PROPOSAL FOR EFFICIENT METHODS TO PRODUCE CURVED PISTON FOR MASS PRODUCTION

by

Jeremy Low Wei Wen

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JANUARY 2013

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CERTIFICATE OF APPROVAL

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A project dissertation submitted to the

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Approved:

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May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or person

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Jeremy Low Wei Wen

ABSTRACT

In the century that we are in today, the demand for more efficient and cleaner engine has been on a rise. The curved piston engine possesses very high potential for commercialization because of its many advantages compared to the conventional internal combustion engine. These engines are mostly still in the conceptual stage where many patents are found but none of it have been commercialized or mass produced. Hence, this research will be dedicated to experimenting and researching for efficient methods to produce curved pistons for mass production. The structured framework to complete this research will be to experiment and access the efficiency of the casting method to mass produce a curved piston. The outcome of this project will assist industries to systematically identify the gaps and provide the solution related to the mass production of curved pistons. Therefore the industries could efficiently produce and move forward in the production and innovations of rotary engines.

ACKNOWLEDGMENTS

First and foremost, I would like to extend my deepest gratitude to my project supervisor, AP. Ir. Dr. Masri Baharom who has been my supervisor and mentor throughout the whole Final Year Project. Not only was he a teacher and a coach, he was also a great role model in terms of working behavior and attitude towards others. He always had on a positive outlook on everything that we did and I would also like to thank him for the trust that he had in me to allow me to lead and drive this project on my own.

I would also like to express my appreciation to Dr. Ahmad Majdi B A Rani, Dr Setyamartana Parmanand and all the members of the Mechanical Department who have been supportive and willing to help out by dedicating their time and effort to teach and guide me.

Finally, I would like to my family and friends for their continued encouragement and support, for without them, I would have not been who and where I am today.

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ABBREVIATIONS & NOMENCLATURES

CAD	-	Computer Aided Design
CAE	-	Computer Aided Engineering
ABS	-	Acrylonitrile Butadiene Styrene

CHAPTER 1

INTRODUCTION

1.1 Background

The piston is the first element in the chain of power-transferring parts in a piston engine. Its main function is to convert thermal energy into mechanical energy. However, its purpose is not limited to only that, a piston together with the piston rings seals the combustion chamber from the crankcase and conducts the heat generated to the coolant and cylinder walls. Piston features include the piston head, piston pin bore, piston pin, skirt, ring grooves, ring lands, and piston rings (Basshuysen& Schafer, Modern Engine Technology, from A to Z, 2006). These various functions and features of a piston make it one of the most important components of an engine, thus making the task of designing and manufacturing it complicated. This project will cover the design and fabrication for mass production of curved piston head, ring grooves and the piston rings.

A curved piston is used in a rotary type internal combustion engine or also known as toroidal engines. The difference between rotary engines and a regular engine is that the pistons in the rotary engine move in a rotary motion, around a circular shaped cylinder. These pistons vary according to the shape, angle and size of the engines. So far, there are very few known rotary engines which are widely used in the automotive industry. Amongst the famous rotary engines are the likes of Bradshaw engine, Morgado engine and the Wankelengine. Hence, the manufacturing of the pistons for rotary engines are currently still in the conceptual stage and presents a great opportunity for research studies.

Another vital component of a piston is the piston rings. Piston rings are an expandable split ring used to provide a seal between the piston and the cylinder wall. Piston rings are commonly made from cast iron. Cast iron retains the integrity of its original shape under heat, load, and other dynamic forces. Piston rings seal the combustion chamber, conduct heat from the piston to the cylinder wall, and return oil to the crankcase. Piston ring size and configuration vary depending on engine design and cylinder material. Piston rings commonly used on small engines include the compression ring, wiper ring, and oil ring (Basshuysen& Schafer, Modern Engine Technology, from A to Z, 2006) (Windsor, 2008).

Mass Production means the method of producing goods in large quantities at low cost per unit. But mass production, although allowing lower prices, does not have to mean low-quality production. Instead, mass-produced goods are standardized by means of precision-manufactured, interchangeable parts(F.Thompson). The methods for mass producing a piston have been available for a long time now, but with the introduction of curved pistons, more extensive research has to be done so that the quality of the curved pistons produced are always maintained.

1.2 Problem Statement

The curved piston engine or rotary engine is a new and upcoming concept of an internal combustion engine. The curved piston engine possesses very high potential for commercialization because of its many advantages compared to the conventional internal combustion engine. These engines are mostly still in the conceptual stage where many patents are found but none of it have been commercialized or mass produced. The methods of mass producing the curved piston are currently not available and therefore draw attention for research.

1.3 Objective & Scope of Study

Objective of this study is to propose efficient methods to produce curved pistons for mass production.

Scope of study:

a) Propose mass production method for curved pistons
b) Forecasting the demands for curved piston engines
c) Simulate and prove that mass production methods are feasible

CHAPTER 2

LITERATURE REVIEW

Internal combustion engines are heat engines that convert the chemical energy of a fuel into mechanical energy by means of combustion process. Diesel and gasoline engines are among the most widely used internal combustion engines. Internal combustion engines are used to power road and rail vehicles, ships and airplanes as well as steady-state facilities such as emergency generators. Currently, there are many kinds of internal combustion engines in the market, ranging from two-stroke and four-stroke engines, naturally aspirated and supercharged engines, self-ignition and externally ignited engines, single-fuel and multifuel engines (Basshuysen & Schafer, Modern Engine Technology, from A to Z, 2006).

The next big innovation in the world of engines is the rotary engines. Rotary engines are becoming more and more popular nowadays because it is considered to be more efficient. Rotary engines claim to be substantially free from vibration and noise, small in friction loss, improved in mechanical efficiency to a considerable extent, compact and lightweight, and applicable to a reciprocating piston engine(Mashimo & Ito, 2002). In a conventional piston engine, where the piston moves in an up and down movement within the cylinder, the pistons are subjected to periodic side pressure caused by the tilting of the connecting rod. Hence, the piston experiences a phenomenon called "piston slap" where the pistons hit and rub the cylinder walls. This is the major factor in vibrations, noises and friction losses in the conventional piston engine(Mashimo & Ito, 2002). On the other hand, a piston in a rotary engine's cylinder is curved in shape and the piston rocks back and forth at an angle. This rotary motion of the pistons in the rotary engine helps reduce vibration and friction loss.

The Bradshaw engine is one of the earliest known rotary engine. It is created by Granville Bradshaw in 1955(Bradshaw, 1961). The Bradshaw engine consists of a single toroidal chamber and four double ended pistons. The pistons reciprocate in the chamber in pairs and the cylinder rotates around them. However, Brashaw's design of the engine is not the best. Many critics have been aimed at the oversized design of its engine and also the expensive cost of manufacturing its pistons.

One of the latest and well known rotary engine is the Morgado engine, or also known as the MYT engine which was introduced by its inventor Raphael Morgado in 2006(Morgado, 2004). The Morgado engine has an operating principle similar to that of a Bradshaw engine. It has a single toroidal chamber, 4 double ended curved pistons and the pistons in the toroid move back and forth in conjunction with a rotating crank and connecting rod assembly. It claims to be the best power to weight ratio engine out there. A rotary engine generally consists of a curved cylinder, curved pistons, a rotor, connecting rods and a crankshaft.

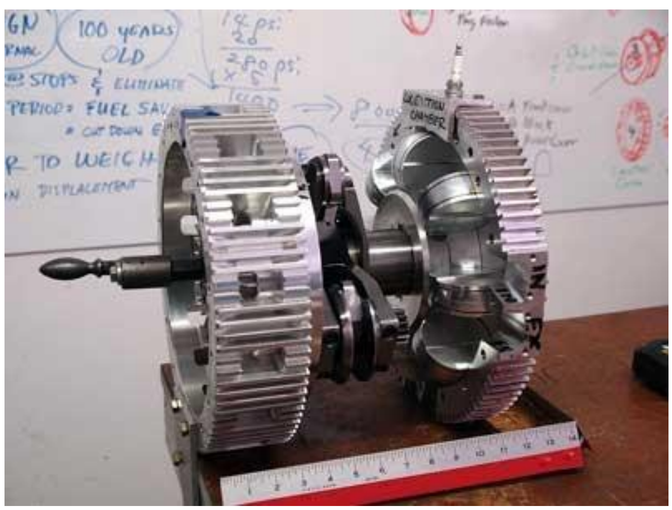


Figure 1: Morgado (MYT) Engine.

A piston is a component in an engine which accepts the pressures created by the ignition of the fuel and air mixture, transferring these forces via the wristpin and the connecting rod to the crankshaft. A piston is manufactured in multiple ways, namely die casting, centrifugal casting, continuous casting, forging, liquid pressing, tempering or machining(Basshuysen & Schafer, Internal Combustion Engine Handbook, 2004). All these methods have been tried and tested on a conventional piston. Can they be adapted to be used on a curved piston?

Forging or warm flow pressing is used to manufacture pistons and piston skirts for engines subject to heavy load. Aluminum alloys are used. Forged pistons are not used today for passenger car engines because they are too heavy(Basshuysen & Schafer, Modern Engine Technology, from A to Z, 2006). Die casting is the process in which aluminum alloys are manufactured into pistons. Molten aluminum alloys are melted and then poured into specially prepared molds to solidify into the shape of a piston.

Today, a vast majority of pistons are produced using casting. Gray cast iron pistons are cast using sand casting method whereas aluminum pistons are primarily cast using chilled casting process. The molds, made of ferrous materials, cause quick solidification of the molten metal. This produces pistons with fine-grained structure with good strength properties. Optimized mold casting together with carefully designed riser and gating technology is vital in order for error-free castings. In order to meet high demands and to mass produce pistons, all steps including pouring molten metal into casts are automated. Here, multiple molds and robot arms are used to maximize the output of the plant.

Casting has many advantages as well as disadvantages. Objects that are casted can vary from 5 grams to 200 tons. This shows the flexibility in the casting process. Besides that, casting can also be effectively used to produce parts that are complex in design with multiple bends or holes. The casting process allows for intricate design of parts and tools with minimal limitations. And most importantly, casting is cost saving. It is a process which is relatively cheap.

