

**INCORPORATING DESIGN FOR MANUFACTURE AND ASSEMBLY  
METHODOLOGIES INTO THE DESIGN OF A MODIFIED SPARK PLUG**

**NIK MOHD FARID BIN CHE ZAINAL ABIDIN**

A project report submitted in partial fulfillment of the  
requirements for the award of the degree of  
Master of Mechanical Engineering  
(Advanced Manufacturing Technology)

**Faculty of Mechanical Engineering  
Universiti Teknologi Malaysia**

**JUNE, 2007**

To my beloved wife Silah Hayati Kamsani, my father Hj Zainal Abidin Harun,  
my mother Nik Maimunah Nik Daud and my siblings  
I love you all.

## ACKNOWLEDGEMENTS



I would like to express my utmost appreciation to Tuan Haji Dr. Ariffin Bin Abdul Razak who is my thesis supervisor for his guidance, advice, encouragement, and support through out the project.

Also, I would like to thank all of my friends, colleagues, and those who are directly or indirectly help me in completing this thesis.

Finally to my wife, parents, siblings, and parents-in-law thank you so much for all your tremendous support to ensure that I complete my thesis.

May Allah S.W.T bless all of us. Amin.

Nik Mohd Farid bin Che Zainal Abidin

June 16, 2007

## **ABSTRACT**

Air Pressure Plug is a product that can be used to inflate the inflatable items using the air from the internal combustion engine, which is channeled out using this device. This product is a good design to be commercialized. However, before releasing to the market, the product has to be cheap and good quality. Therefore, to achieve this goal, design for manufacture and assembly methodologies are used to evaluate the design of the product. Specifically, DFMA, which is Boothroyd-Dewhurst based software, and TeamSET, which is based on Lucas-Hull, are used to evaluate the product. The results for both analyses are compared to look for any variation in term of parts to be eliminated and combined.

## ABSTRAK

Air Pressure Plug adalah satu produk yang boleh digunakan untuk mengisi angin pada barang-barang seperti tayar, pelampung, atau tilam angin dengan menggunakan angin dari kebuk pembakaran dalaman enjin. Angin disalurkan keluar dari dalam enjin dengan menggunakan produk tersebut. Produk tersebut adalah sangat berpotensi untuk dipasarkan. Walau bagaimanapun, produk itu haruslah berkualiti dan murah sebelum ianya dijual di pasaran. Oleh yang demikian, untuk mencapai matlamat tersebut, kaedah "*Design for Manufacture and Assembly*" (DFMA) digunakan untuk menilai reka bentuk produk. Dua perisian yang berbeza digunakan untuk menilai reka bentuk produk iaitu perisian DFMA yang berdasarkan teknik Boothroyd-Dewhurst dan TeamSET yang berdasarkan teknik Lucas-Hull. Hasil keputusan penilaian dengan menggunakan kedua-dua perisian itu dibandingkan di antara satu sama lain untuk mengenalpasti sebarang perbezaan berdasarkan komponen yang akan dibuang dan dicantum dengan komponen lain bagi mengurangkan jumlah komponen.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>TITLE</b>	i
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iv
	<b>ACKNOWLEDGEMENT</b>	v
	<b>ABSTRAK</b>	vi
	<b>ABSTRACT</b>	vii
	<b>TABLE OF CONTENTS</b>	viii
	<b>LIST OF TABLES</b>	xiii
	<b>LIST OF FIGURES</b>	xiv
	<b>LIST OF APPENDICES</b>	xix
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Introduction to the Problem	1
	1.2 Objective of Project	2
	1.3 Scope of Project	2
	1.4 Project Methodology	2
	1.5 Significant of Findings	5
	1.6 Report Structure	5
	1.7 Summary	7

