0.609375\ \text{inch}^2}$

Flywheel is use to store the rotational energy of steam engine during operation. The larger weight of flywheel will produce the larger momentum of flywheel and it helps the steam engine running continuously and this will increase the steam engine performance. [7]

4.4 Simulation Analysis

This steam engine was applied the Stephenson Gear System. This gear system is a comparatively simple operation but one requiring great care. On account of the angularity of the rods, it is impossible to adjust any link motion to give equal cut-off at all points for both strokes of the piston. The most satisfactory arrangement is one which provides for an equalization of the lead and cut-off at mid-gear.

In the other words, the Stephenson Gear System can help the steam engine reach the good timing in operates the sliding valve. The timing can be tune by adjusting the clamp of gearing system. The different timing of the steam engine by adjusting the Stephenson Gearing System will be discussed.

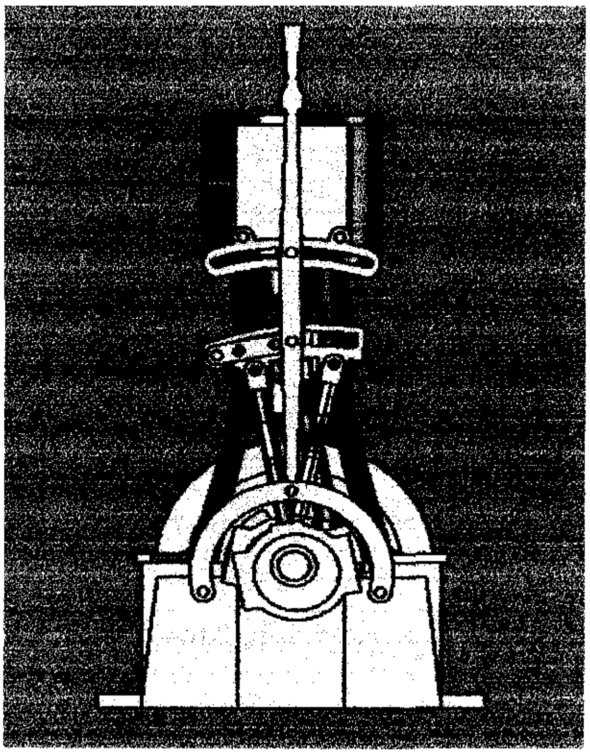


Figure 4.7: Standard clamp position

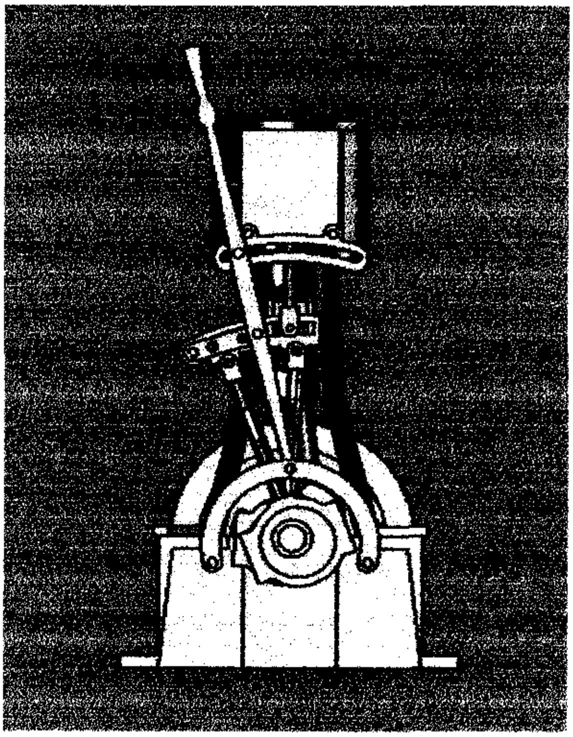


Figure 4.8: Tuning clamp position

4.4.1 Good Timing

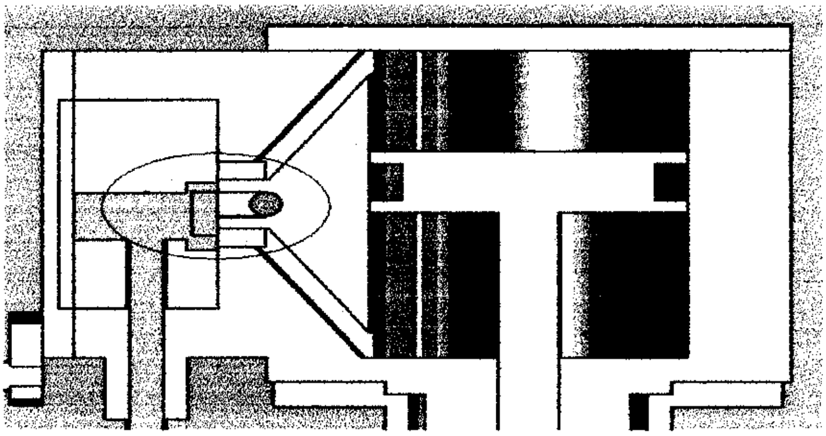


Figure 4.9: Sliding valve position in good timing operation

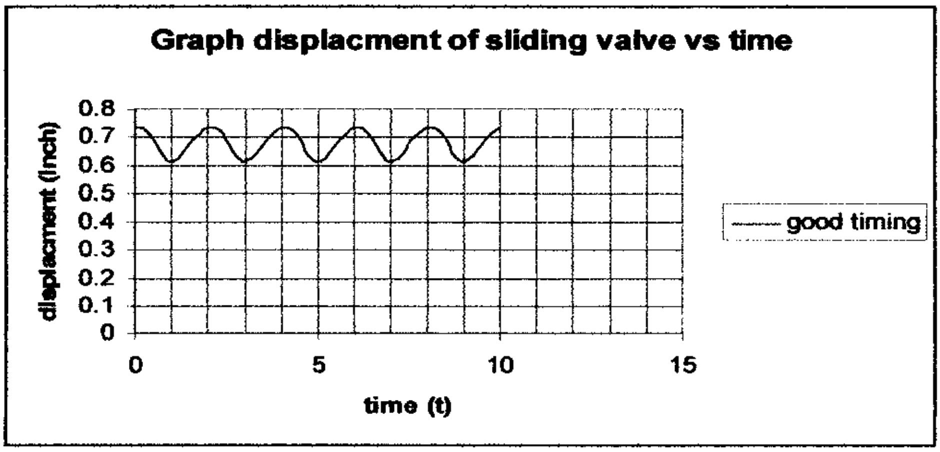


Figure 4.10: Displacements of sliding valve in good timing operation

The good timing for sliding valve can be determine when the cut-off of the steam occur when the piston reach at the top dead center or bottom dead center of the cylinder. This timing allow the steam push the piston to the downwards or upwards at the right time and result the harmonic movements of the piston.

From the simulation of good timing, the Figure 4.9 show that the sliding valve just can reach the exhaust port border before reciprocate again. The simulation graph, the smooth reciprocating movement of sliding valve can identify by the smooth curve of the graph.

4.4.2 Bad Timing

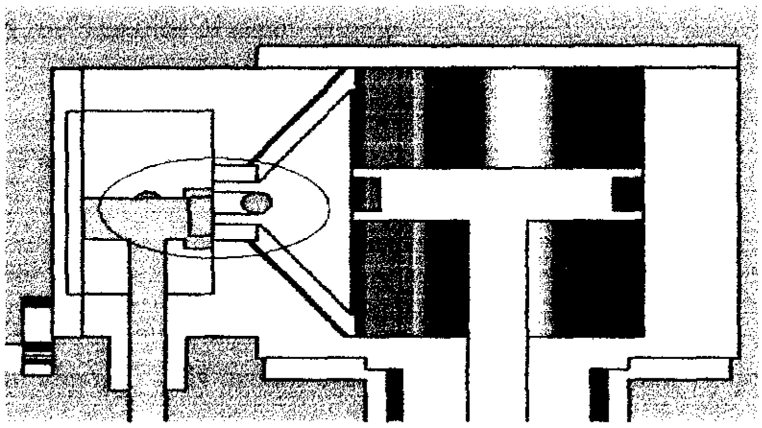


Figure 4.11: Sliding valve position in bad timing operation

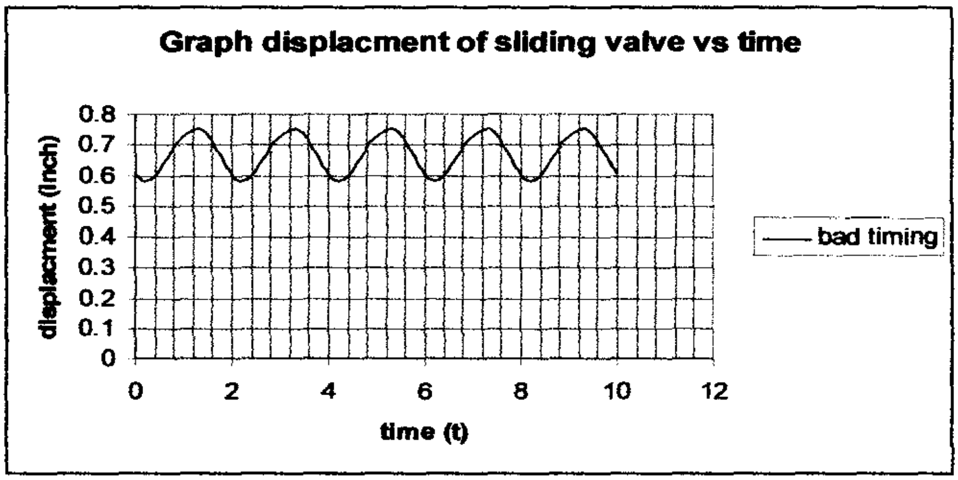


Figure 4.12: Displacements of sliding valve in good timing operation

Figure 4.11 show that the sliding valve past the exhaust port border and this produce the bad timing of the steam engine. It is because, the cut-off of the steam occur not at the exact time and this waste the steam energy applied in the cylinder. The steam also easy to condense because of, the bad timing on moving the sliding valve will trap the steam and increasing the pressure for the bottom or top side of the cylinder. The will damage the steam engine and decreasing steam engine performance.

Figure 4.12 also show that the sliding valve not moving in the good harmonic motion and resulting the small curve graph. This phenomenon also reduces the efficiency and performance of steam engine

4.4.3 Good Timing versus Bad Timing

In steam engine, the exact cut-off of the steam is the major issue to determine the performance of steam engine. By adjusting the reverse lever, the steam engine timing became change. This occurs because of little adjustment in gearing system. The result is the different distance of sliding valve movement.

From the Figure 4.13, the bad timing produces the big displacement of sliding valve compare with the good timing sliding valve displacement. With the big displacement, the timing to cut-off the steam in intake port will increase and this situation can be observed by referring the graph below.

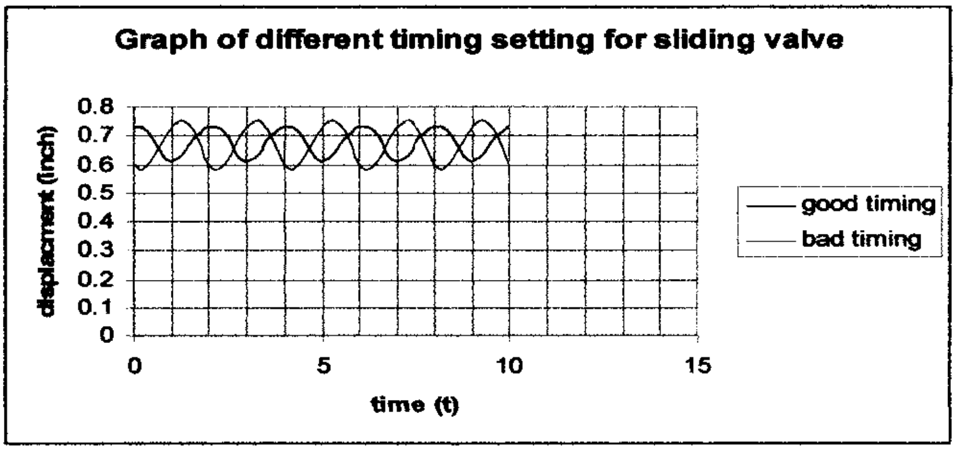


Figure 4.13: Displacements comparison of sliding valve

4.5 Manufacturing Process

Much exacting work is required in building this steam engine such turning, drilling, milling, tapping, boring and casting. This kind of work required the high technical skills on handling the machine, and the safety factor during working needs to consider. Because of that, the right process in producing steam engine components is list in Figure below. The right manufacturing process also will influence the behaviors of steam engine components.