The casting process has its disadvantages as well. The products produced from the casting process are not finished yet. It has to be polished and cleaned before being able to be shipped. Hence, depending on the technology used for casting, the finishing and polishing of the molded parts will tend to be more costly than the actual casting process itself. Besides that, the cast products are superior for compressive loads but poor in terms of tensile or shock loads.

There are two kinds of die casting machines available at the moment. One is the hot-chambered die casting machine and the other is the cold-chambered die casting machine. The hot-chambered die casting machine is primarily used for casting of metals with low melting points (< 800°F). Whereas the cold-chambered die casting machines are used with higher melting point metals. A furnace is needed to melt the alloys or metals then, the liquid alloys are manually ladled into the cold-chambered die casting machine. This process of die casting curved pistons will use the cold-chambered die casting machine.

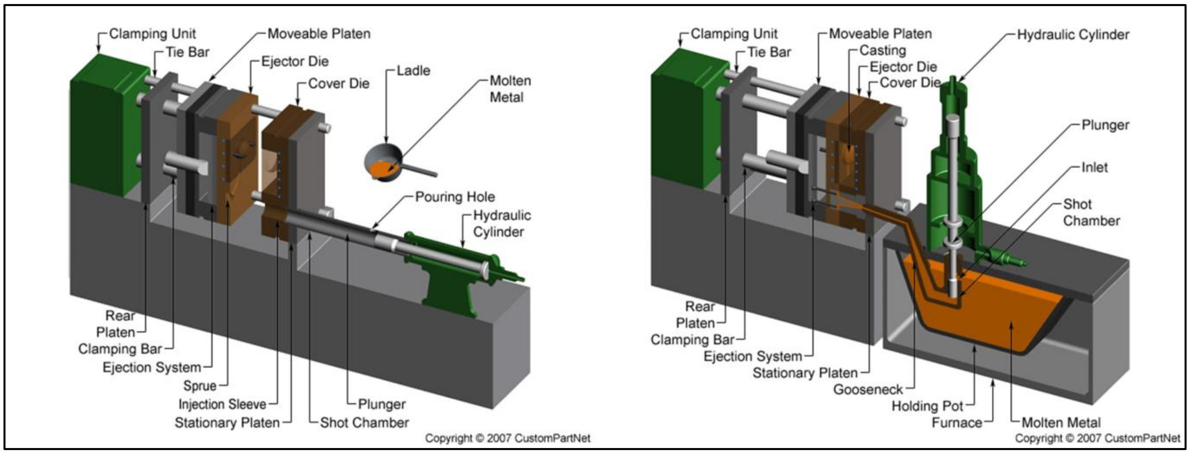


Figure 2: Left: Cold-chambered Die Casting Machine; Right: Hot-chambered Die Casting Machine

A piston ring on the other hand is also an important part of the engine. Piston rings are metallic gaskets whose functions are to seal the combustion chamber against the crankcase, to transmit heat from the piston to the cylinder wall, and to regulate the amount of oil present on the cylinder sleeve. It is necessary for this purpose that the piston rings to be in close contact with both the cylinder wall and the ring groove on the piston. Contact with the cylinder wall is ensured by the spring action inherent to the ring itself, which expands the ring radially (Basshuysen & Schafer, Internal Combustion Engine Handbook, 2004). There are conventionally 3 rings on a piston. The top ring, also known as the compression ring, assumes the sealing function and dissipates heat to the cylinder walls. They are located in the first ring groove, nearest to the piston head. The second ring, also known as intermediate ring or wiper, assist the compression ring in sealing the combustion chamber and dissipating heat. Besides that, the wiper also helps control the lubricating oil consumption. The third ring, also known as oil control ring, regulates and limits the oil on the cylinder walls. It scrapes excess lubricating oil off of the cylinder wall and returns it into the cylinder chamber. Piston rings are usually produced using high-quality cast iron with lamellar graphite interstratifications and nodular graphite (Basshuysen & Schafer, Modern Engine Technology, from A to Z, 2006).

Figure 3: Piston and Piston Rings.

The term "Manufacturing" is derived from the Latin words, *manus* (hand) and *factus* (make), which literally translate to *made by hand*(Groover, 2008). In the olden days, this is how products were produced, by hand in small workshops. As times passes and demand for commercial goods increased, factories were built to house the workers as well as mass machineries and mass manufacturing is born. Today, in the system for mass manufacturing, it is far more complex and much more planning has to be put in place in order for the processes and operations to run smoothly. Planning in terms of man power, supply of raw materials, and much more is needed.

Mass Production means the method of producing goods in large quantities at low cost per unit. But mass production, although allowing lower prices, does not have to mean low-quality production. Instead, mass-produced goods are standardized by means of precision-manufactured, interchangeable parts(F.Thompson). The methods for mass producing a piston have been available for a long time now, but with the introduction of curved pistons, extensive research has to be done so that the quality of the curved pistons produced are always maintained.

CHAPTER 3

METHODOLOGY & PROJECT WORK

3.1 Methodology and Project Work

In designing a die-casting process to mass produce a product, an ideal methodology has been designed as a guideline. The flow diagram is depicted here as prepared by Bill Andresen in his book titled “Die Casting Engineering”.

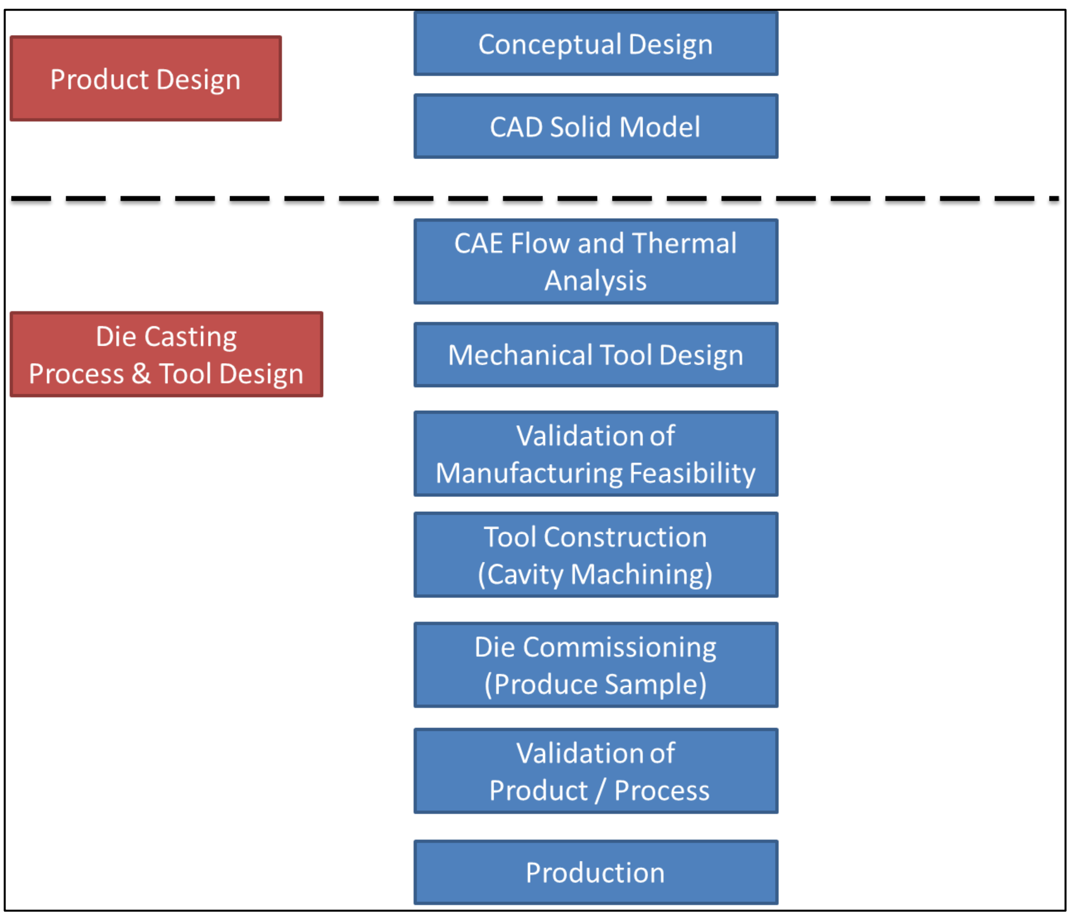


Figure 4: Ideal methodology in die casting process design.

For a comprehensive plan like this, feedback and data is required from the metal flow and thermal analysis (Andresen, 2005). Hence, to prove that this project is indeed feasible, all these design and data will be analyzed. But due to the limitations in resources and time, certain steps in the methodology above are not able to be carried out. For example; Tool constructions (cavity machining) and Die Commissioning (produce sample).

The design of the manufacturing process is divided into 2 portions, the first being the product design and the second being the die casting process and tool designs. In early stages of a product design, a conceptual design must be available. Next, CAD solid model of the desired product must be produced according to specification. Then, we can proceed to the next phase.

In the die casting process and tool design, CAE flow and thermal analysis is done to simulate the flow of material in the molds and the thermal effects on the model. After obtaining the simulated results, the time taken for each die casting cycle can be estimated. Besides that, air bubble traps can also be predicted in each design. After validating that the design is feasible, the manufacturing process design can begin. In designing the manufacturing process, one must consider the state of the material after the casting process. After completing the die casting process, the product is not finished as it still has to undergo certain process such as drilling, polishing, inspection and packing before it can be shipped.

The following chapter will display the data collected and discussions.