<b>2</b>	<b>LITERATURE REVIEW</b>	<b>8</b>
2.1	Introduction	8
2.2	Internal Combustion Engine	9
2.2.1	Two-strokes Engine	9
2.2.2	Four-strokes Engine	10
2.2.3	Spark Plug	12
	2.2.3.1 Principles of Spark Plug	13
	2.2.3.2 Components of Spark Plug	13
2.3	Overview of Design For Manufacture and Assembly	16
2.4	Design for Manufacture (DFM)	16
2.4.1	DFM Guidelines	17
2.4.2	DFM Methodology	18
2.4.3	Boothroyd-Dewhurst DFM Methodology	18
	2.4.3.1 Process Capability	20
2.5	Design For Assembly (DFA)	22
2.5.1	DFA Guidelines	23
	2.5.1.1 Design Guidelines for Part Handling	23
	2.5.1.2 Design Guidelines for Insertion and Fastening Insertion	26
2.6	DFA Methodologies	30
2.6.1	Boothroyd-Dewhurst DFA Methodology	30
	2.6.1.1 Theory of Evaluation	30
	2.6.1.2 Evaluation Procedure	31
2.6.2	Lucas DFA Methodology	36
	2.6.2.1 Theory of Evaluation	36
	2.6.2.2 Evaluation Procedure	36
2.6.3	Hitachi Assemblability Method (AEM)	44
	2.6.3.1 Theory of Evaluation	45
	2.6.3.2 Evaluation Procedure	47
2.7	TeamSET	48
2.7.1	Design for Assembly (DFA)	48
2.7.2	Manufacturing Analysis	53

2.8	DFMA	56
2.8.1	DFM Concurrent Costing	56
2.8.2	Design for Assembly	60
2.9	Summary	66
<b>3</b>	<b>AIR PRESSURE PLUG: A PRODUCT CASE STUDY</b>	<b>67</b>
3.1	Introduction	68
3.2	Concept Generation	68
3.3	How to use Air Pressure Plug	68
3.4	Advantages of Product	69
3.5	Product Structure and Part Quantity	70
3.6	Assembly Drawing	71
3.7	Exploded Drawing	72
3.8	Bill of Materials	72
3.9	Parts Function and Critics	74
3.10	Summary	76
<b>4</b>	<b>DFMA SOFTWARES ANALYSIS ON THE AIR PRESSURE PLUG</b>	<b>77</b>
4.1	Introduction	77
4.2	Analysis Using TeamSET	78
4.2.1	Analysis	78
4.2.2	Result	87
4.3	Analysis Using Boothroyd-Dewhurst (DFMA)	92
4.3.1	Analysis	93
4.3.2	Result	102
4.4	Summary	109



<b>5</b>	<b>PROPOSED IMPROVEMENT OF THE AIR PRESSURE PLUG</b>	<b>110</b>
5.1	Introduction	110
5.2	Parts Elimination	111
5.3	Concept Generation	111
5.3.1	Design Concept 1	111
5.3.2	Design Concept 2	113
5.3.3	Design Concept 3	114
5.3.4	Design Concept 4	115
5.4	Proposed Improvement	116
5.5	Summary	119
<b>6</b>	<b>EVALUATION OF THE NEW DESIGN OF AIR PRESSURE PLUG</b>	<b>120</b>
6.1	Introduction	120
6.2	Evaluation Using TeamSET	121
6.2.1	Analysis	121
6.2.2	Result	125
6.3	Evaluation Using Boothroyd-Dewhurst (DFMA)	129
6.3.1	Analysis	129
6.3.2	Result	132
6.4	Summary	137
<b>7</b>	<b>DISCUSSION</b>	<b>138</b>
7.1	Introduction	138
7.2	Evaluation Comparison	139
7.2.1	Analysis Comparison	139
7.2.2	Result Comparison	146
7.3	Summary	151

<b>8</b>	<b>CONCLUSIONS AND FUTURE WORK</b>	
	<b>RECOMMENDATIONS</b>	<b>151</b>
8.1	Conclusions	151
8.2	Future Work Recommendations	152
	<b>REFERENCES</b>	<b>153</b>
	<b>APPENDICES</b>	<b>154 - 163</b>

## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Shape Generation Capabilities of Processes	24
2.2	Design for assembly worksheet	32
2.3	Completed worksheet analysis for the controller assembly	34
2.4	Design changes and associated savings for the controller assembly	34
2.5	Completed analysis for the controller assembly redesign	35
2.6	Example of summary of analysis result	65
4.1	Manufacturing Analysis results for all the manufactured parts of the product	87
4.2	Manufacturing Analysis results for all the manufactured parts of the product	103
6.1	Manufacturing Analysis results for housing and handle of the improved product	125
6.2	DFM Concurrent Costing results for housing and handle parts of the improved product	133
7.1	Cost per part of the manufactured components using TeamSET	147
7.2	Cost per part of the manufactured components using Boothroyd-Dewhurst DFMA	147
7.3	DFA (TeamSET) results comparisons between old and new design	148
7.4	DFMA results comparisons between original and new improved design of product	149
7.5	Comparison between TeamSET and Boothroyd-Dewhurst DFMA	149

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Project methodology	3
2.1	Operation of two strokes cycle petrol engine	10
2.2	Operation of four strokes cycle petrol engine	12
2.3	Spark and ignition in the spark plug	13
2.4	Components of spark plug	14
2.5	Compatibility matrix between processes and materials	19
2.6	Maximum possible symmetry of the part	24
2.7	Asymmetrical part	24
2.8	Design to avoid part jamming	24
2.9	Part design to avoid tangling	25
2.10	Part design to be avoided	25
2.11	Part that can and cannot jam during insertion	26
2.12	Parts that are difficult and easy to insert	26
2.13	Part that is easy and difficult to insert	27
2.14	Part that can hang up and falls into place	27
2.15	Part that uses standard component	27
2.16	Part with one axis of reference	28
2.17	Holding part during assembly	28
2.18	Part locating during assembly	29
2.19	Various fastening methods in order of increasing cost	29
2.20	Reposition of part during assembly	29
2.21	Controller assembly	33
2.22	Conceptual redesign of the controller assembly	35
2.23	The Lucas DFMA (design for mechanical assembly)	37

## LIST OF FIGURES – CONTINUED

2.24	Various symbols used for processes in assembly sequence flow-chart	40
2.25	Manual pump design	41
2.26	Assembly sequence flow chart of pump	42
2.27	Redesign of pump	43
2.28	Assembly sequence flowchart for redesign pump	43
2.29	Assemblability evaluation and design improvement flow diagram	44
2.30	Examples of AEM symbols and penalty scores	46
2.31	An example of AEM procedures	47
2.32	Part assembly window	48
2.33	Functional analysis window	49
2.34	Handling analysis	50
2.35	Insertion processes	50
2.36	Secondary operations	51
2.37	DFA analysis summary window	52
2.38	Example of TeamSET assembly report	52
2.39	Example of design to cost	53
2.40	Primary processes in manufacturing analysis	54
2.41	Materials selection for manufacturing analysis	54
2.42	Grade of materials in manufacturing analysis	55
2.43	Manufacturing analysis summary	55
2.44	Main analysis window	57
2.45	Process and material selection window	57
2.46	Main analysis window of a valve	58
2.47	Examples of parameters for the semi-automatic sand casting process	59
2.48	Mold core 1 process parameters	59
2.49	Graph of cost comparison between two processes	60
2.50	DFA main window	61
2.51	Inserting part etc to a DFA window	61
2.52	Example of DFA main window for a piston	62