Figure 4.14: Table of manufacturing process

Manufacturing process	Components
Turning	Stand, eccentrics, crosshead pin, cylinder, crankshaft, connector, crankshaft, connecting rod, piston assembly, glands, eccentrics straps, drag link, clamp, block, countersink, reverse gear
Drilling	Stand, eccentrics, crosshead pin, cylinder, crankshaft, connector, crankshaft, connecting rod, piston assembly, glands, eccentrics straps, drag link, clamp, block, countersink, reverse gear
Milling	Base, anchor pin, sliding valve, main bearing, cylinder
Tapping	Base, main bearing, piston assembly
Boring	Piston assembly, cylinder
Casting	Cylinder, flywheel

4.5.1 Turning

Turning process is the main manufacturing process in building small steam engine. It is because, major components of small steam engine have round shape, and the process to produce the components is perform by turning the workpiece on a lathe machine.

Turning process can be done on *all* types of materials by using the single-point or form tools. Then, to do this manufacturing process, it requiring less-skilled person and this is ease the students to handling this machine. [2]

4.5.2 Drilling

Another major manufacturing process in building small steam engine is drilling process. This is because, many components of steam small steam engine requiring the round holes for assemble the steam engine components.

In small steam engine, there are many size and depth holes and this various size and depth required the skilled person to make the accuracy holes locations. Basically the hole is drill in the mating components to get the accuracy during assembling process.[2]

4.5.3 Milling

The accuracy shape of small steam engine components is desire to get the good performance the engine. This accuracy shape can be produce by the milling process such slab milling, face milling and end milling.

During milling process, the spindle speed should be set in the suitable value and the cutter should in be in regular and sharp teeth. Without these considerations, the rough surface finish will be finding on the components surface.[2]

4.5.4 Tapping

Steam engine components are assembling by bolts and nuts. Because of that, threads should be produce on the assembling components by tapping process. The threads must be straight and this required the skilled person to produce the good treads.

During tapping process, components should be design so that all cutting operations can be complete in one setup. Then, the thread sections should not be interrupting with slots, holes, or other discontinuities.[2]

4.5.5 Boring

The circular internal profile can be produce by boring process. Then, the boring process just can be done on the materials with the high modulus elasticity to minimize deflection and avoid vibration and chatter.

This process should be handling by the skilled person, because boring machine has high maintenance in dimensional accuracy and the mistake will produce the significant problem on the machine.[2]

4.5.6 Casting

Sand casting is the best process in producing the cylinder and flywheel of small steam engine. This is because, this process can be done on many desire shape, size and weight of components. After that, this process has a low tooling maintenance and cost.

Without proper operation in making the steam engine components by sand casting process, the components may have coarse finishing surface and wide tolerance. All of this will give bad performance of steam engine during operation and the steam energy will be waste by this bad components. [2]

4.6 Conclusion

From the theoretical calculations and simulations analysis, the results show that the designed parts of steam engine was passed the desired principles in developing steam engine. The steam engine model was running with the desirable movement when the steam pressure applied to the piston and the sliding valve cut-off timing performance can be increase by adjusting the Stephenson Gearing System. In other word, the steam engine efficiency can be increase due to the improvement of the steam cycle and steam management.

Next, the suitable manufacturing process to develop steam engine was selected base on the DFMA (Design for Manufacturing and Assembly) rules. As the results, this steam engine can be manufacture with least cost and simple manufacturing process. The recommendation on manufacturing process also considered the safety factor and this high safety factor allowed many persons to manufacture this steam engine.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Developing steam engine is the challenging works because, steam engine operates with steam power and this steam power should be manage properly in order to get best performance of steam engine and to avoid the damage of steam engine during operations. In this project, the double-acting steam engine model with Stephenson Gearing System was successfully designed because:

i. All of the components of steam engine were designed base on the Mechanical Principles of Steam Engine. With this, the calculations analysis shows that the parameter of steam engine components can be accepted and the designed components can be withstand with the steam pressure.

ii. The Stephenson Gearing System can operate wisely on the steam engine model and this device was influence the cut-off timing of the sliding valve. In the other words, the Stephenson Gearing System can increase the cut-off timing performance of sliding valve.

iii. This steam engine model can be manufacture and assembly. It is because, the steam engine model was designed base on the DFMA (Design for Manufacturing and Assembly) concepts and this concept will ease during manufacturing and assembling process of steam engine.

5.2 Recommendation

After the project had been done successfully, some recommendation can be made to improve this project result. There are:

i. When making drawing of steam engine components by SolidWorks 2005, the image of the drawing should be adjust to the high quality image. This will help the entire components can be mating without problem during assembly process.

ii. In making simulation on the steam engine model, the components should be decrease in order to decrease the boundary setting on the steam engine model. These decreasing components will help to get the best results in simulations.

iii. In building the real steam engine, the recommendation manufacturing process should be follow in order to get the good quality of the components. With this, the assembly process can be done without any mating problem and finally the good performance of steam engine will be produce.

REFERENCES

1. Halliday, Resnick, Walker. *Fundamentals of Physics.* 6th Edition. Singapore.Wiley.2003.

2. Serope Kalpakjian, Steven R. Schmid. *Manufacturing Engineering and Technology*. 4th Edition. Prentice Hall. 2000.

3. Yunus A. Cengel, Michael A. Boles. *Thermodynamics; An Engineering Approach.* 4th Edition in SI Units. Mc Graw Hill. 2000.

4. http://demoroom.physics.ncsu.edu/html/demos/523.html

5. http://en.wikipedia.org/wiki/Steam_locomotive_component

6. http://kesr-operating.org.uk/stephenson.htm

7. http://kmoddl.library.cornell.edu/stillImages/Redtenbacher/small/

8. http://thumbs.dreamstime.com/thumb_172/1186249862kh20rQ.jpg

9. http://www.deutsches-museum.de/typo3temp/pics/7be20babc8.jpg

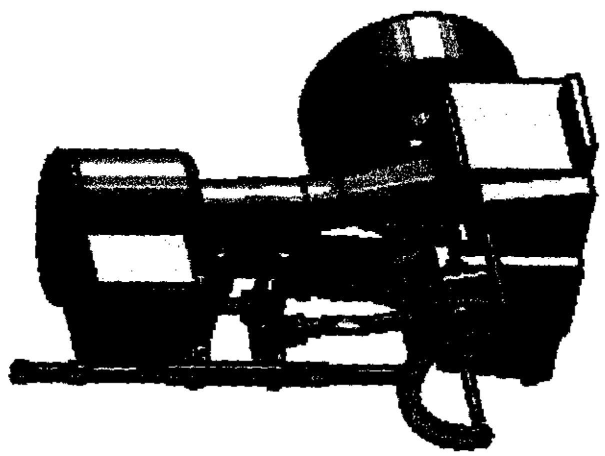
10. http://www.greensteamengine.com/index.html

11. http://www.sdrm.org/faqs/boilers/page84.html

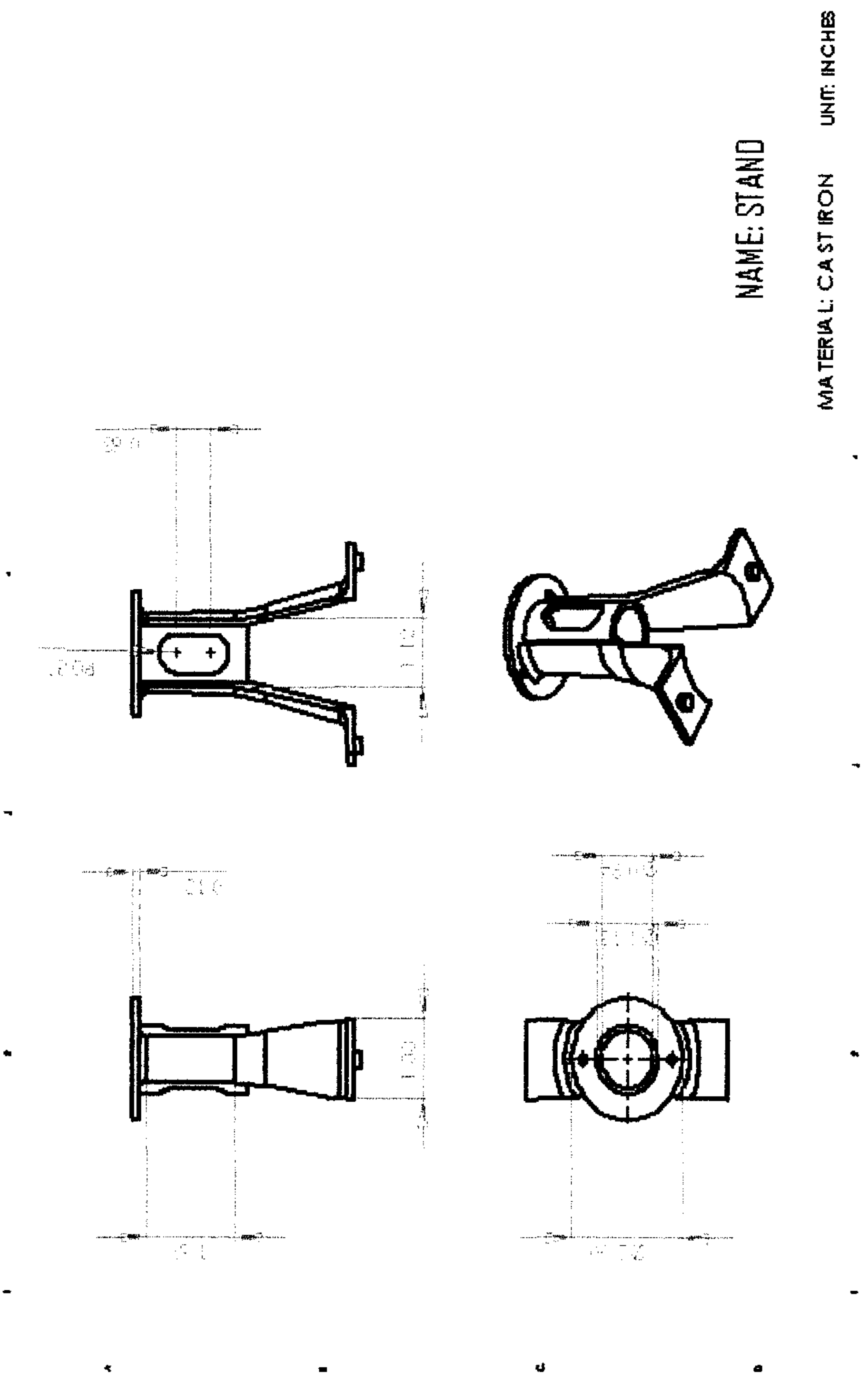
12. http://www.stuartmodels.com/inprod_det.cfm/section/readytorun/mod_id/2