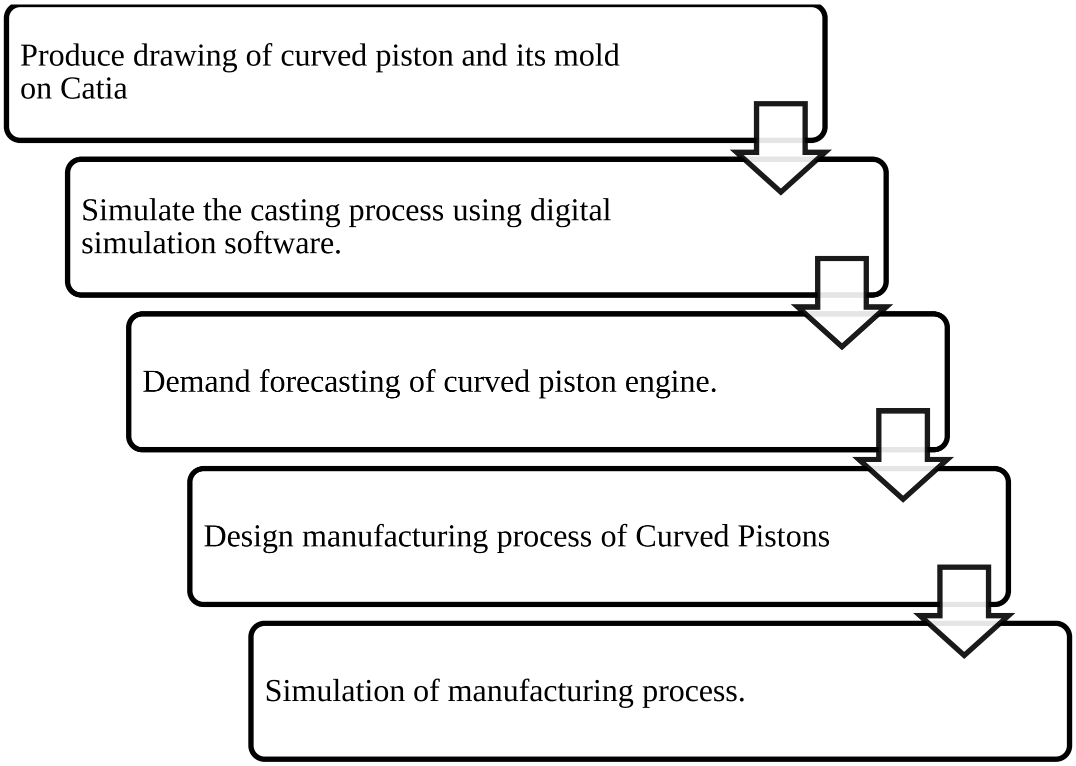


Figure 5: Process flow of FYP

3.2 Key Milestones

The key milestones of this project are as follows:

- Complete drawings of curved piston and its mold.
- Digital simulation of casting process.
- Forecasting of demand and simulate manufacturing process.
- Design of Manufacturing Process
- Simulation of Manufacturing Process
- Report Preparation

3.3 Gantt Chart

Table 1: Gantt Chart

No	Milestone	April	May	June	July	August	September
1	Complete drawings of curved piston and its mold.	X	X				
2	Digital simulation of Casting process.		X	X	X		
3	Forecasting of demand			X			
4	Design of Manufacturing Process			X	X	X	
5	Simulation of manufacturing process.					X	X
6	Report Preparation						X

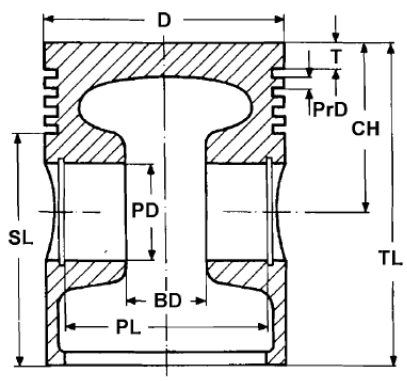
* Project works which are done are marked 'X'.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 CAD of Curved Piston

The figure below shows the design guidelines for the conventional piston. As the curved piston will be used in a gasoline engine, the dimensions and design adheres to the general guidelines below.



		%D	
		Gasol.	Diesel
D	Diameter	100	100
TL	Total length	70-110	90-160
SL	Skirt length	40-100	50-110
CH	Compression height	35-70	50-100
T	Topland height	6-12	10-22
PrD	Piston ring distance	4-5	7-9
PL	Pin length	85	85
PD	Pin diameter	22-30	30-44
BD	Bearing distance	25-40	28-46

Figure 6: General Guidelines for Piston Designs.

The curved piston used in this project will be designed by first determining the diameter. The diameter of the curved piston is set to be 50mm. The curved piston is also designed to be curved at a 47° angle to the plane.

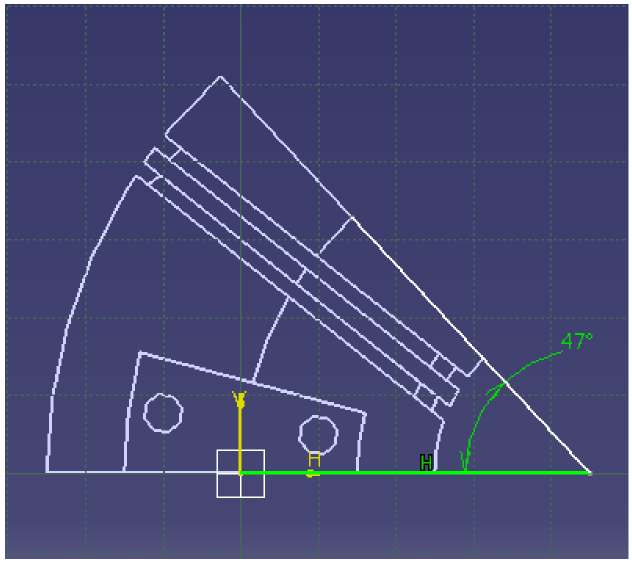


Figure 7: Curved Pistons angle.

The dimensions of the curved pistons are as follows:

Table 2: Dimensions of Curved Piston.

Parts of Piston	Dimension (mm)	% D
Diameter, D	50mm	100%
Total Length	57.42mm	114%
Skirt Length	22.1mm	44.2%
Compression Height	30.63mm	61.26%
Topland Height	3mm	6%
Piston Ring Distance	2.5mm	5%
Pin Diameter	5mm x 2 pins	20%

The CAD models of the curved piston are designed using Catia V5 and the drawings are as follows:

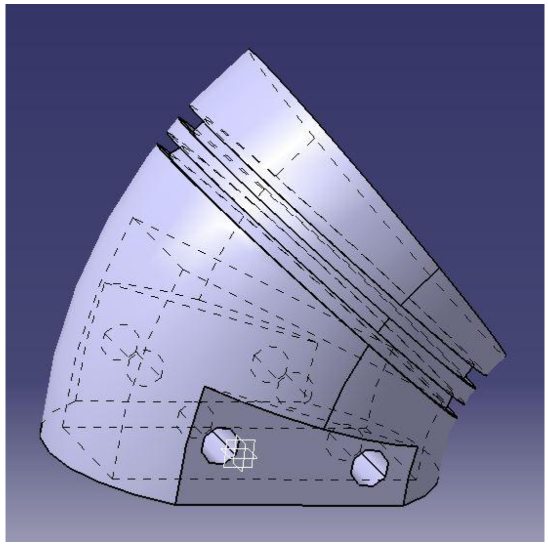


Figure 8: 3D view of curved piston.

Figure 8 shows the 3D view of the finalized curved piston. The curved piston will consist of 2 piston ring grooves, 2 pin holes and a hole cut out in the middle of the piston to reduce its weight.

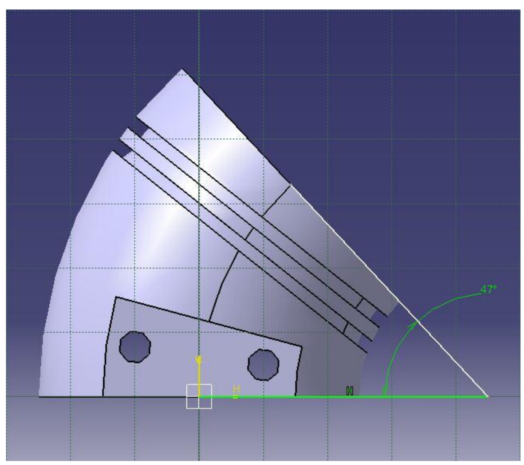


Figure 9: Side view of the curved piston.

Figure 9 shows the curved nature of the curved piston. The curved piston is curved at a 47° angle to the plane. The curved angles are constant throughout the design of all other parts of the piston.

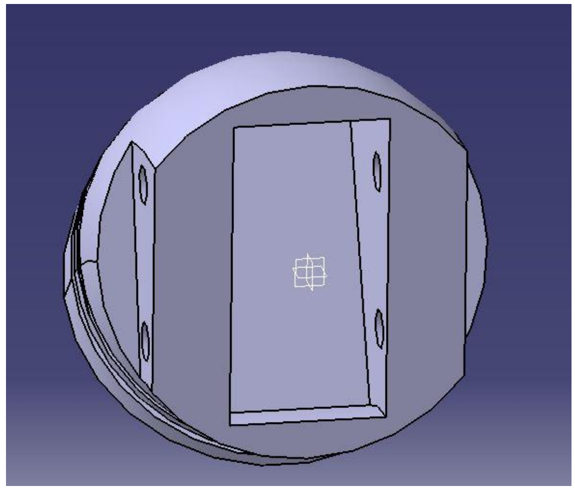


Figure 10: Bottom view of Curved Piston.

Figure 10 shows the size of the cut out parts on the sides and middle of the piston. The purpose of removing these parts is to first and foremost reduce the weight of the piston. By reducing the weight of the piston, the flywheel design can be smaller and the combustion energy will be transferred efficiently. Besides that, these parts are also removed to reduce the heat retention in the piston. By lowering the overall weight and material on the piston, heat can be quickly transferred to the cylinder walls.

4.3 CAD of Curved Piston Mold.

The CAD of curved piston's mold is detailed below.

Table 3: Dimensions of Mold.

Mold (Combined)	Dimensions (mm)
Height	70mm
Length	100mm
Thickness	60mm

The designs of a mold are not as simple as it seems. There are many rules in the design of molds. These rules are based on logic, convenience and economy (Rees, Understanding Injection Mold Design, 2001) . Since the molds are designed to be reused many times for mass production, mild steel alloy molds are used. A mold design can be of a 2-part mold, 3-part mold or 4-part mold.

The design of the curved piston requires a 3-part mold because of its unique curved design and angled cut-outs. The drawing and design of the molds are also done using Catia V5 and the figure below shows the design of the molds.