## LIST OF FIGURES – CONTINUED

2.53	Evaluation criteria in DFA window	63
2.54	Example of suggestions for redesign of the parts	64
2.55	Example of DFA for redesign piston	65
2.56	Example of breakdown of time per product chart	66
3.1	Air Pressure Plug	68
3.2	Application of the Air Pressure Plug	69
3.3	Hand pump	70
3.4	Foot pump	70
3.5	Mini air compressor	70
3.6	Product structure of Air Pressure Plug	71
3.7	An assembly drawing of the Air Pressure Plug	71
3.8	Exploded drawings of the Air Pressure Plug	72
3.9	Bills of material for the Air Pressure Plug	73
3.10	Parts' function and critics for the product	74
4.1	Primary process selection for housing	79
4.2	Material selection for housing	79
4.3	Type of geometry for housing	80
4.4	Complexity of geometry for housing	80
4.5	Complete Manufacturing Analysis for housing using investment casting	81
4.6	Manufacturing Analysis for purchased part	82
4.7	Functional analysis for housing	83
4.8	Manual handling analysis of housing	84
4.9	Secondary operations of housing	84
4.10	Insertion process for sparkplug sub-assembly	85
4.11	Design for Assembly window for Air Pressure Plug	86
4.12	Graph of components cost for different processes	88
4.13	Design for Assembly summary for Air Pressure Plug	89
4.14	TeamSET assembly report for an original design of Air Pressure Plug	90
4.15	Design to Cost for Air Pressure Plug	91
4.16	DFM Concurrent Costing window	93

## LIST OF FIGURES – CONTINUED

4.17	Process and material selection window	94
4.18	Investment casting step-by-step process	95
4.19	Investment casting process for housing part	96
4.20	Assembly cluster for investment casting of the product	97
4.21	Secondary operation using generic manual lathe	98
4.22	Single point threads operation for housing part	99
4.23	Design for Assembly window	100
4.24	DFA analysis on the shaft	101
4.25	Graph of manufactured parts cost for different processes	104
4.26	Chart shows various breakdown of assembly time per product	105
4.27	Suggestions for redesign for current design	106
5.1	Design concept 1	109
5.2	Design concept 2	110
5.3	Design concept 3	111
5.4	Design concept 4	112
5.5	The new design of housing	113
5.6	The existing design of product part	113
5.7	Electrode of the insulator bent upward	114
5.8	The exploded drawing of the improved design of Air Pressure Plug	115
5.9	Cross section of the improved design of Air Pressure Plug	115
6.1	Primary process selection for new housing	121
6.2	Material selection for new housing	123
6.3	Complete Manufacturing Analysis for new housing	123
6.4	Design for Assembly window for the improved Air Pressure Plug	124
6.5	Graph of components cost for improved product	126
6.6	Design for Assembly summary for improved Air Pressure Plug	127
6.7	TeamSET assembly report for improved design of Air Pressure Plug	127

**LIST OF FIGURES – CONTINUED**

6.8	Design to Cost for improved Air pressure Plug	128
6.9	Process and material selection window for new housing	129
6.10	Investment casting process for new housing	130
6.11	Design for Assembly window for improved Air Pressure Plug	131
6.12	Graph of manufactured parts cost against life volume for improved product	133
6.13	Chart shows various breakdown of assembly time per product (improved product)	134
6.14	Suggestion for redesign for improved design	135
7.1	List of primary processes for handle	140
7.2	List of compatible materials for handle	140
7.3	DFM Concurrent Costing process and material selection for handle	141
7.4	Manufacturing analysis of a handle	142
7.5	Die casting operation process parameters for handle	143
7.6	Various analyses in TeamSET DFA	144
7.7	Design of assembly window for O ring in DFMA	145



**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A1	Project Schedule (Gantt chart) for Semester 1	154
A2	Project Schedule (Gantt chart) for Semester 2	154
B	Capabilities of a range of manufacturing processes	155 ~ 158
C	Data for estimated times for manual handling (Boothroyd-Dewhurst)	159
D	Data for estimated times for manual insertion (Boothroyd-Dewhurst)	160
E	Lucas DFA method - Manual Handling and Manual Fitting Analysis	161
F	Detailed result of the DFA of the old design of product based on Boothroyd-dewhurst DFMA software	162
G	Detailed result of the DFA of the old design of product based on Boothroyd-dewhurst DFMA software	163

## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction to the Problem

Air Pressure Plug is a product that inflates the inflatable items. It is a device that uses the air generated from the internal combustion engine. Air as a by-product of combustion can be channeled out from the engine through this product. Air Pressure Plug has a very good potential to be commercialized based on the number of inquiries received when the product was exhibited locally and internationally. It is targeted to be commercialized by end of 2007. Two major factors that have to be emphasized before the product can be released to the market are the price and quality of the product. These factors are one of the few factors that will determine the product successfulness in the market place. Therefore, it is crucial to study and analyze the product to achieve optimum cost without scarifying the quality of the product. In fact, the product has to be a best quality product. One of the tools that can be used to minimize the product cost and to increase the product quality is through applying Design for Manufacturing and Assembly (DFMA) methodologies to the product design. Design for Manufacturing and Assembly (DFMA) is an approach that eases the manufacturing and assembly of the product. Specifically, this project shall use Boothroyd-Dewhurst and TeamSET-based Lucas Hull DfMA softwares to evaluate the product design. Parts of the product that have potentials to be improved will be identified by the software. After the improved design has been made, product shall again be evaluated before the product is ready for fabrication.

## **1.2 Objective of Project**

The objective of the project is to design and evaluate the original and improved Air Pressure Plug using Boothroyd-Dewhurst and TeamSET-based Lucas Hull DfMA softwares.

## **1.3 Scope of Project**

The scopes of the project are:

1. The use of Air Pressure Plug as a case study product.
2. The use of Boothroyd-Dewhurst and TeamSET-based Lucas Hull DfMA softwares for product evaluations.
3. Product improvement for product structure simplification.
4. Comparison on product assemblability design efficiencies.

## **1.4 Project Methodology**

The project is conducted in two consecutive semesters which are summarized in Figure 1.1.