13. http://www.theengineshop.net/casting.shtml

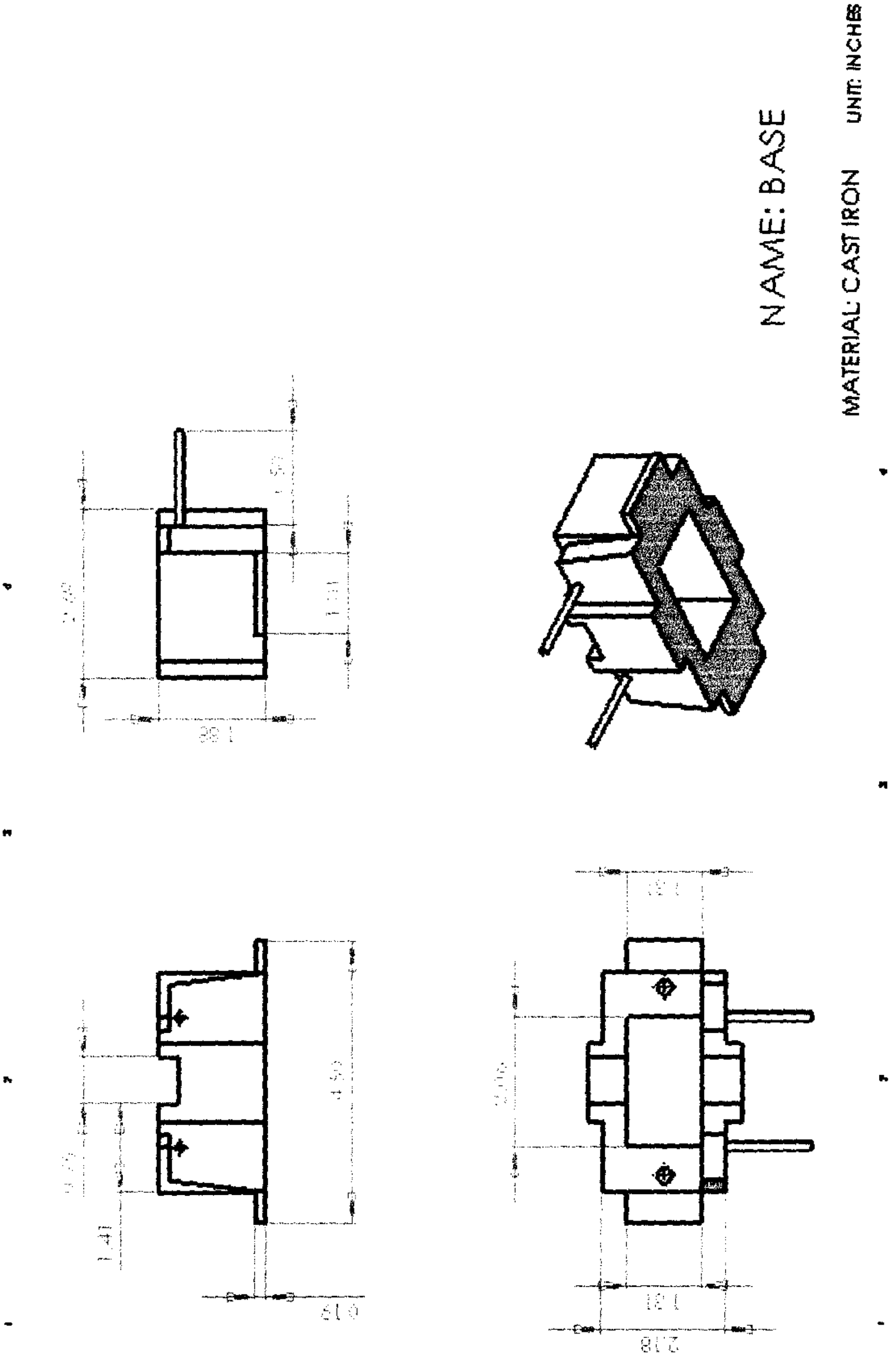
APPENDIX A



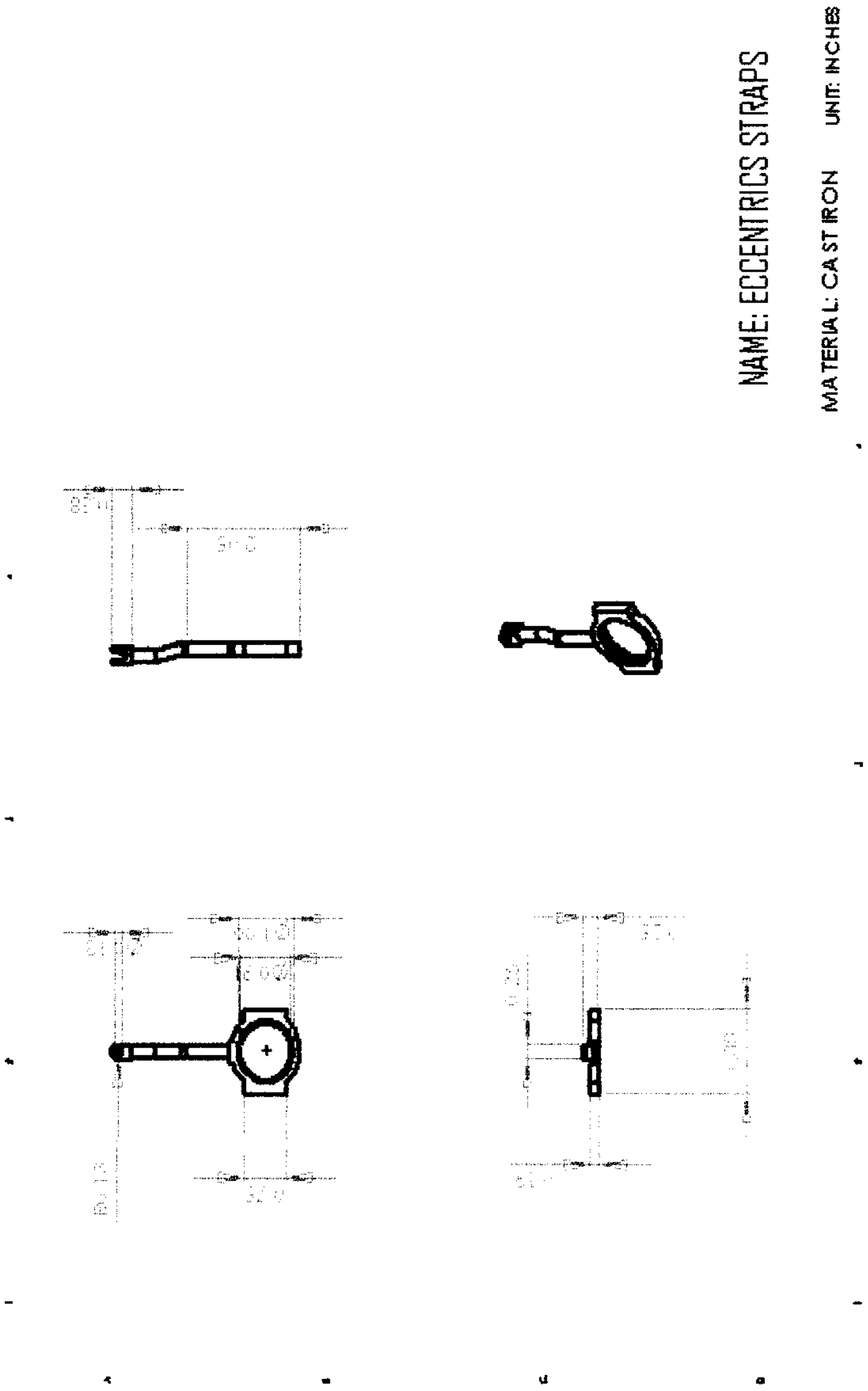
APPENDIX B



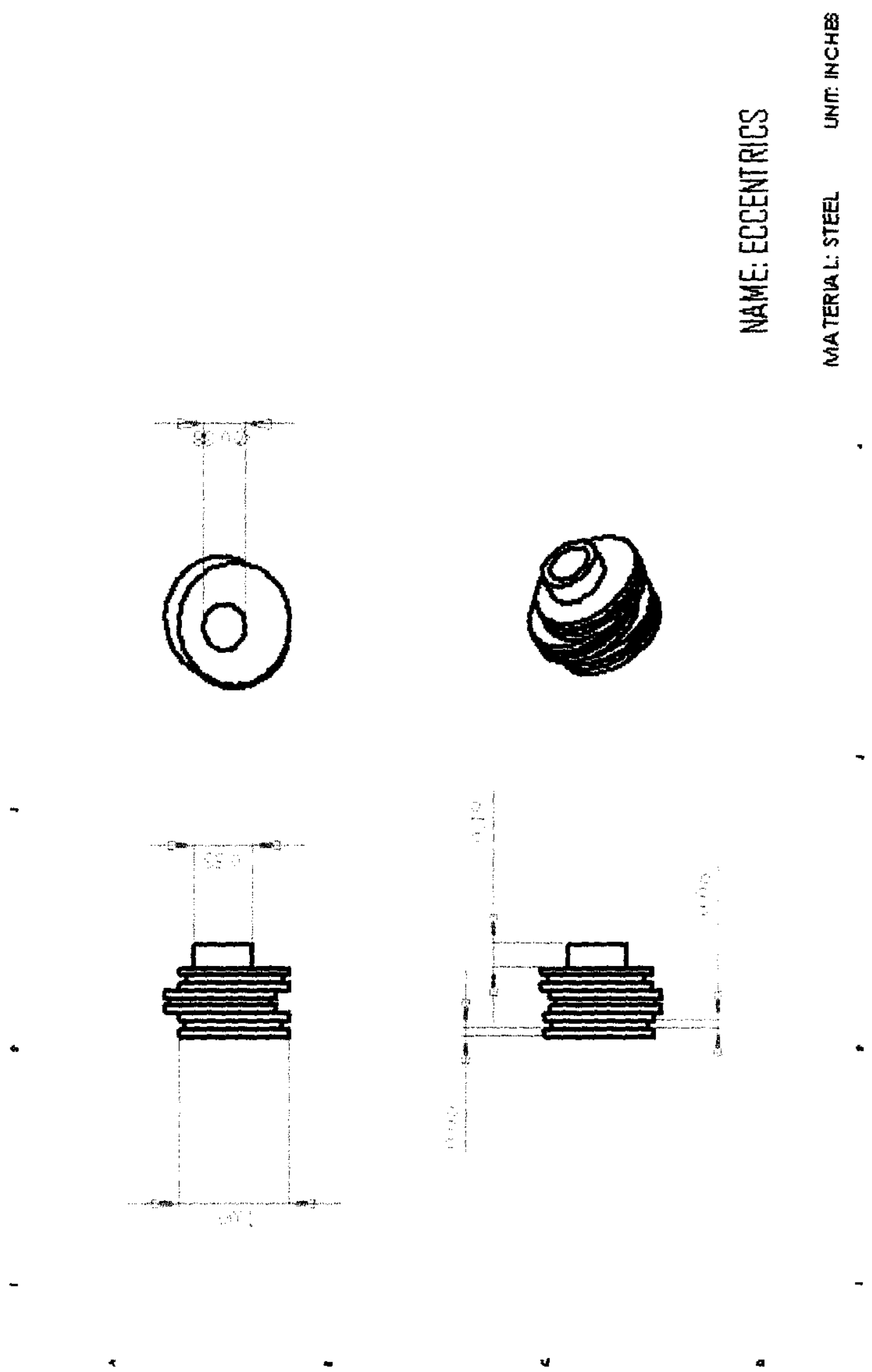