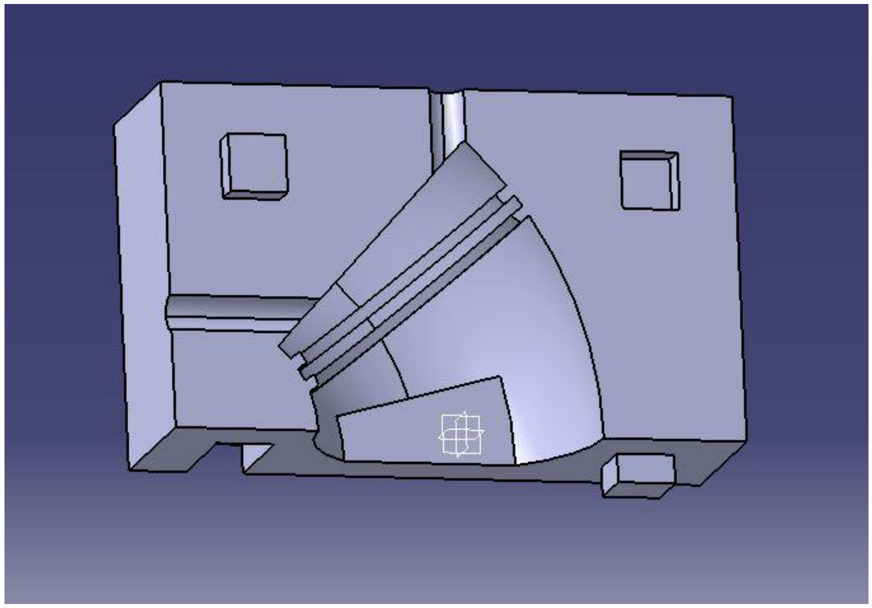


Figure 11: Left Side Mold

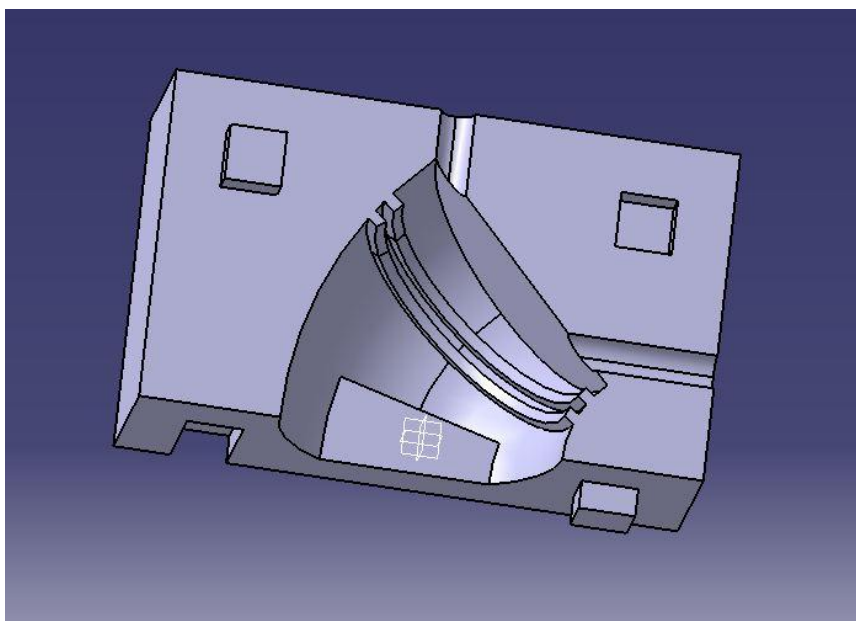


Figure 12: Right Side Mold

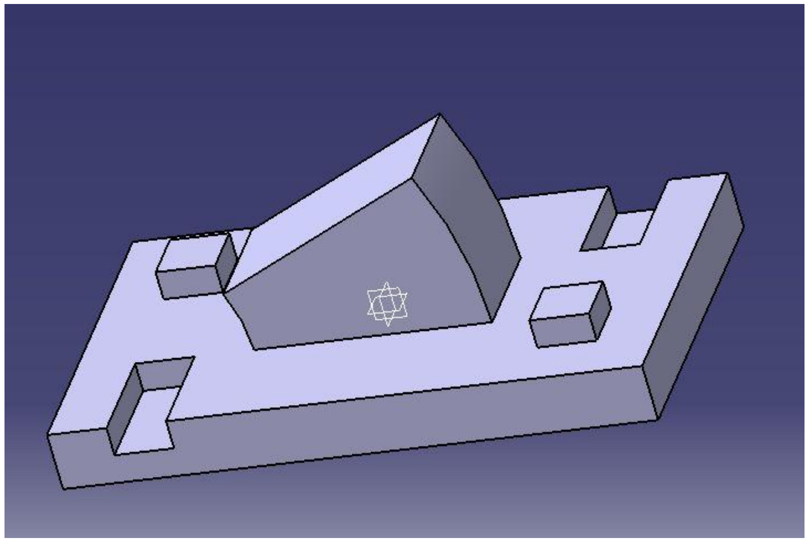


Figure 13: Bottom part of Mold.

Molten aluminium alloy will be pumped into the die from the top of the mold (z-direction). The computer aided engineering (CAE) flow and thermal analysis of the die casting process will be discussed in the next section.

4.4 CAE Flow and Thermal Analysis.

CAE Flow and Thermal analysis is essential in a die casting process design as to predict the die casting cycle time, air bubble traps and process feasibility. The CAD solid model design of the curved piston is imported from Catia V5 into SolidWorks. The flow and thermal analysis of the die casting process is simulated using an extension to the Solidworks software called SimpoeWorks. SimpoeWorks is the first and only complete plastic injection simulation solution fully embedded into the SolidWorks graphic user environment.

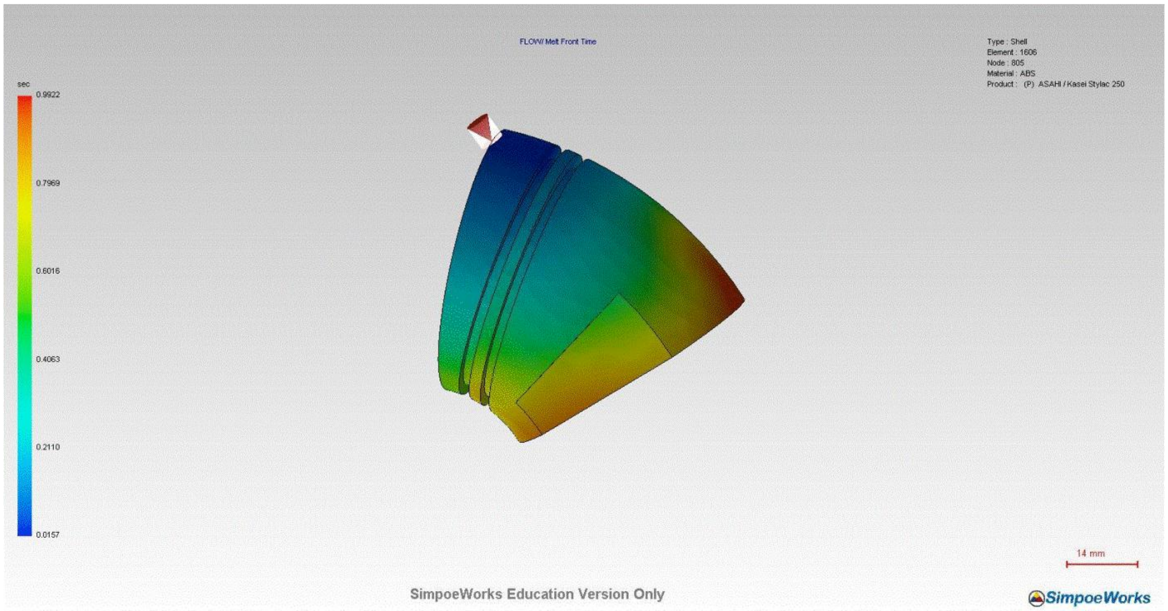


Figure 14: Model of Curved Piston in Simpoeworks

Due to the limitations in software capabilities, the simulations of the die casting process can only be done using polymers as the material instead of aluminium alloy. Hence, certain assumptions and alterations have to be done. Since, aluminium alloy cannot be simulated; a polymer that has the closest viscosity to aluminium has to be chosen as the material for simulations. The viscosities of aluminium alloy at specified temperatures are as follows:

Table 4: Viscosity of Aluminium Alloy versus Temperature

Temperature (°C)	Viscosity (cP)
662	1.379
685	1.324
700	1.268
718	1.250

Since the die casting process of curved piston will be carried out at 700°C, the viscosity value or 1.268 cP is chosen as a baseline. Details of the material chosen for simulation are as follows:

Table 5: Material Parameters

Material Parameter	Details
Polymer Name	Acrylonitrile Butadiene Styrene (ABS)
Product Name (Manufacturer)	Kasei Stylac 250 (ASAHI)
Melting Temperature	230°C
Density	0.66 g/cm³
Viscosity	0.89 cP

The material ABS is chosen because of it has the closest value of viscosity to Aluminium Alloy. All the details of the material are obtained from the SimpoeWorks database. The next parameter to be determined is the flow parameters. The flow parameters consist of the filling time, maximum injection pressure, and maximum injection flow rate and gravity direction. The filling time of aluminium alloy die casting process is generally set to be below 1 second at high pressure and high temperature where it solidifies rapidly (Andresen, 2005). The flow parameters are as follows:

Table 6: Flow Parameters.

Parameters	Values
Filling Time	0.51s
Max. Inject(Machine) Pressure	200 MPa
Max. Inject(Machine) Flow Rate	400 cc/s
Gravity Direction	Z-direction

The summary of flow results are as follows:

Table 7: Summary of Flow Results.

Overall Cycle Time	191.6 sec
X-dir. Clamping Force	0.33 Tonne (0.36 Ton U.S)
Y-dir. Clamping Force	0.50 Tonne (0.55 Ton U.S)
Z-dir. Clamping Force	0.45 Tonne (0.50 Ton U.S)
Requiring injection pressure	4.03 Mpa (583.96 psi)
Averaged perfect cooling time	107.50 sec
Pressure Holding Time	8.34 sec

In this simulation run, the total cycle time data is obtained. Besides that, the required clamping force on the die is also recorded. With the clamping force data and injection data in hand, we can choose a die casting machine that has the capability to achieve those numbers. The next simulation is run to simulate the number of air bubble traps in the die casted curved pistons.