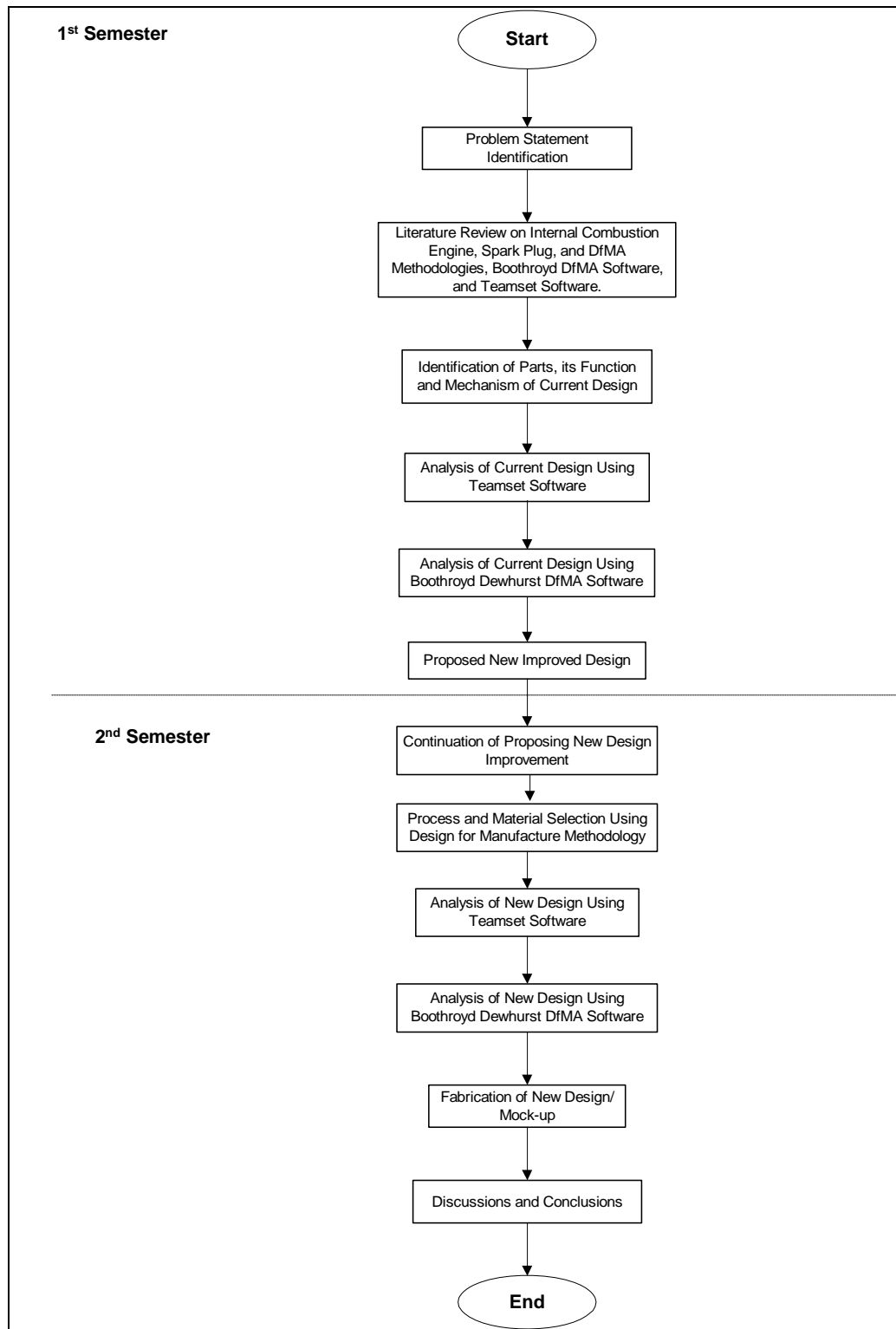


Figure 1.1: Project methodology.

This project shall be completed in two semesters. The project activities for every semester are demonstrated in Gantt chart in Appendix A1 and Appendix A2.

This project begins as soon as the problem statement has been identified in the first semester. It is important to identify the problem because it shall reflect the direction of this project. Next stage is literature review of the related areas that are internal combustion engine, spark plug, Design for Manufacturing and Assembly (DFMA) methodologies, DFMA software (based on Boothroyd-Dewhursts method) and TeamSET software (based on Lucas-Hull method). At this stage it is important to learn and explore how to use those softwares because it is used to evaluate the current production the later stage. Then, study on the current design of the product is conducted by identifying various components of the product, its various functions and mechanisms. The following stage is to do analysis using both softwares which are DFMA and TeamSET. Based on the evaluation of the product, a new an improved design of the Air Pressure Plug is proposed.

In second semester, continuation of the earlier proposed new improved design of an Air Pressure Plug takes place in which various components function and mechanisms shall be identified. Using Design for Manufacture methodologies process and material selection are made for each components of the product. Then new improved design of product is evaluated and analyzed using DFMA and TeamSET softwares. After satisfied with the improvements done to the design, the new design shall be fabricated in which a mock-up of the product will be produced. The mock-up of the product shall be tested in term of its assemblability in which the product shall be easier to assemble compared with the previous design. Finally, this project shall discuss the results and findings of this project and make conclusion for the whole project from first semester to the second semester.

## **1.5 Significant of Findings**

The main purpose of the Design for Manufacturing and Assembly (DfMA) methodologies is to achieve product structure simplification. By applying DfMA, the Air Pressure Plug product structure can be simplified through elimination of unnecessary parts or components. These parts elimination translates into reduction of assembly and total product cost. Also, it shall improve the product quality through process and material selection, and product assemblability. Once all of these are achieved the product can be commercialized and released to the market. In fact, this approach shall increase the product competitiveness in the market place.

## **1.6 Report Structure**

Chapter 1 covers the introduction of this project by looking at problem identification, objective and scope of the project. It also briefly explains the project methodology from the beginning of the project 1 in semester 1 until the completion of project 2 in semester 2. Then it touches on the significant of the findings of this project, report structure for project 1 and summary of the project 1.

Chapter 2, which is the literature review, covers internal combustion engine, design for manufacture and assembly methodologies, TeamSET and DFMA software. In the area of internal combustion engine, two types of internal combustion engines, which is two-strokes and four strokes engine, are being discussed in term of basic principles. Also covered in this area is the spark plug in which basic principle and identification of various components with brief explanation on its function and manufacturing processes. Then, TeamSET and DFMA software are covered by looking at how that software can be used to help the execution of this project.