APPENDIX C



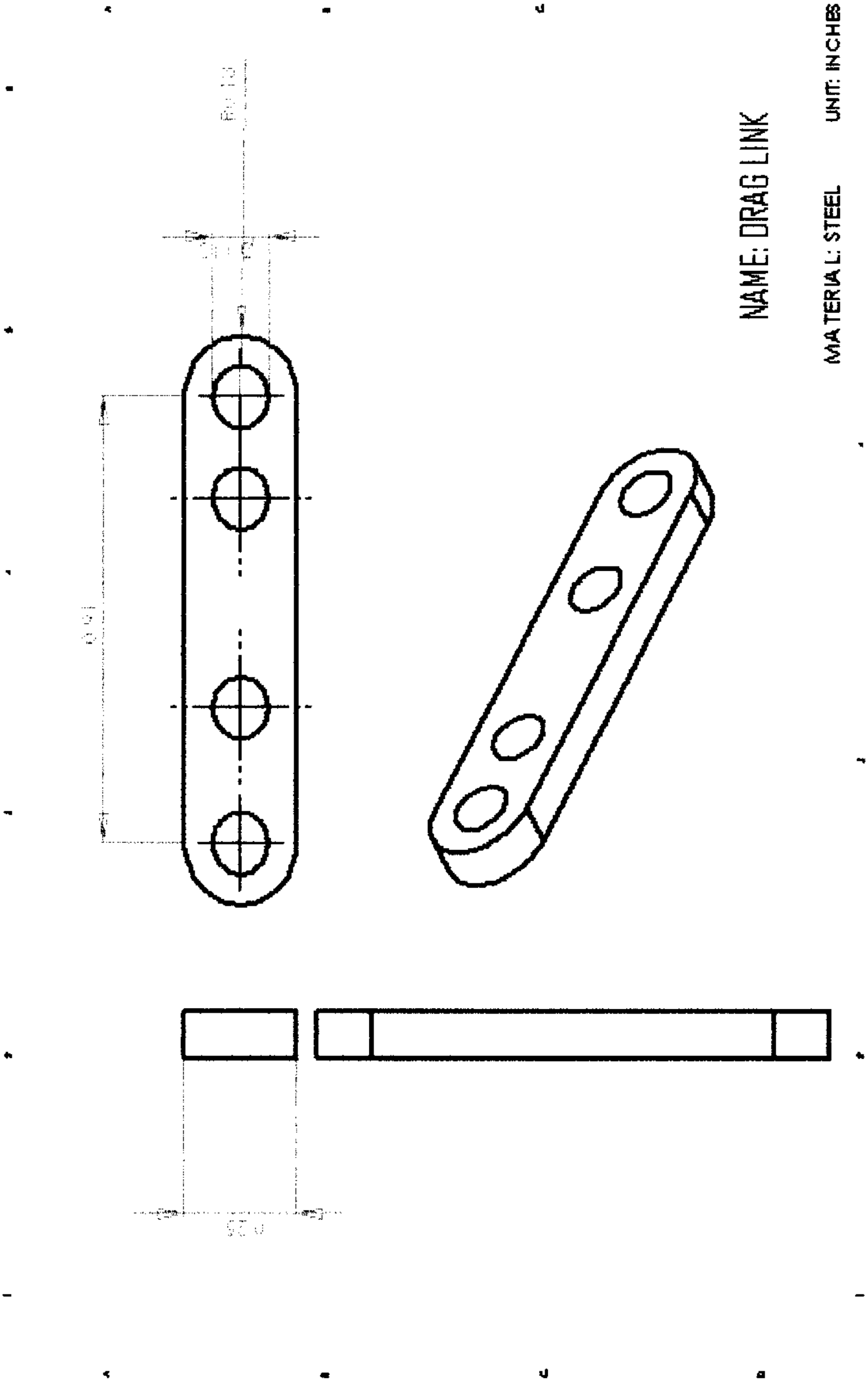
APPENDIX D



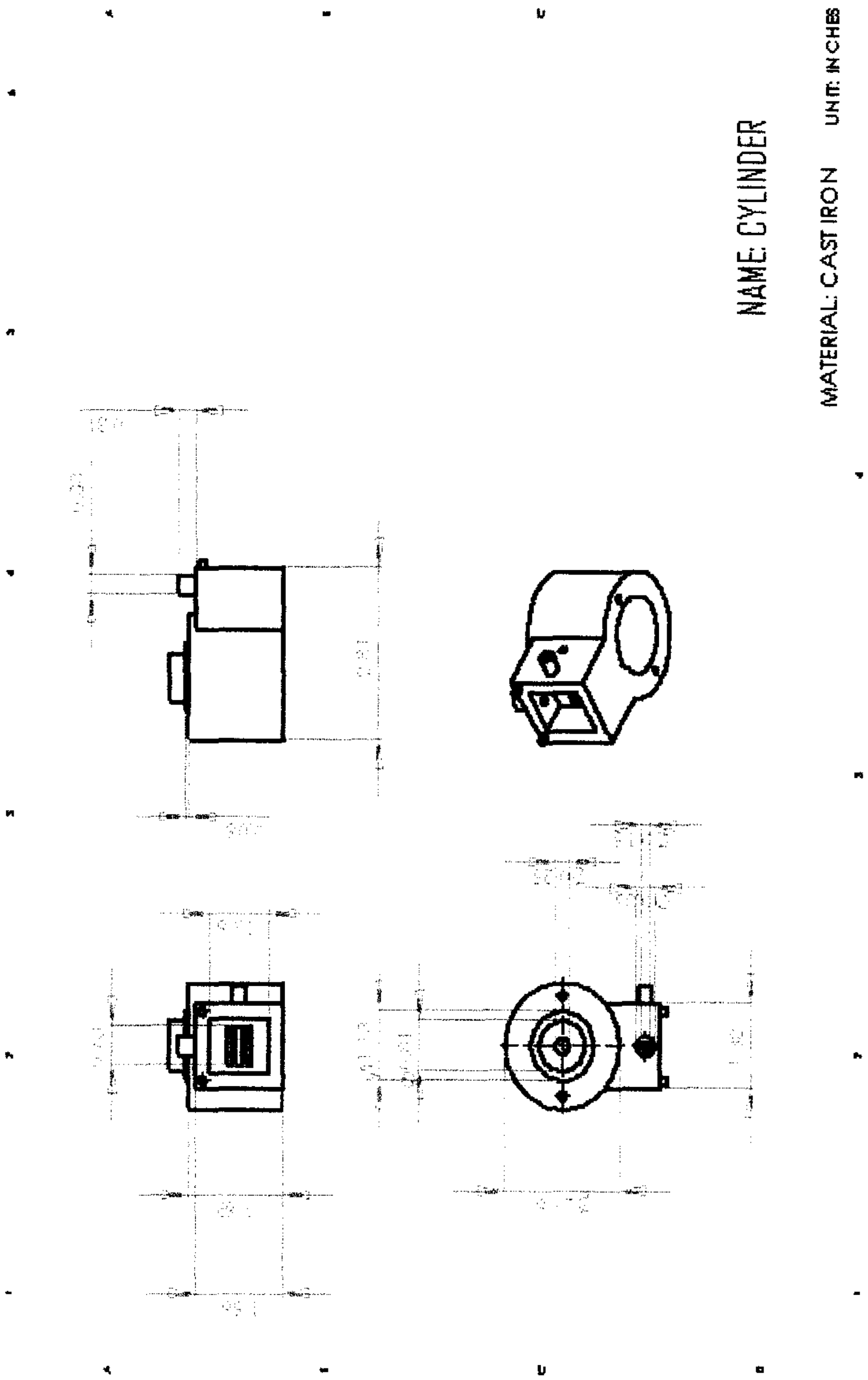
APPENDIX E



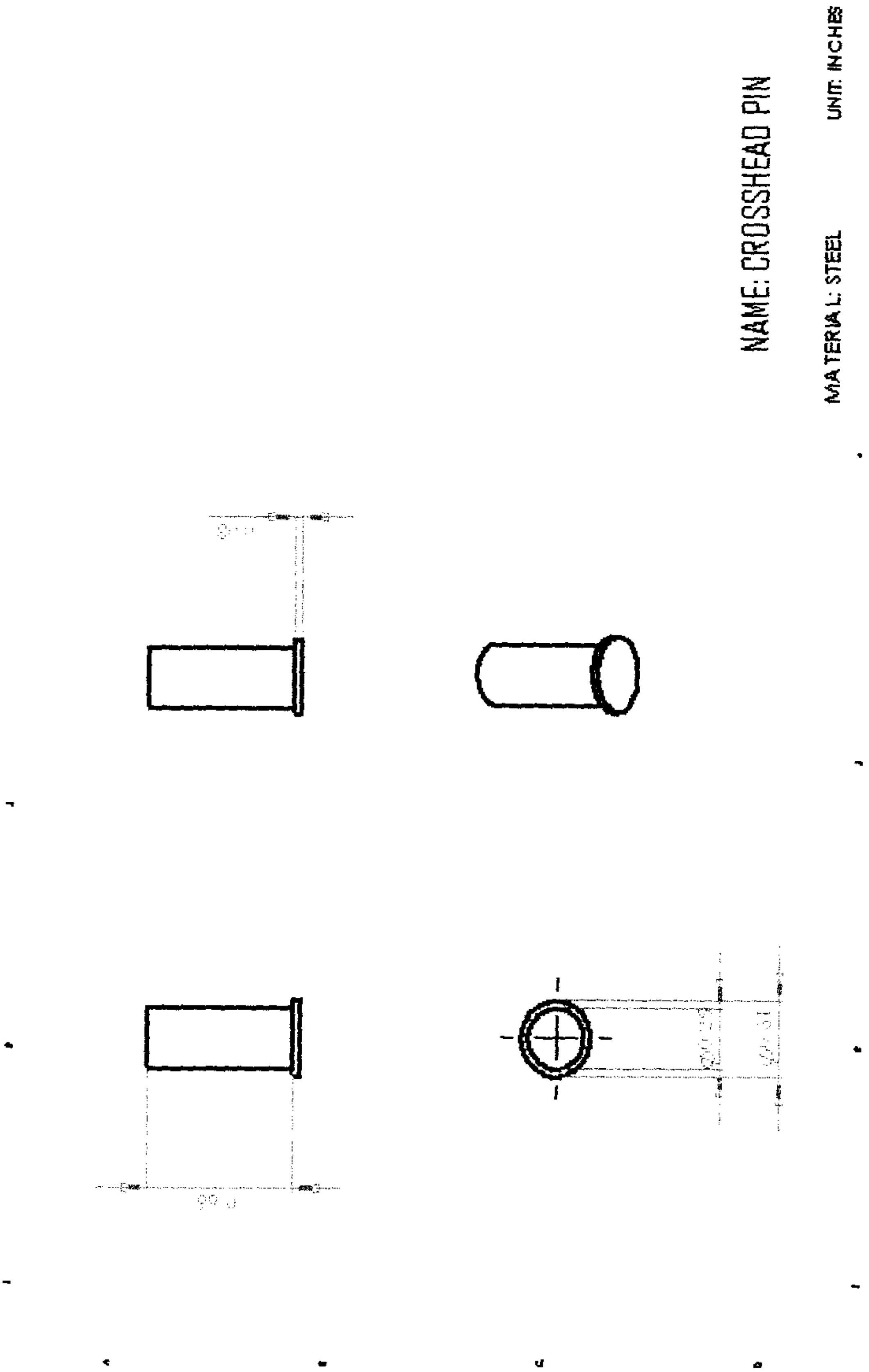
APPENDIX F