Air bubble traps in die casted products might cause defects in its molecular structures and weaken the overall structure. Hence, it is best to minimize or avoid completely the air bubble trapped in the design. The number of gates was varied to choose the design with the least air bubble traps. The number of gates that were simulated was 1 gate, 2 gates and 4 gates. The results were as follows:

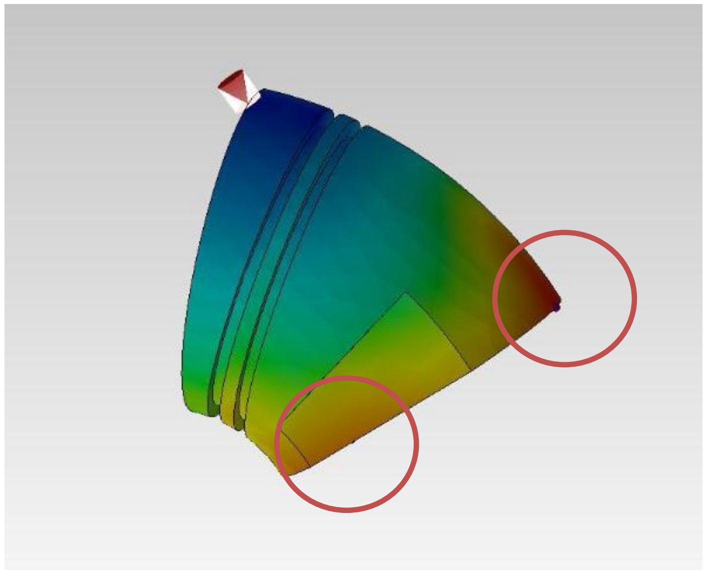


Figure 15: Air bubble traps (1 gate)

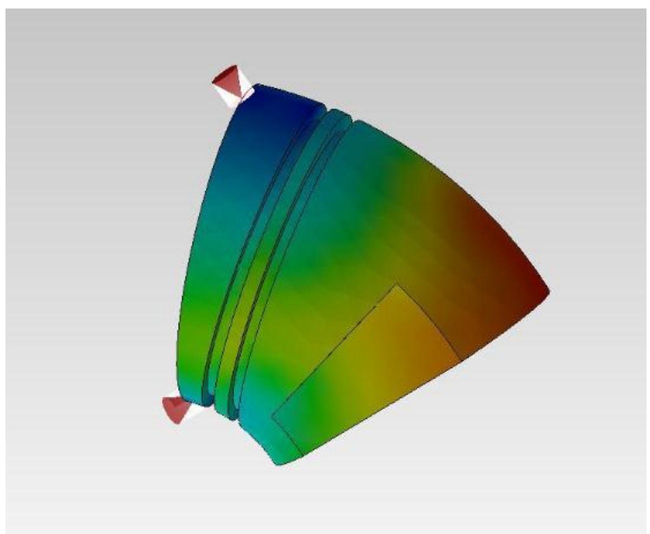


Figure 16: Air bubble traps (2 gates)

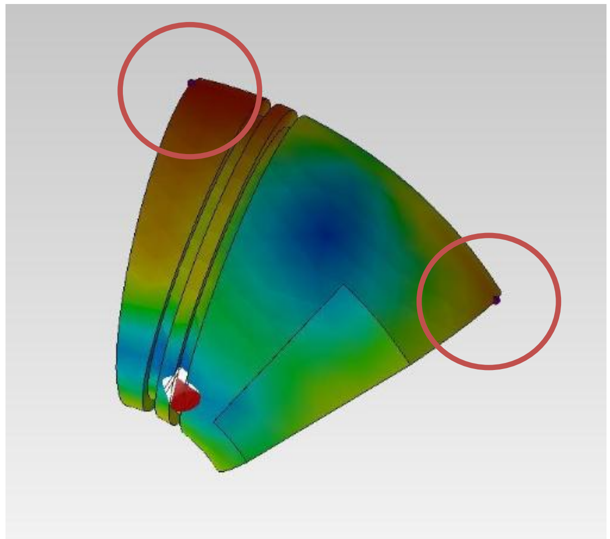


Figure 17: Air bubble traps (4 gates)

As shown in figures 15 and 17, air bubble traps are present in the casted product. But with the usage of 2 gates, the air bubble traps in the casted product is eliminated. Hence, the best mold design should have 2 gates (Figure 16). The selections of gate position are automated by SimpoeWorks. The software will select the optimum gate positions according to the best possible fit.

The final sets of data to be retrieved from SimpoeWorks are the thermal analysis. While this portion of the data is important, due to limitations in the software, thermal analysis is not comparable. This is because the melting and boiling temperature of ABS is considerably lower than aluminium alloy. The results from the thermal simulation of ABS are as follows:

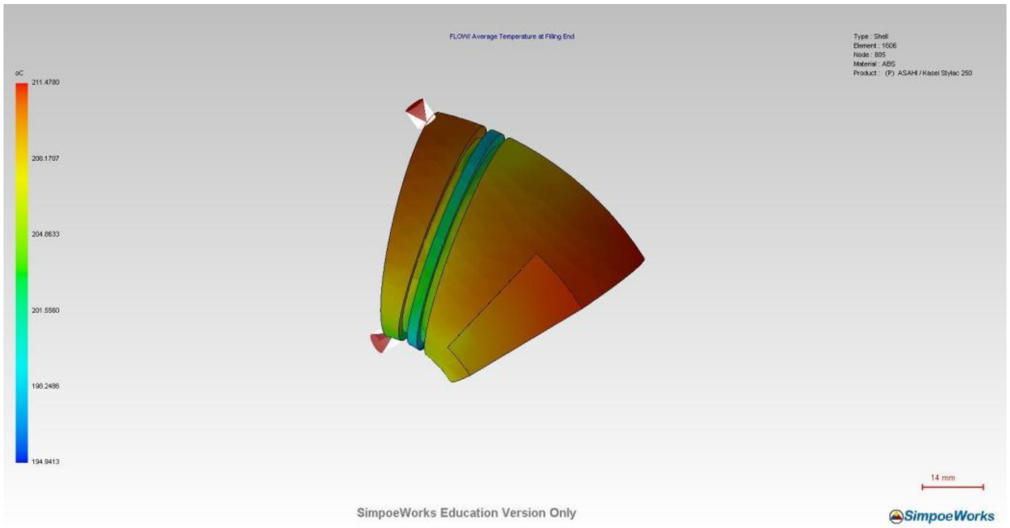


Figure 18: Average Temperature at Filling End

Table 8: Thermal analysis of ABS simulations.

Main Material Melt Temperature	230 °C
Mold Wall Temperature	80 °C
Max. central temperature	230.18 °C
Max. average temperature	211.48 °C
Max. bulk temperature	230.24 °C

4.5 Demand Forecasting

In order to be able to design a manufacturing system that is feasible, a forecasting model must first be drawn out to forecast the demands of a product. With the data of the forecasted demands, the capacity of the manufacturing plant and sizing of machineries can be determined appropriately. In forecasting the demands of the curved piston, a few assumptions have to be made. The assumptions are as follows:

- Curved piston engines are used by year 2015.
- Only passenger cars use curved piston engines.
- A total of 20% of car assembled annually uses curved piston engines.

To forecast the demands of passenger cars from the year 2015 to 2025, data of the number of cars assembled in Malaysia from the year 1980 to 2012 is obtained from the Malaysian Automotive Association.

Table 9: Summary of passenger and commercial vehicles produced and assembled in Malaysia from year 1980-2012.

Year	Passenger Cars	Commercial Vehicles	4x4 Vehicles	Total Vehicles
1980	80,422	23,805	-	104,227
1985	69,769	37,261	-	107,030
1990	116,526	63,181	11,873	191,580
1995	231,280	45,805	11,253	288,338
2000	295,318	36,642	27,235	359,195
2005	422,225	95,662	45,623	563,510
2006	377,952	96,545	28,551	503,048
2007	403,245	38,433	-	441,678
2008	484,512	46,298	-	530,810
2009	447,002	42,267	-	489,269
2010	522,568	45,147	-	567,715
2011	488,261	45,254	-	533,515
2012	509,621	59,999	-	569,620

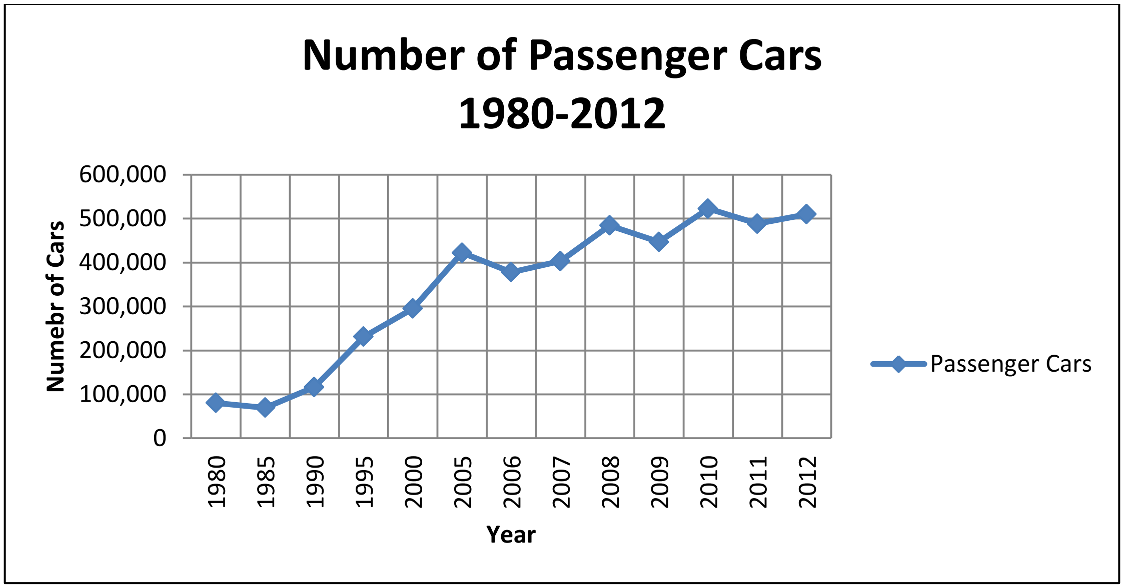


Figure 19: Number of Passenger Cars from 1980-2012.