Chapter 3 is a case study of the product. The product selected for case study is an Air Pressure Plug. Basic design concept of the product is touched in the early chapters. Also, method of using the product is briefly explained showing photos of various steps. In this chapter, the product is broken down to each part which illustrated in exploded drawing of the product. In addition, identification of each part function and mechanism is covered. Report on the analysis done using TeamSET and DFMA softwares, is provided. Based on the analysis of the results, a new improved design is proposed.

Chapter 4 covers the evaluation of the current design of Air Pressure Plug using both TeamSET and Boothroyd-Dewhurst DFMA softwares. The software is used to select the appropriate processes and materials for the parts, which is planned to be manufactured. In fact, it will give the estimate cost for the parts to be manufactured. Furthermore, both softwares are used to evaluate the ease of assembly for the product in which both used different Design for Assembly methodology. TeamSET is based on Lucas-Hull DFA methodology, whereas DFMA software is based on Boothroyd-Dewhurst DFA methodology.

Chapter 5 is where the proposed improvement of the Air Pressure Plug is made based on the result of the evaluation which is done in the previous chapter. The improved design is being conceptualized taking into consideration the parts that are recommended to be eliminated. A few conceptual designs are generated and the best conceptual is selected as the improved design of the product.

After coming up with the improved design, the Chapter 6 evaluates the design using TeamSET and Boothroyd-Dewhurst DFMA softwares. Again, similar process of material and process selection, and design of assembly analysis using the two softwares take place.

Chapter 7 is the discussion on evaluation comparison between the old design and the improved design of product for each of the methodology used. Furthermore, evaluations made based on TeamSET and Boothroyd-Dewhurst DFMA softwares are compared to each other.

The final chapter, which is Chapter 8, is the conclusion and future work recommendations. This is where the conclusion on the project is made based on the activities which have been done through out the two semesters. Also included in this chapter is the recommendations of future works related to this area that have not been explored.

## **1.7 Summary**

The project is to improve the existing design of an Air Pressure Plug. Design for manufacture and assembly is applied to the product with the aim of product structure simplification. Specifically, TeamSET and DFMA softwares are used to evaluate the product design in which the resulted into faster and easier product evaluation compared to the manual method. Based on the identification of parts that should be considered for elimination by TeamSET and DFMA, an improved Air Pressure Plug design is proposed. This new improved design shall undergo similar product design evaluation using TeamSET and DFMA in the second semester. Mock-up fabrication of the new design shall also be done in second semester.



## REFERENCES

1. G. Boothroyd, Peter Dewhurst and Winston Knight. *Product Design for Manufacture and Assembly*. 2<sup>nd</sup> edition. New York.: Marcel Dekker, Inc. 2002
2. Srivivasan, S. *Automotive Engines*. New Delhi: Tata McGraw-Hill Publishing Co. Ltd, 2001.
3. Crouse, W. H. and Anglin D. L. *Automotive Engines*. 8<sup>th</sup> edition. New York: McGraw-Hill, 1994.
4. *TeamSET User Guide*. Version 3 CSC Computer Sciences Ltd, 1998.
5. Redford, A and J. Chal *Design for Assembly, Principles, and Practice*, McGraw-Hill Book Europe, 1994.
6. Herrmann, Jeffrey, Hoyce Cooper, Satyandra K. Gupta. Et al. *New Directions in Design for Manufacturing*. ASME 2004 Design Engineering Technical Conferences and Computer and Information in Engineering, Utah USA.
7. Egan, Michael. *Concept Design for Assembly-A Design Theory Perspective* Proceedings of the 1997 IEEE International Symposium on Assembly and task Planning California USA.
8. *Design for Manufacture Concurrent Costing Software User Guide* Version 2.1 Rhode Island, 2005.
9. *Design for Assembly Software User Guide* Version 9.2 Rhode Island, 2005.
10. Heywood, John. *Internal Combustion Engine Fundamentals* McGraw-Hill, 1988
11. Schwaller, Anthony. *Motor Automotive Mechanic*. Delmar Publisher, 1988