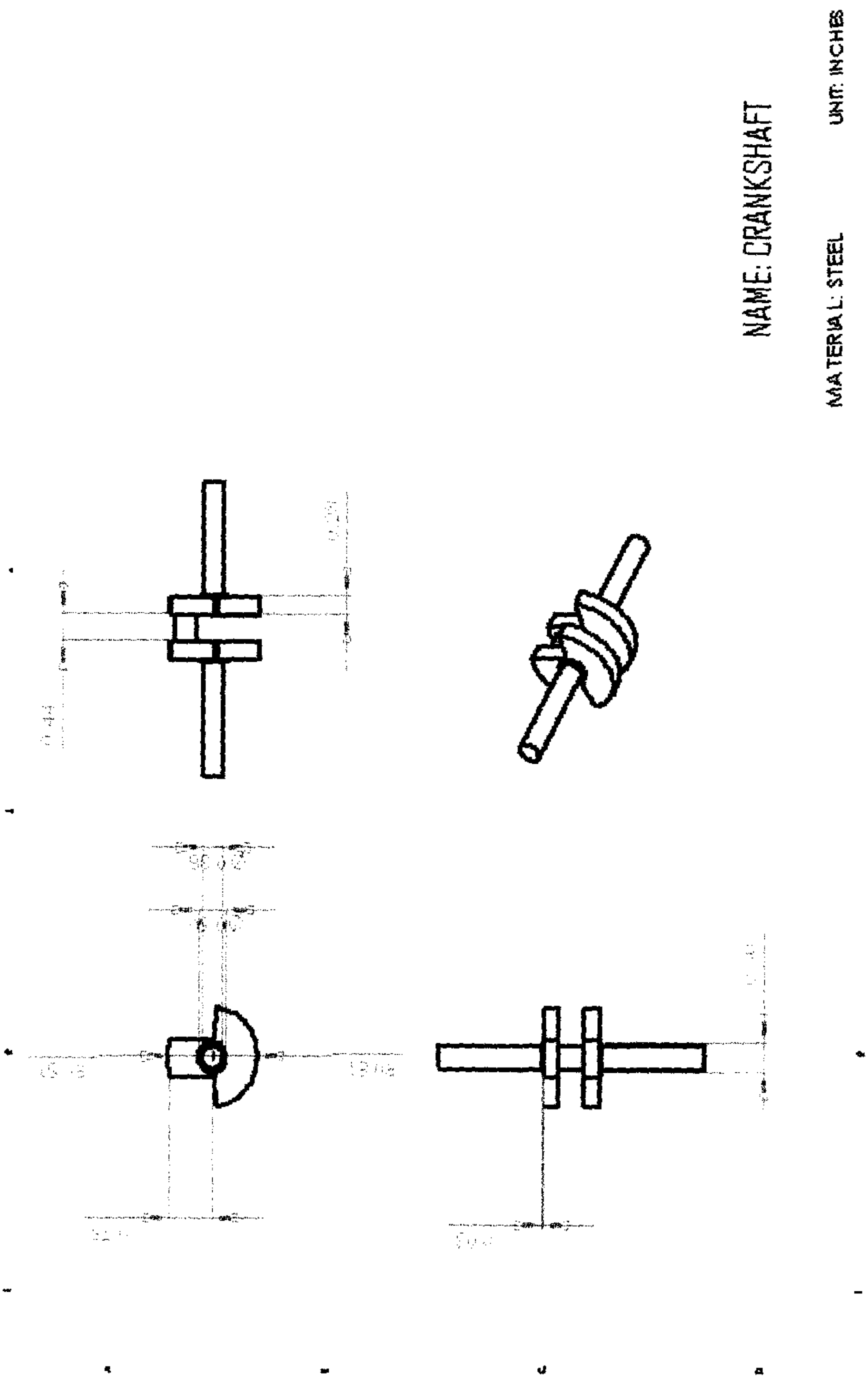
APPENDIX G



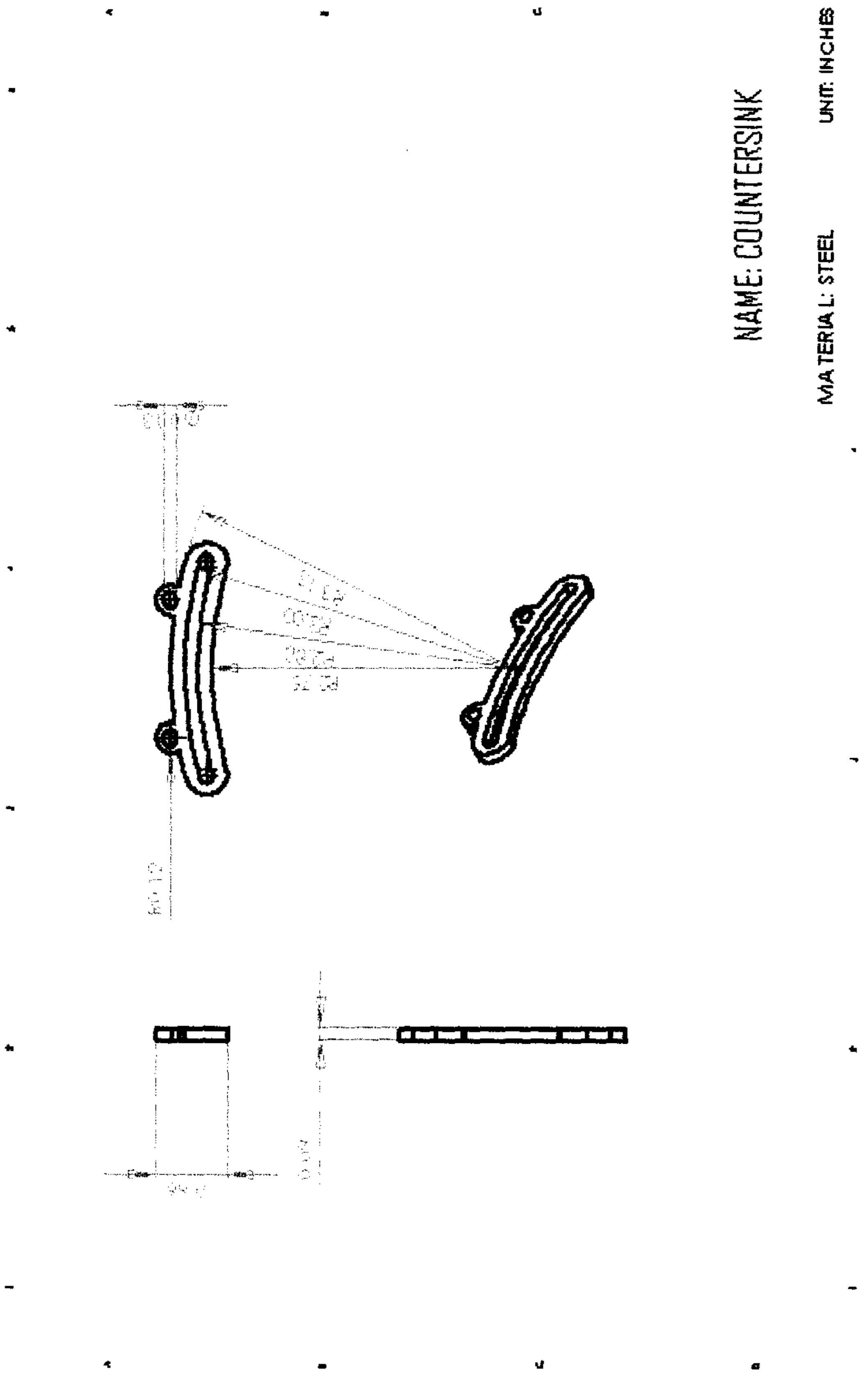
APPENDIX H



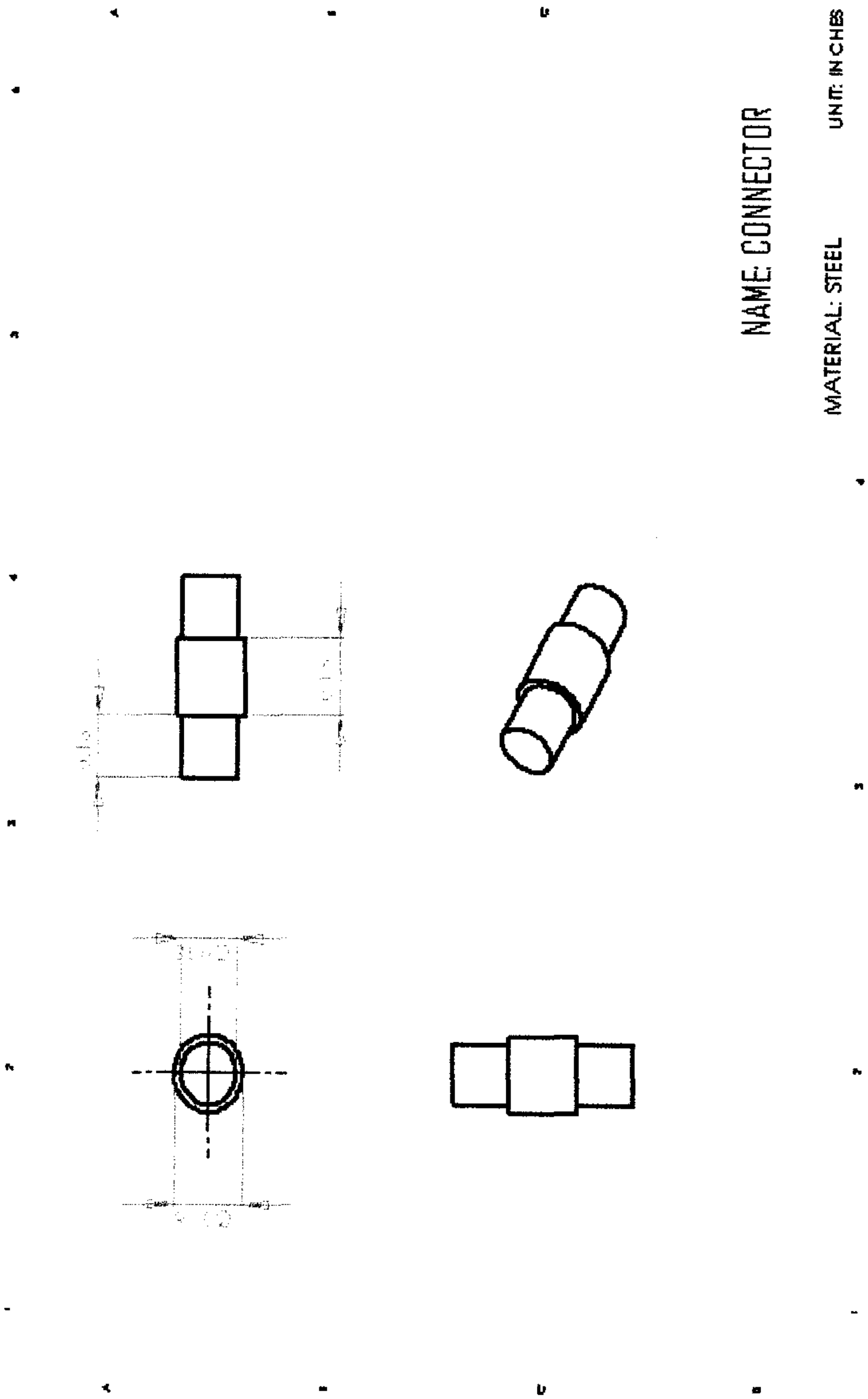
APPENDIX I



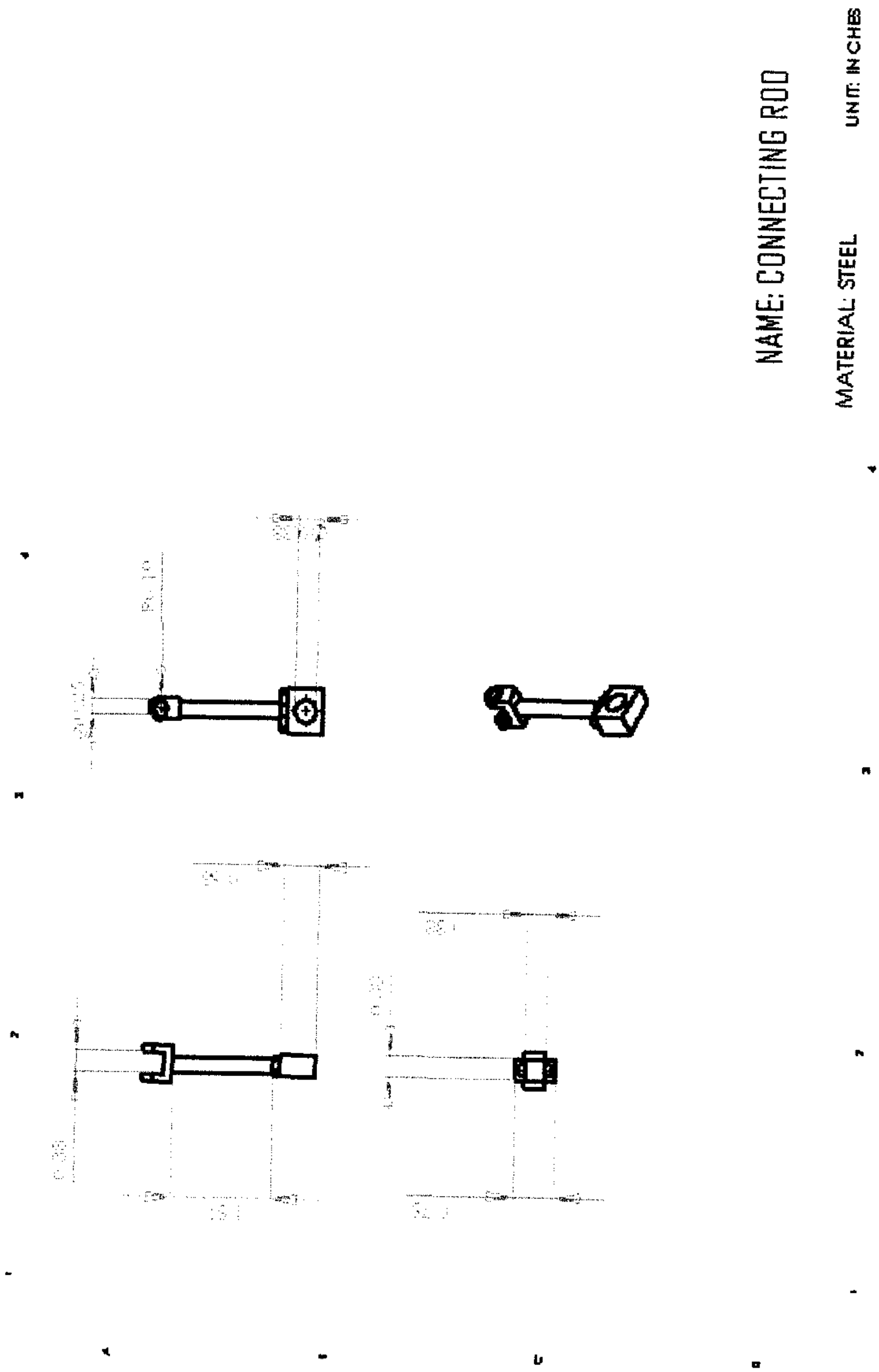
APPENDIX J