To forecast the demand of curved piston engines from year 2015 to 2025, the trend projection method is used. Taking into account the data from the past 7 years for analysis, the table below is produced.

Table 10: Analysis of the historical data into trend projection forecasting.

Year	Time Period, X	Passenger Cars, Y	X^2	XY
2006	1	377,952	1	377952
2007	2	403,245	4	806490
2008	3	484,512	9	1453536
2009	4	447,002	16	1788008
2010	5	522,568	25	2612840
2011	6	488,261	36	2929566
2012	7	509,621	49	3567347
	∑X= 28	∑Y= 3233161	$\sum X^2$= 140	∑XY= 13535739

Data from 7 pass years are taken into consideration for forecasting. Hence, n=7.

$x= \sum X/n$

$x= 28/7$

$x= 4$

$y= \sum Y/n$

$y= 3233161 / 7$

$y= 461880.1429$

$b= (\sum XY - n \times y) / (\sum X^2 - n x^2)$

$b= [13535739 - (7*4*461880.1429)] / [140 - (7*4^2)]$

$b= 21539.1071$

$a= y - bx$

$a= 461880.1429 - (21539.1071*4)$

$a= 375723.7145$

From the calculations shown above, the formula used to forecast the demand from year 2015 to 2025 is as follows:

$$\text{Forecast} = a + b \text{ (timeline,z)}$$

The results of demand forecasting are as below:

Table 11: Forecasted Demand of Curved Piston Engines.

Year	Timeline, Z	Forecasted Value	20% of Total Cars
2013	8	548037	109607
2014	9	569576	113915
2015	10	591115	118223
2016	11	612654	122531
2017	12	634193	126839
2018	13	655732	131146
2019	14	677271	135454
2020	15	698810	139762
2021	16	720349	144070
2022	17	741889	148378
2023	18	763428	152686
2024	19	784967	156993
2025	20	806506	161301

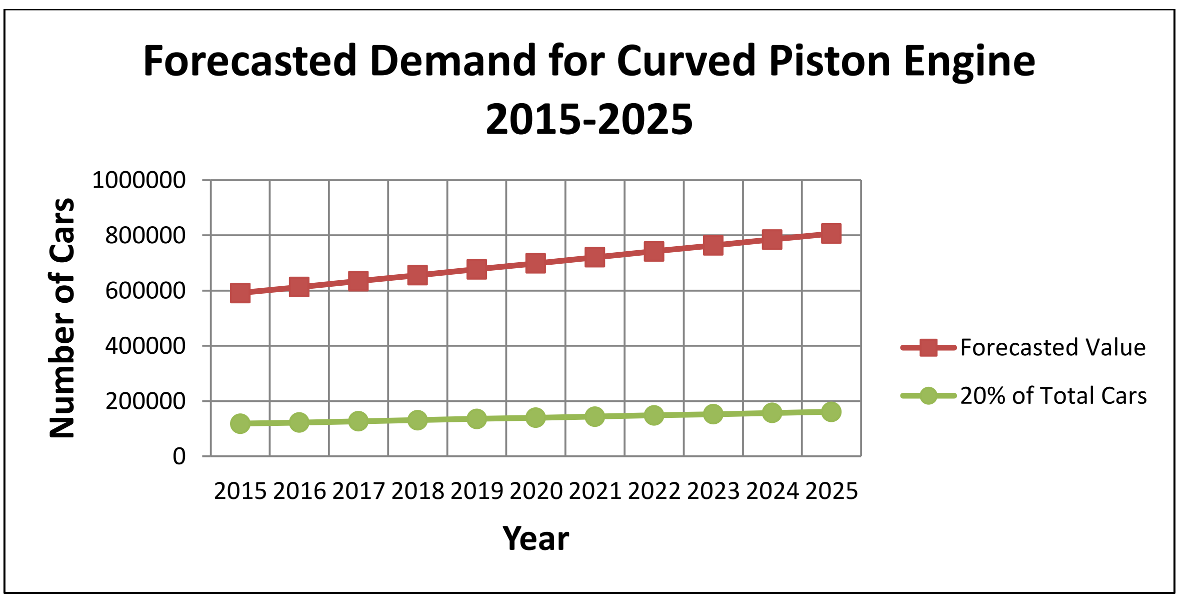


Figure 20: Forecasted Demand of Curved Piston Engine (2015-2025)

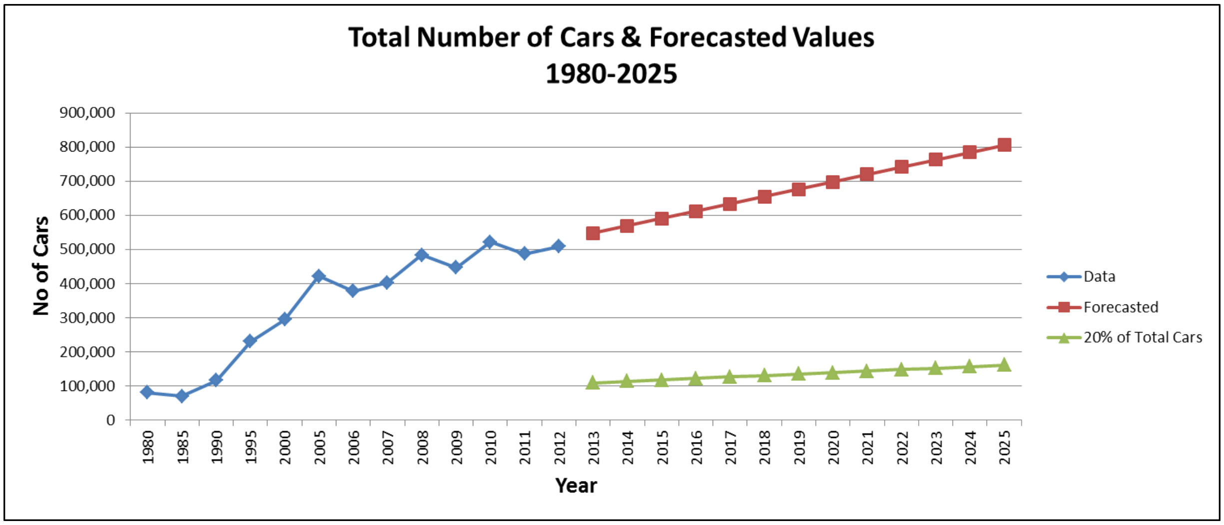


Figure 21: Total number of cars & Forecasted Values.

Summary of demand forecasting of curved pistons are as follows:

- Maximum demand: 161301 units/ year
- Minimum demand: 118223 units/ year
- Average demand: 153738 units/year

From the forecasted values, proper designing of manufacturing machine size and capacities can now be designed accurately.

4.6 Manufacturing Process Design.

The next step after CAD modeling and CAE simulations is to design the manufacturing process to mass produce the curved pistons. The manufacturing process of curved piston includes the start of the process which is the furnace till the last process. The process identified to mass produce the curved pistons are melting of aluminium alloy, die casting, drilling, inspections and finally polishing and finishing.

The first process in the production of curved piston is to melt the solid aluminium alloys in a furnace. Aluminium alloys have a melting point of 660.3°C and a boiling point of 2519°C. Hence, the aluminium alloy will be heated up to a temperature of 700°C and kept at that temperature for the die casting process. To melt the aluminium alloys, a furnace is used. In order to choose the appropriate size and capacity of the furnace, daily production demand must be calculated.

Table 12: Daily operation demands.

Maximum Demand of curved pistons.	161 301	units/year
Annual Operation Days	330	days
Daily Production	500	units
Daily Operation Hours	12	hours
Output per hour	42	units/hour

To calculate the weight of aluminium alloy that the furnace has to provide for, the following calculations are made. The volume of needed to die cast one curved piston is 61.017 cm^3.

Table 13: Weekly weight of Aluminium alloy.

Volume of material needed	61.017	cm3/unit
Daily Volume of Raw Materials needed	30508.5	cm3
Weekly supply of raw material	0.21356	m3/week
Density of Aluminuim	2700	kg/m3
Weekly weight of Aluminium	576.612	kg

The furnace in question will have a capacity which can be able to melt and store one week's worth of molten aluminium alloy for production purposes. Hence, the Tilting Barrel Furnace M300 is chosen.

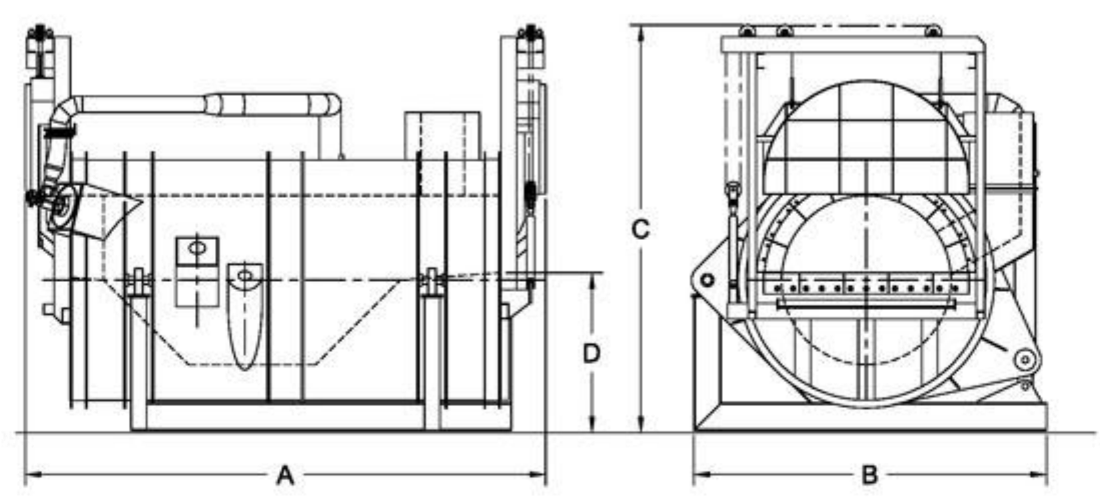


Figure 22: Tilting Barrel Furnace M300. **(Ltd F. P.)**

The tilting barrel furnace M300 is manufactured by Furnace Engineering Pty Ltd. The furnace costs USD 89600 and the specifications are as below:

Table 14: Specifications of Furnace.

Model No.	Continuous Melt Rate kg/hr	Furnace Capacity kg	Well Capacity kg	Dimensions			
				A mm	B mm	C mm	D mm
M300	300	750	400	2700	2000	2100	1000
M500	500	1700	750	3200	2300	2200	1050
M750	750	3200	1250	3350	2400	2600	1200

The next process in mass producing the curved piston is the die casting process. Molten aluminium alloy is manually scooped into the machine using a ladle and the molten aluminium is pumped in the die at high pressure. The dies are held in place under high pressure for 8.34 seconds for molten aluminium to solidify. Casted curved pistons are then allowed to cool for 2 minutes. Taking into the account the filling time, holding time and cooling time, the total cycle time for 1 unit of curved piston is 3.2 minutes. The daily capacity and demand of the die casting machines are as follows:

Table 15: Capacity of Die Casting Machines.

Cycle Time for 1 unit of Curved Piston	3.2	minutes
Cycle time for 500 units of Curved Piston	1600	minutes
	26	hours
Daily operation hours= 12 hours. Hence, required number of machines	4	machines

The die casting machine used is the Evergreat Yota Die-Caster. It has the capability to fulfill the demands of the die casting process. The specifications of the Evergreat Yota machine are as follows:

Table 16: Specifications of Die Casting machine.

Clamping force	150 Ton
Die height	200-500 mm
Max. weight of shot	1.64 kg
Max. casting area	426 cm^2
Electricity	15 kw

The 3rd process step is the drilling of the piston pin holes on the piston. The piston pin holes are 5mm in diameter and it has to be drilled after the die casting process due to the limitations in the die casting process. A total of 2 piston pin holes have to be drilled on the curved piston.

Figure 23: Before and after drilling of piston pin hole.

In calculating the cycle time for the drilling of the piston pin hole, the recommended guidelines for drilling speed and feed rate are referred to.

TABLE 23.11

General Recommendations for Speeds and Feeds in Drilling

		Drill diameter			
Workpiece material	Surface speed	Feed, mm/rev		rpm	
	m/min	1.5 mm	12.5 mm	1.5 mm	12.5 mm
Aluminum alloys	30–120	0.025	0.30	6400–25,000	800–3000
Magnesium alloys	45–120	0.025	0.30	9600–25,000	1100–3000
Copper alloys	15–60	0.025	0.25	3200–12,000	400–1500
Steels	20–30	0.025	0.30	4300–6400	500–800
Stainless steels	10–20	0.025	0.18	2100–4300	250–500
Titanium alloys	6–20	0.010	0.15	1300–4300	150–500
Cast irons	20–60	0.025	0.30	4300–12,000	500–1500
Thermoplastics	30–60	0.025	0.13	6400–12,000	800–1500
Thermosets	20–60	0.025	0.10	4300–12,000	500–1500

Note: As hole depth increases, speeds and feeds should be reduced. Selection of speeds and feeds also depends on the specific surface finish required.

Figure 24: Recommended drilling speed and feed rate.

Calculations for cycle time of drilling are as follows:

Table 17: Drilling parameters.

Diameter of Hole, D	5	mm
feed rate, f	0.3	mm/rev
RPM, N	800	rpm
Depth of hole, h	20	mm

Material removal rate, MRR= [(∏D^2) /4] * f * N

= [(∏*5^2)/4] * 0.3 * 800

= 4712.3 mm^3/min

Volume of hole removed= $\prod * r^2 * h$

$= \prod * 2.5^2 * 20$

$= 392.7\ mm^3$

Drilling time of 2 holes= (Volume/MRR)*2

= (392.7 / 4712.3)*2

= 0.16667 min

= 10.00021 s

The drilling is done using a drill press which is manually operated by an operator.

Figure 25: Floor Production Drill Press. **(Ltd, 2012)**

The final process before packaging and shipping is to the polishing and finishing process. The die casted curved pistons will not have a smooth finish to it and has to be polished. This is to make sure that its outer surface is smooth and sharp edges are removed. The purpose of polishing and removing of sharp edges are to avoid damage to the cylinder walls. This process is also done manually by an operator using sand belts and buffers. Total time for polishing and removing sharp edges of curved piston is approximately 1 minute per unit.

In every mass production process, there are bound to be defects. In order to avoid shipping defects to customers, inspections must be done. There are 2 kinds of inspection. The first being inspection for variables, where one or more quality characteristics are measured using instrument. The next kind of inspection is inspection for attributes, where a product is inspected to determine if it conforms to standard.

Besides that, inspections can also be done as a final step before shipping or in between other process. To determine which type of inspection is to be done which will save the company more money annually, calculations must be done.

Assumptions:

Average demand per year = 153738 units

Table 18: Inspection Calculations.

Qo	153738 units
q	0.05
n	3
Df	21927
Cpr	RM 1
Csf	2.5
Cs	0.25

Where,

Qo= Total quantity,

q= defect rate,

n= number of process,

D_f= total quantity of defects produced

C_{pr}= Cost of Processing

C_{sf}= Cost of final sorting

C_s= Cost of sorting

C_b= Cost of Sorting the batch

Final Inspection vs Distributed Inspection:

Q_f= Final quantity of defect free units

$Q_f = Q_o (1-q)^n$

$= 153738 (1-0.05)^3$

= 131811 units.

Final Inspection:

$C_b = Q_o (nC_{pr} + C_{sf})$

$C_b = 153738 [(3*1) + 2.5]$

= RM845559/ year

Distributed Inspection, inspection after every process:

$C_b = Q_o [1+ (1-q) + (1-q)^2 \ldots\ldots + (1-q)^{n-1}] (C_{pr} + C_s)$

$C_b = 153738 [1+ (1-0.05)^2] (1+0.25)$

= RM548172/ year

Hence, it is more economical to conduct inspections after every process in the manufacturing line. Instead of having final inspections, the company stands to save RM297387 per year.

In conclusion, the manufacturing process will be as follows:

Table 19: Total Operation Time for Manufacturing Process (1 unit Curved Piston)

Process	Cycle Time
Manual Ladling from Furnace to Die Casting Machine	5 sec
Die Casting Process	191.6 sec
Inspection 1	30 sec
Drilling	10 sec
Inspection 2	30 sec
Finishing and polishing	60 sec
Total Operation Time (1 unit of curved piston)	326.6 sec (5.4 mins)

4.7 Validation of Manufacturing Feasibility.

To validate that the manufacturing process is indeed feasible, a mass production simulation is done using manufacturing software called Witness. Witness grants its users access to manufacturing data via simulation of the manufacturing process in a plant. The data varies as input of machines, cycle times and raw material flow changes. To simulate the real time scenario of the manufacturing flow, a few parameters are determined.

Table 20: Annual Operation Hours

Taking the Maximum demand per year= 161301 units.	
Operation hours:	330 days/year
	7 days/week
	12 hours/day

The cycle time of each process is needed in order to simulate the manufacturing process. An operation cycle time, Tc of a product is defined as the time that one work unit spend being processed, loaded/unloaded and transported. (Groover, 2008)

$$T_c = T_o + T_h + T_{th}$$

Where

To = Operation time,

Th = Loading/ Unloading

Tth = Tool handling time. (Changing of setup)

Hence, the cycle time for each process is detailed below:

Table 21: Cycle time for each process.

Process	Station	Operation Time, To	Loading/ Unloading Time, Th	Tool Handling Time, Tth	Total Cycle Time, Tc
1	Manual Ladling	5 sec	-	-	5 sec
2	Die Casting	191.6 sec	10 sec	-	201.6 sec
3	Inspection 1	30 sec	10 sec	-	40 sec
4	Drilling	10 sec	30 sec	10 sec	50 sec
5	Inspection 2	30 sec	10 sec	-	40 sec
6	Finishing	60 sec	10 sec	10 sec	80 sec
Total Cycle Time					416.6 sec 6.94 mins

The molten aluminium alloy is manually ladled into the die casting machine by an operator. This operation is fairly straightforward and should take approximately 5 seconds per shot. Next, in the die casting machine, the total cycle time which includes the filling time, pressure holding time and cooling time is 3.2 minutes. The loading and unloading time for each unit of curved piston on die casting machine is 10 seconds. As the die casting machine is a high production rate machine, tool change and setup time is negligible.

The first inspection will be done after the die casting process. This inspection will be done to look for any defects in the casting process and should take an approximate of 30 seconds per unit. The loading and unloading time of one unit curved piston to the inspection time is 10 seconds. For the case of drilling process, as the calculation shows, 10 seconds is taken to drill 2 pin holes per unit of curved piston. Including the loading and unloading of curved piston on the drilling platform, the cycle time for curved piston on drilling piston equals to 50 seconds. The second inspection is done to check should there be any cracks to the curved pistons due to the drilling process. A poka-yoke rig is used to check the quality of the pin holes drilled. 10 seconds is taken to load and unload the inspected curved pistons.

The final process is the polishing and finishing process, where an operator manually polishes and finishes the surface of the curved piston. This step of the manufacturing process should take 80 seconds.

Hence, the total cycle time for one unit of curved piston is 6.94 minutes.

Case 1:

Operation hours= 330 days/year, 7days/week, 12hours/day.

- One production line with one die casting machine, one drill press and one finishing station.