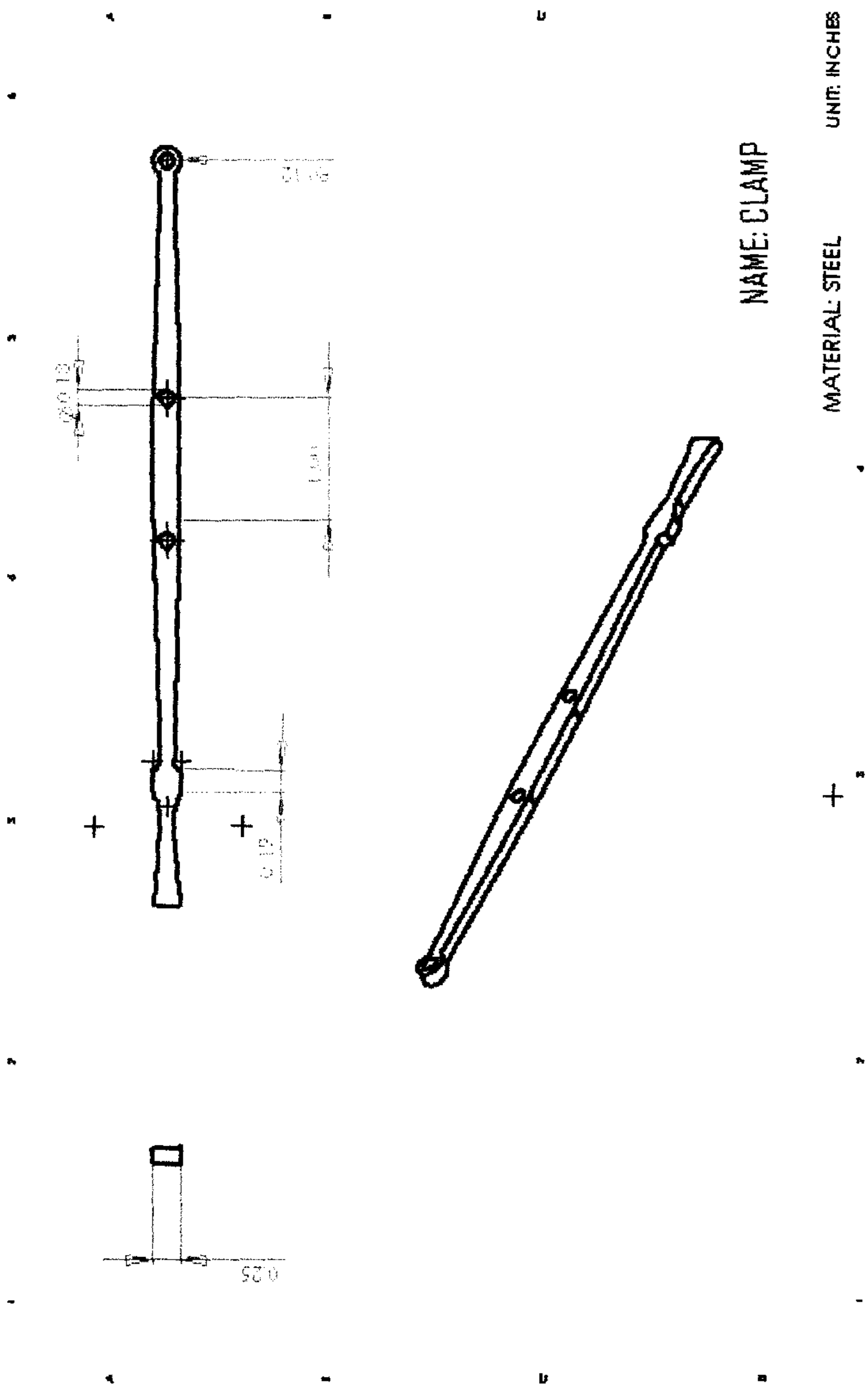
APPENDIX K



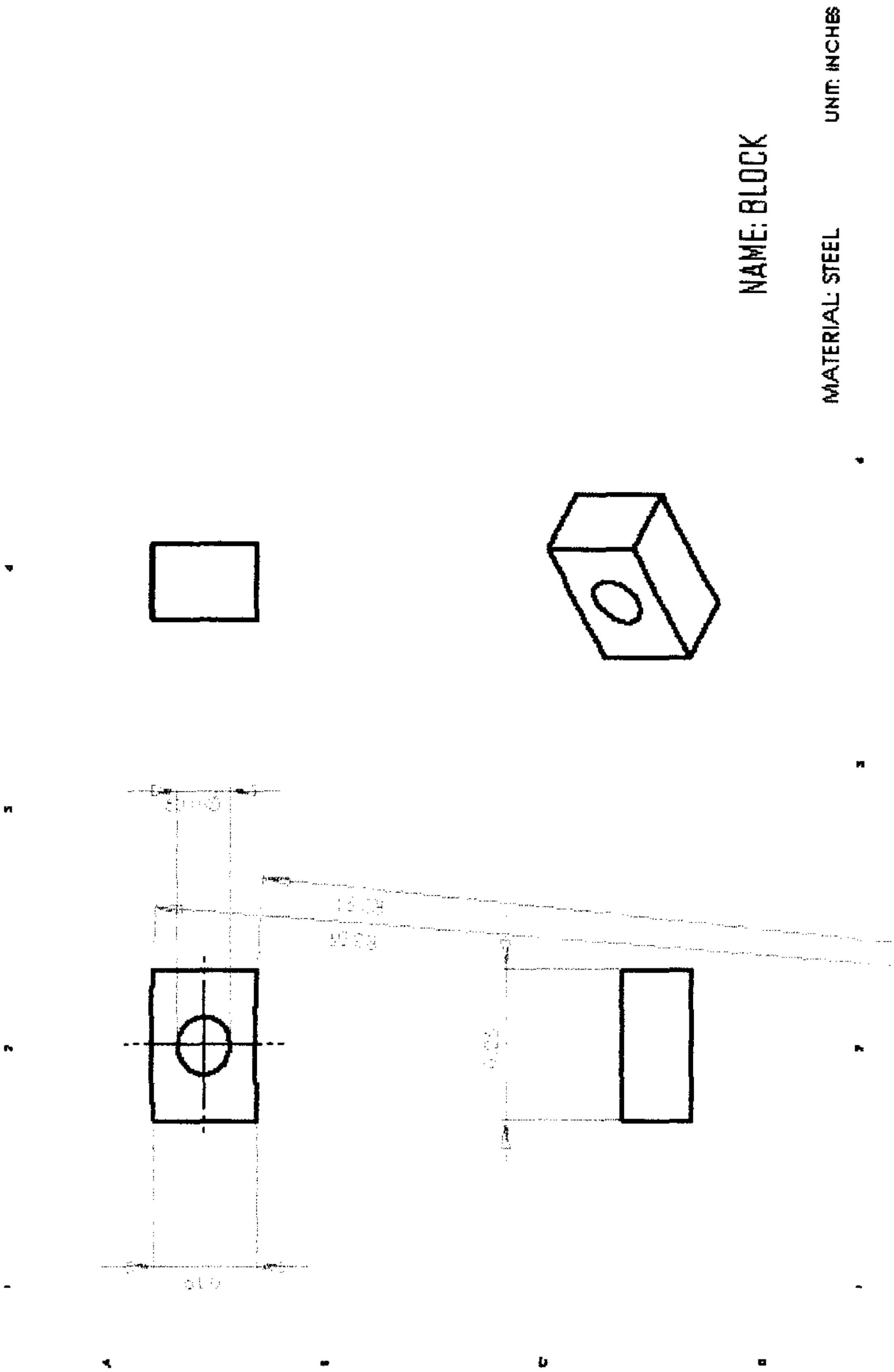
APPENDIX L



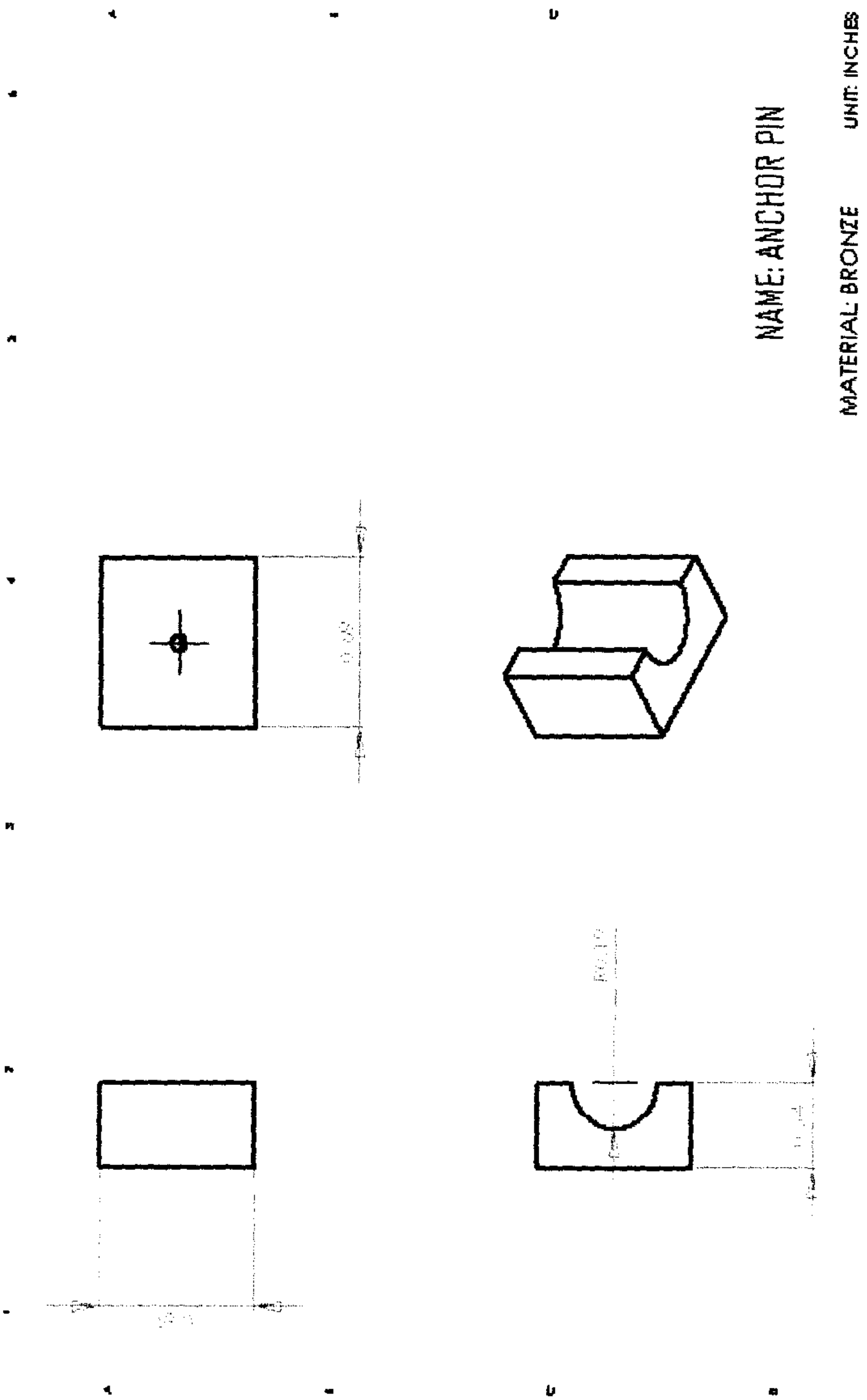
APPENDIX M



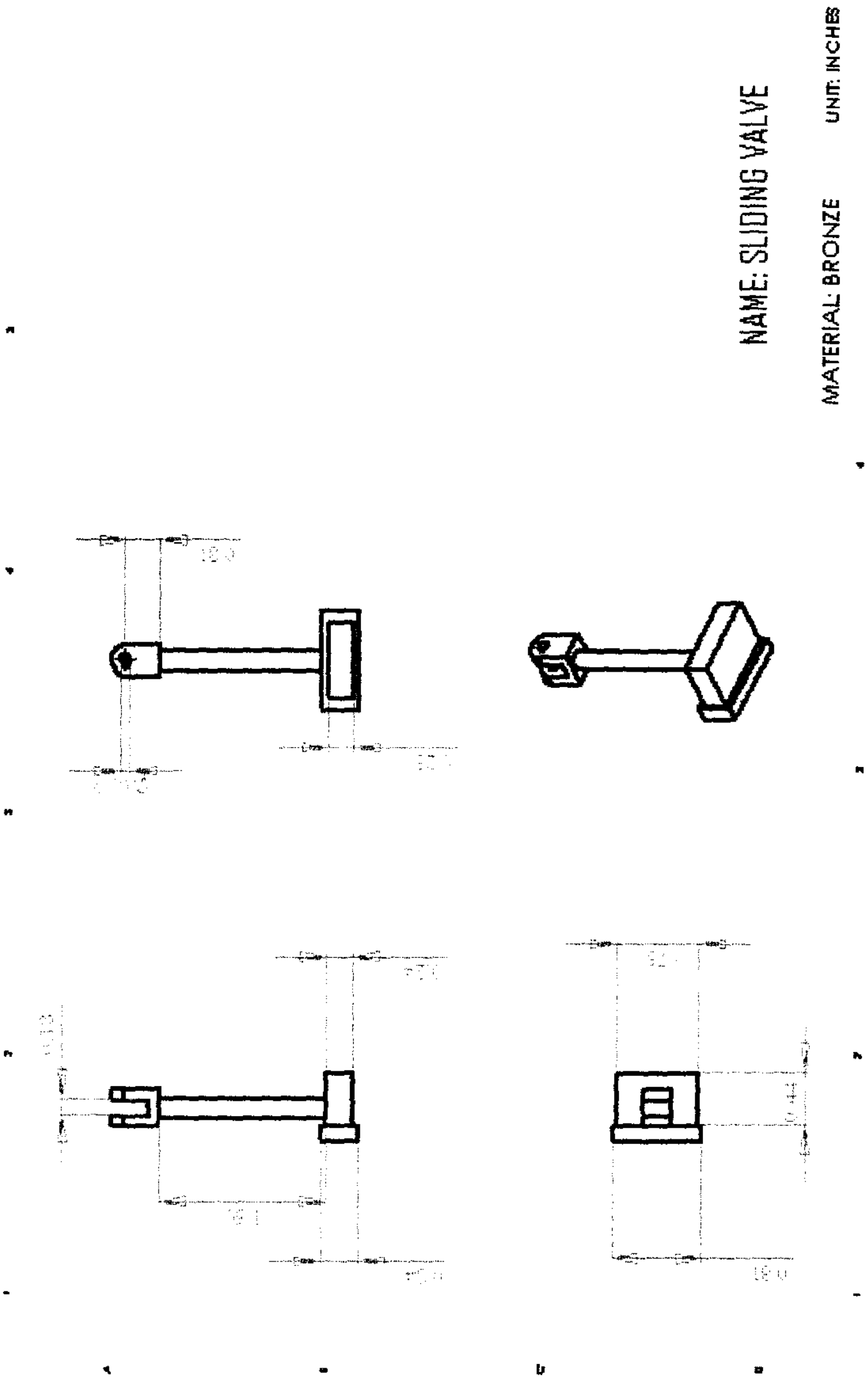