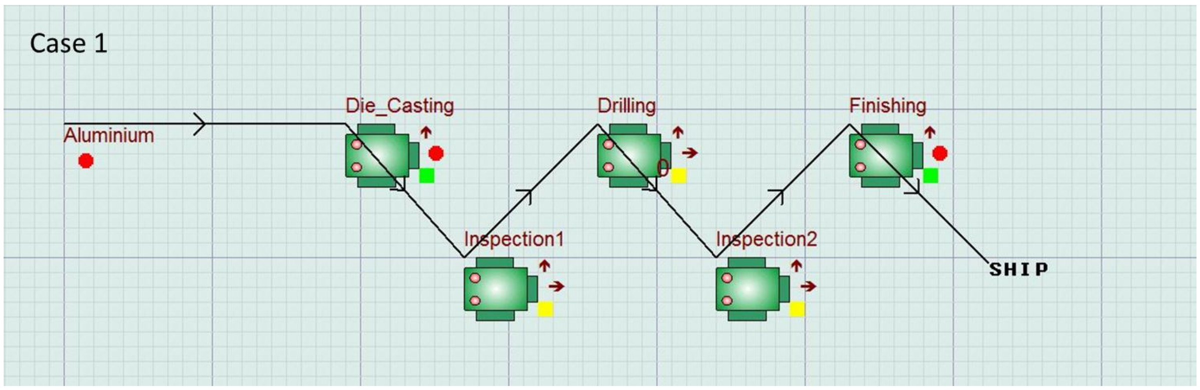


Figure 26: Witness simulation (Case1)

In this first case, only one production line is used. The results of this simulation are as shown below:

Table 22: % Idle and % Busy of machines. (Case1)

Name	Die Casting	Inspection 1	Drilling	Inspection 2	Finishing
% Idle	1.14	84.55	94.75	84.55	69.11
% Busy	98.86	15.45	5.25	15.45	30.89

Table 23: Number of Curved Pistons processed, shipped, scrapped and WIP. (Case1)

Name	No. Entered	No. Shipped	No. Scrapped	W.I.P
Aluminium	146803	139459	7341	3

The table 22 above shows the % Idle and % Busy of the machines during the annual operations. As shown in the results, the die casting machine is fully utilized most of the time. But the inspection stations and drilling press are idle most of the time while waiting for parts to process showing that this set-up is not efficient. Besides that, the number of parts shipped does not meet the annual demand of 161301 units. This current set up only managed to ship 139459 units. Hence, more manufacturing lines need to be added to be able to meet the demand.

Case 2:

Operation hours= 330 days/year, 7days/week, 12hours/day.

- 4 manufacturing lines with 4 die-casting machines and finishing station
- 2 lines of inspection and drilling stations.

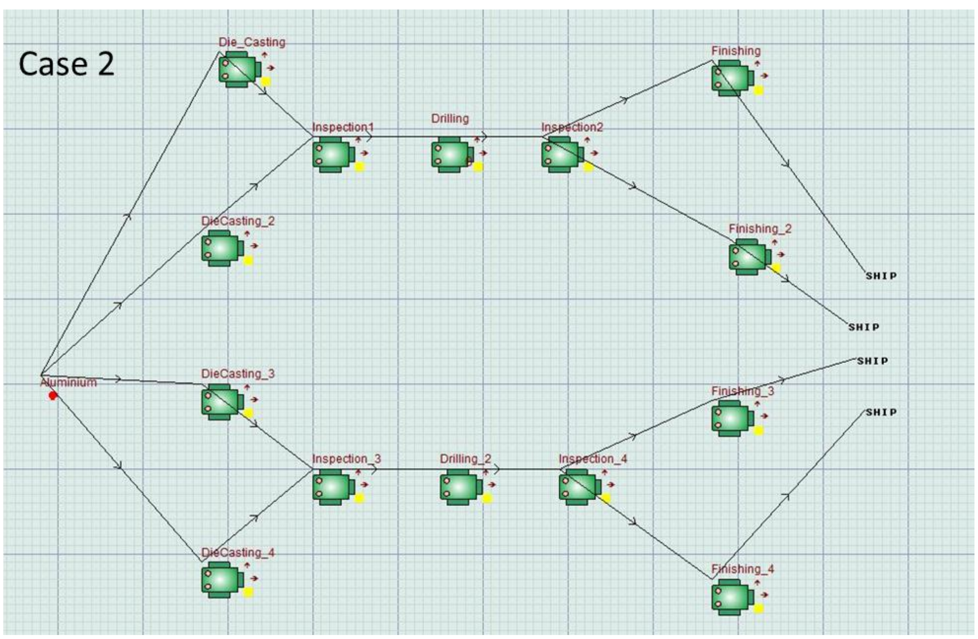


Figure 27: Witness simulation (Case2)

Results of simulation are as follows:

Table 24: % Idle and % Busy of Machines. (Case2)

Name	DieCasting_1	DieCasting_2	DieCasting_3	DieCasting_4	Inspection1
% Idle	1.14	1.08	1.15	1.08	69.11
% Busy	98.86	98.85	98.85	98.85	30.89

Table 25: % Idle and % Busy of Machines. (Case2)

Name	Inspection2	Inspection3	Inspection4	Drilling_1	Drilling_2
% Idle	69.11	69.11	69.11	89.5	89.5
% Busy	30.89	30.89	30.89	10.5	10.5

Table 26: % Idle and % Busy of Machines. (Case2)

Name	Finishing_1	Finishing_2	Finishing_3	Finishing_4
% Idle	69.11	69.11	69.11	69.11
% Busy	30.89	30.89	30.89	30.89

Table 27: Number of Curved Pistons processed, shipped, scrapped and WIP. (Case2)

Name	No. Entered	No. Shipped	No. Scrapped	W.I.P
Aluminium	193526	184305	9676	6

As shown in the results, the numbers of curved piston shipped are able to meet the maximum annual demand. In fact, it exceeded the annual demands by 20000 units. But on the other hand, there are a large number of machines that have a high percentage of idle. Hence, cost of waiting time will increase. Operators in the inspection and drilling stations will waste a lot of time annually not doing anything. Hence, this model is still not feasible.

Case 3:

Operation hours= 330 days/year, 7days/week, 12hours/day.

- 4 die-casting machines
- 2 finishing stations
- 1 line of inspection and drilling.

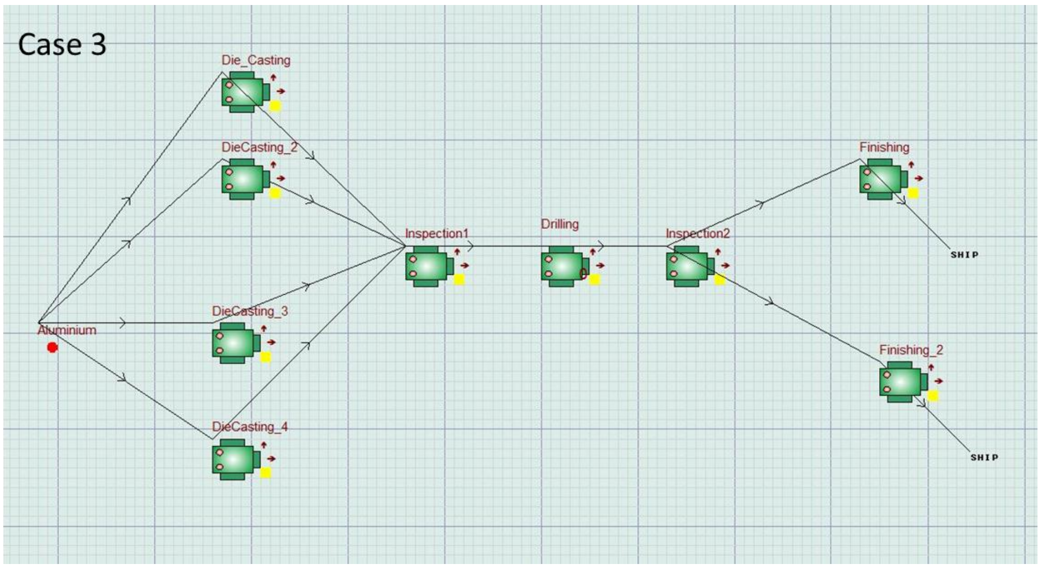


Figure 28: Witness simulation (Case3)

Results from this simulation are as below:

Table 28: % Idle and % Busy of Machines. (Case3)

Name	DieCasting_1	DieCasting_2	DieCasting_3	DieCasting_4
% Idle	1.14	1.08	1.02	0.96
% Busy	98.86	98.85	98.85	98.85
Name	Inspection1	Inspection2	Drilling_1	Finishing_1
% Idle	38.22	38.22	78.99	38.22
% Busy	61.78	61.78	21.01	61.78

Table 29: Number of Curved Pistons processed, shipped, scrapped and WIP. (Case3)

Name	No. Entered	No. Shipped	No. Scrapped	W.I.P
Aluminium	170677	162544	8127	6

This process layout shows that the annual demand can be met with optimum machine usage. The die casting machines are utilized fully, while the inspection stations and finishing stations are also utilized efficiently. Minimal waste of idle time is present in this set up. This proves that the manufacturing process set up is feasible and able to meet the annual demands.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Future Work and Recommendations

Future work for this project are to continue with the proposal for efficient methods to mass produce other parts of the rotary engines such as the crank shafts, the cylinder and engine block. Besides that, future study also can be extensively done on the performance and the applications of the rotary engine in the industry of automotive and machinery. Should the rotary engine be successfully applied to our daily use, the consumption of fuel and power can be greatly optimized. With the great power to weight ratio of the rotary engines, it can also benefit users by the scaling down of machines and automotive size. Mass producing the entire rotary engine will further reduce the cost of production and thus, the public will greatly benefit from this innovative invention.

5.2 Conclusion

A mass production system is successfully proposed for the curved piston. Studies and simulations done on Simpoeworks are prove that the die casting method is effective and feasible to be used to mass produce a curved piston. The die casting process designed has no air bubble traps and this will guarantee a die casted product with minimal defects.

Besides that, the demand forecasting that was done shows an increase in demand for curved piston engines in the future with an average demand of 153738 units/year from years 2015 to 2025. The results of demand forecasting allows for a feasible and efficient design in manufacturing process.

The demand for curved piston is also proven to be able to be met using the designed mass production process. The Witness simulation was used to prove this. The Witness simulation shows that the maximum annual demand of 161301 units/year of curved piston are met with minimal waste in machine idling time.

Chapter 6

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6.1 References

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