APPENDIX N



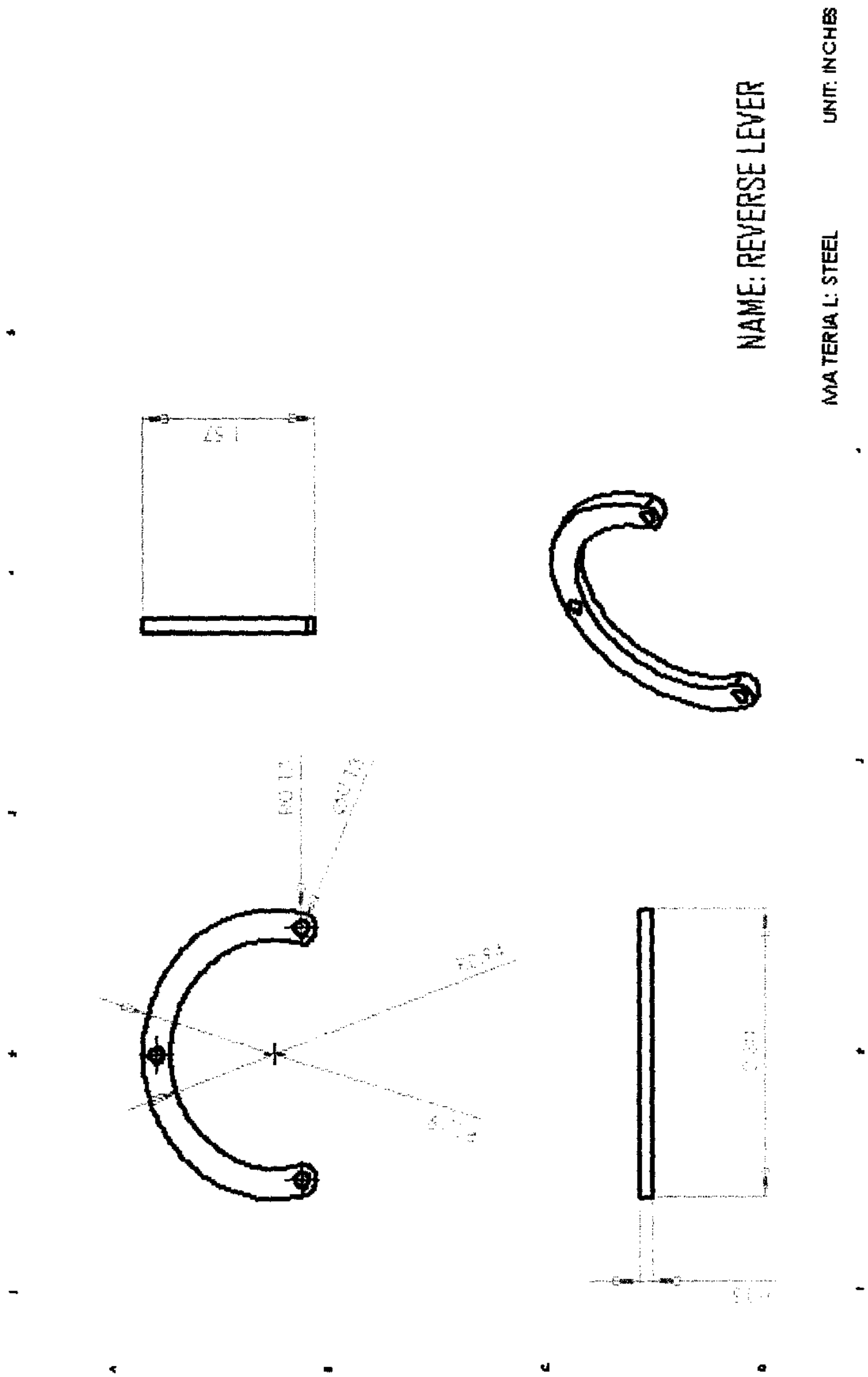
APPENDIX O



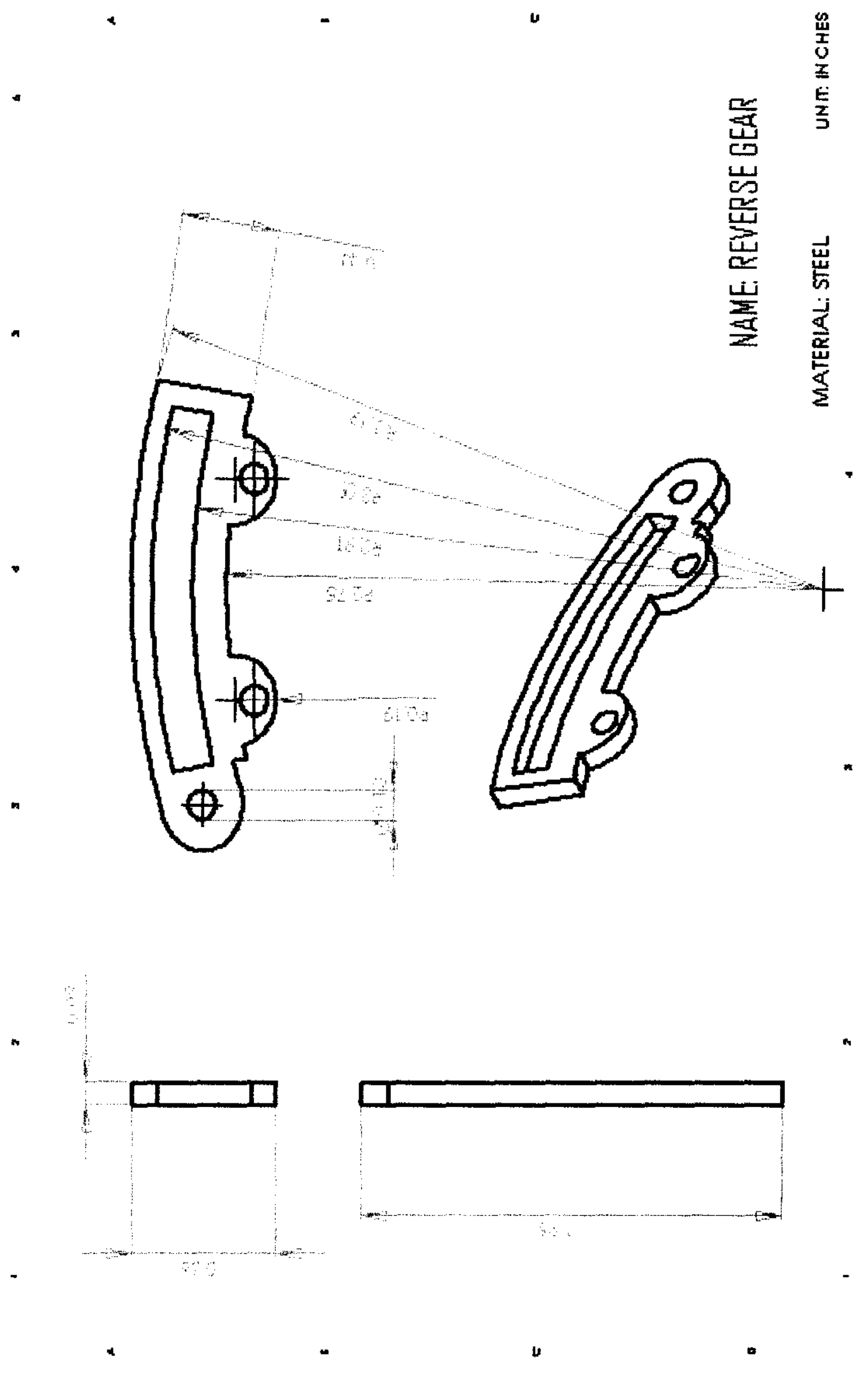
APPENDIX P



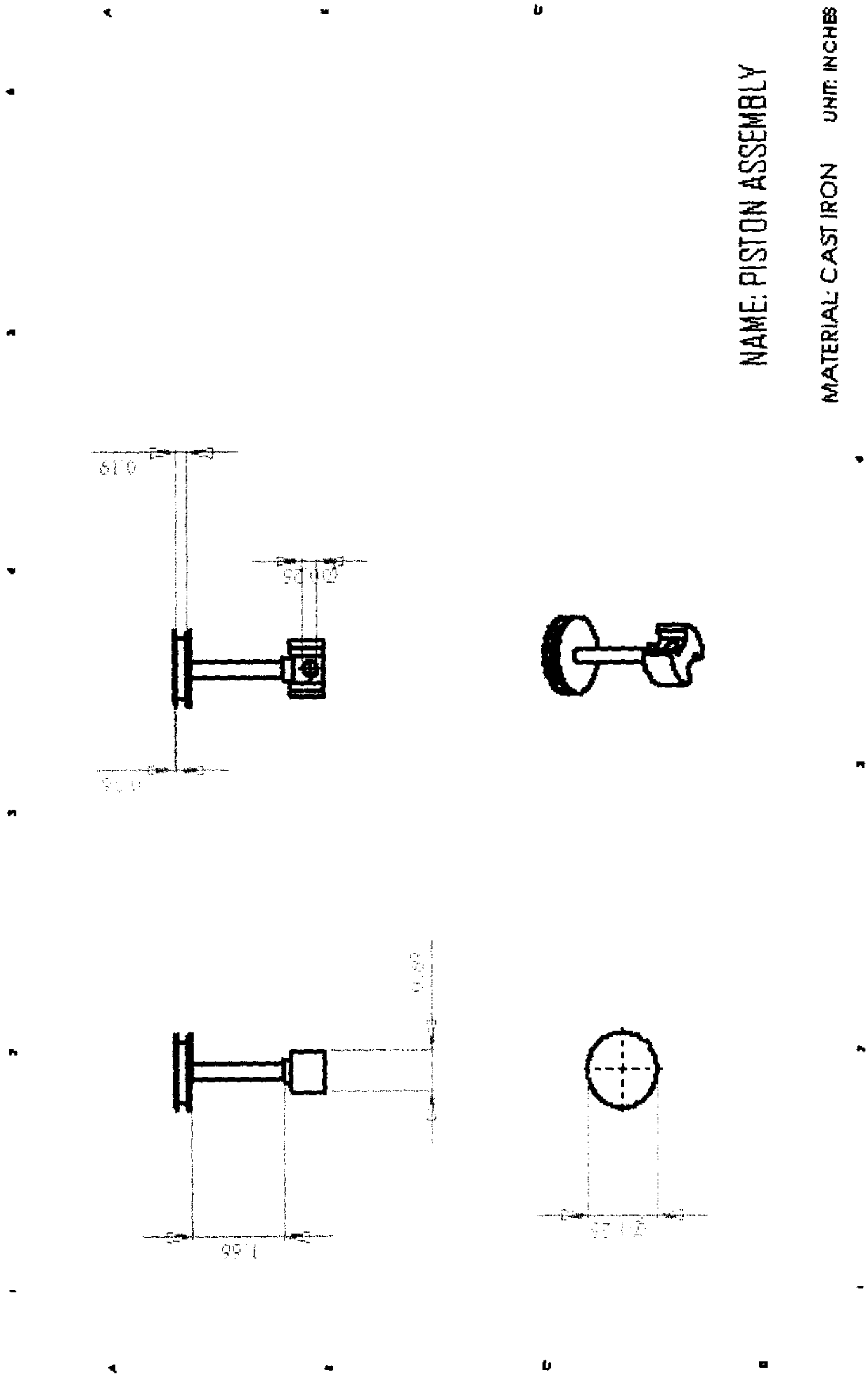
APPENDIX Q



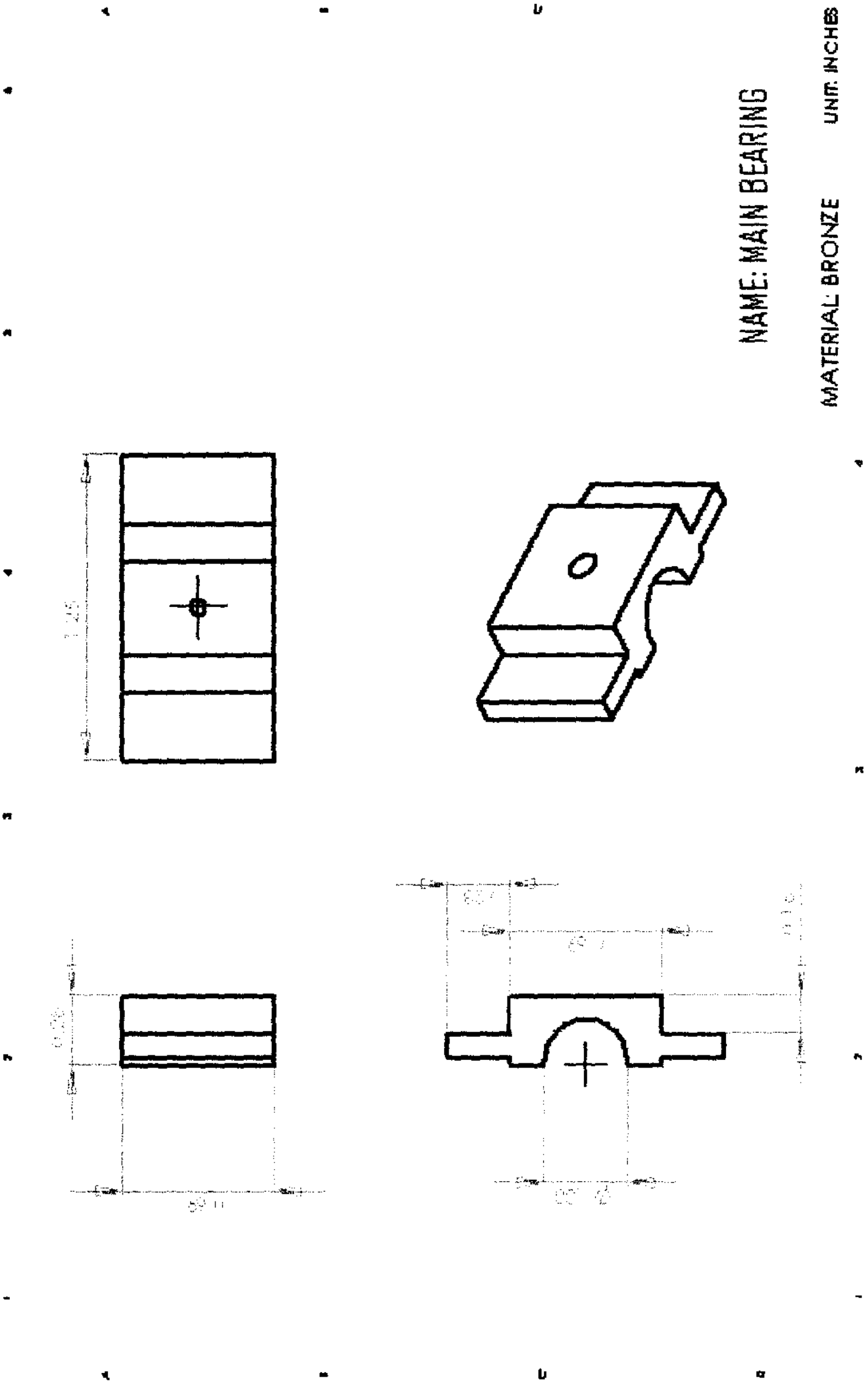
APPENDIX R



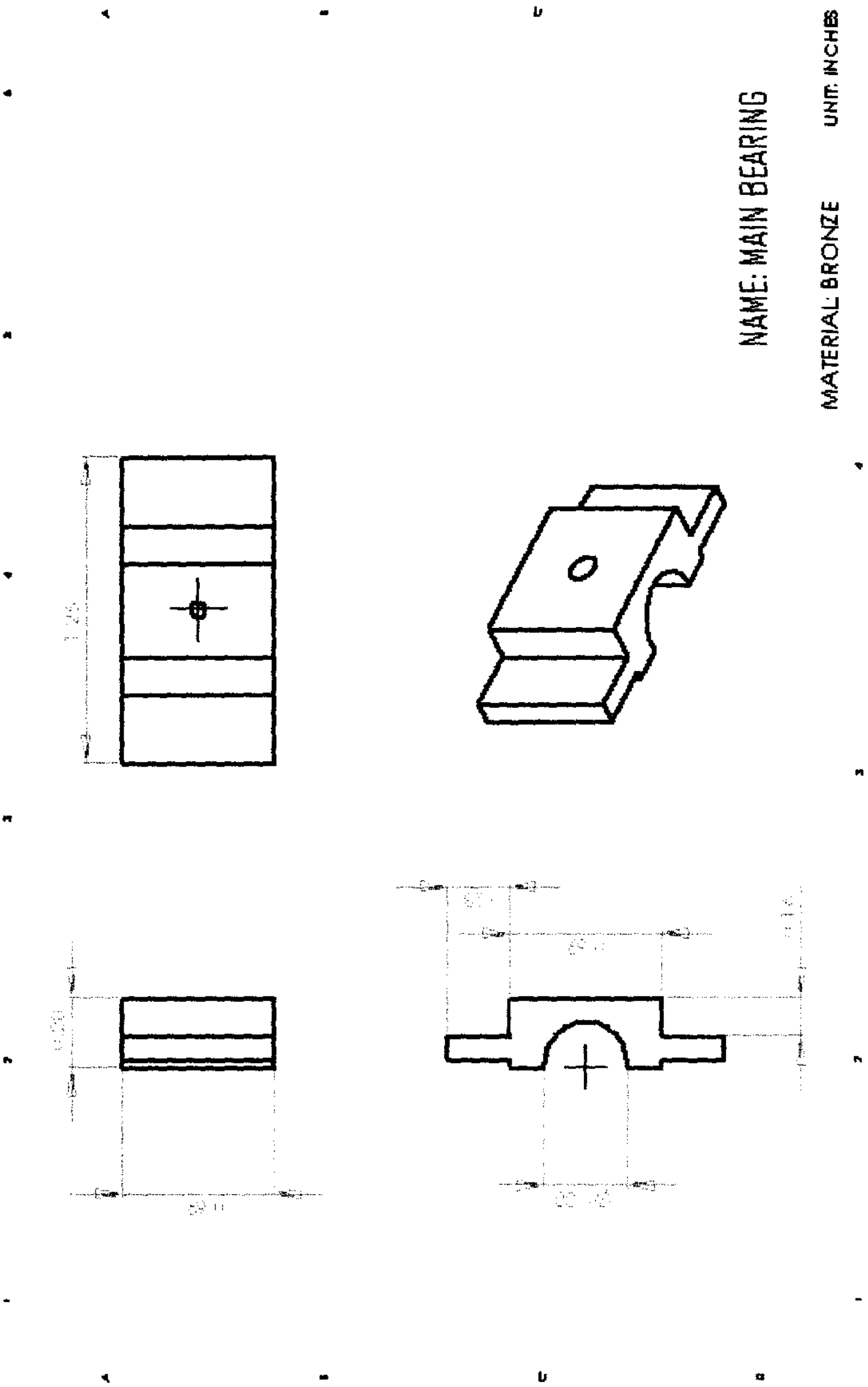
APPENDIX S



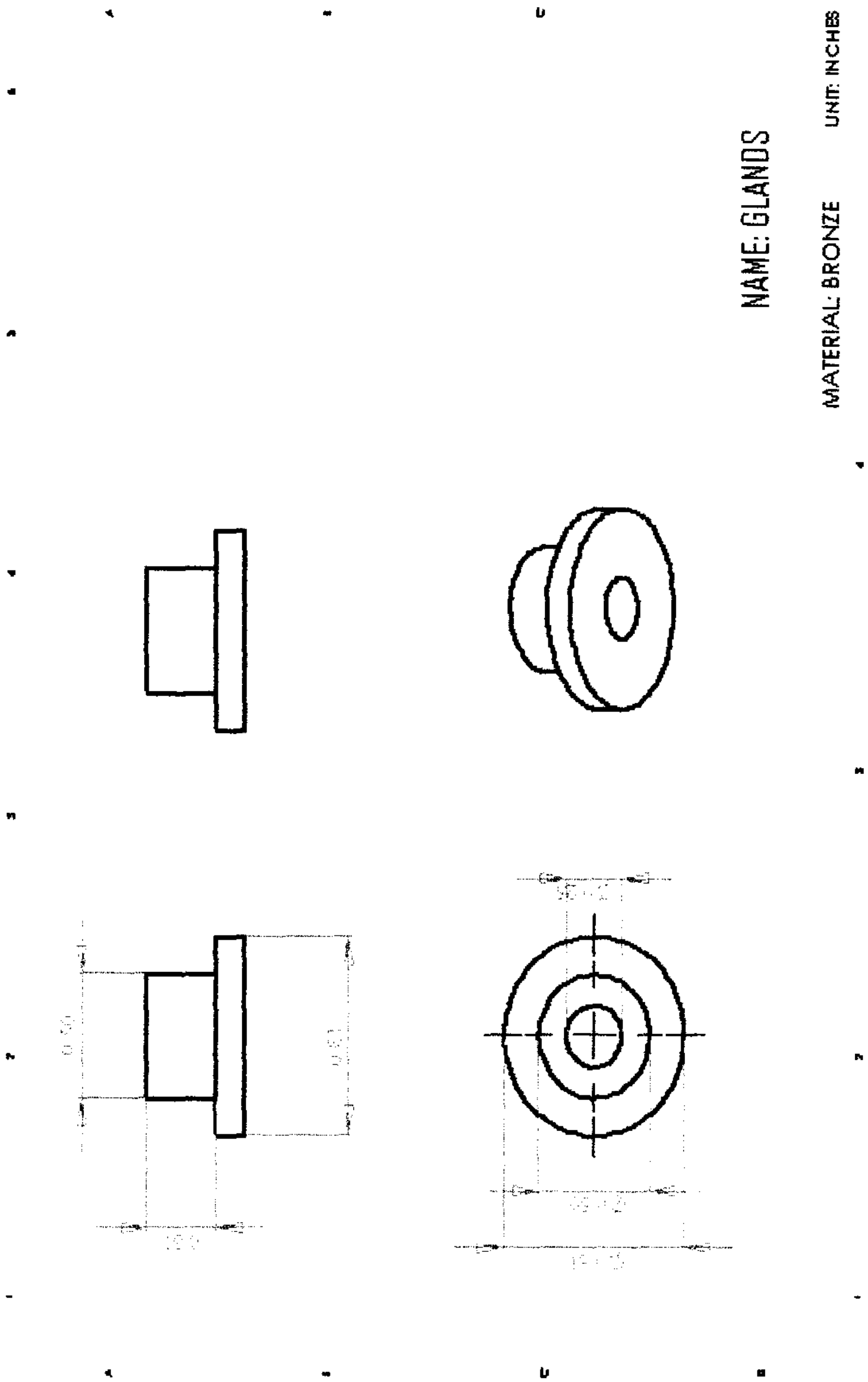
APPENDIX T



APPENDIX T



APPENDIX U



APPENDIX V