PREDICTION OF FORCE IN INTERFERENCE FITS FOR CYLINDRICAL COMPONENTS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

AUGUST 2014

ACKNOWLEDGEMENT

In preparation in this thesis, I am glad with the consent from God that I am able to complete this research of Master in Mechanical Engineering with success.

I wish to express my sincere appreciation to my main thesis supervisor Dr. Jamaludin Taib for encouragement, guidance and critics on the research. I am also thankful to Dr. Mohd. Shuisma who is the co-supervisor of this research, have given me numerous guidance advices and motivation. Their support throughout the research is indeed very helpful for my success in the thesis.

For my family, I believe the hard time is over and thanks for the support and time given to complete this research during these three years.

Lastly, for my friends and colleagues who help also supported me and many thanks is all I can say for my appreciation.

ABSTRACT

Determining the forces with suitable geometrical dimension and tolerance will be finalized in engineering drawing during the typical design process. Specifically, when two cylinders are fitted, the aim is to ensure that the attached-force and detached-forces are within the specified force range of 70 to 220 N. These forces are meant for the human capability to assemble and disassemble the accessories without affecting the function of the household appliances such as vacuum cleaner. Currently, attached-force and detached-force testing on cylinders is carried out to determine appropriate tolerance fitting of the two cylinders. However, this method is time consuming and takes typically 162 minutes to perform. To address this issue, this research was conducted by proposing the use of mathematical equations and simulation to verify the Finite Element Analysis (FEA) model to replace the time consuming testing. A four-phase procedure was conducted. In the first phase, a test rig has been developed, test conducted and experimental data collected. In the second phase, the data was analyzed using statistical analysis and mathematical equations for attached and detached forces to be developed. In the third phase, the FEA model was developed and a comparison made between the simulated and experimental data. Finally, two case studies were carried out to monitor the behavior of attached-force should there be changes in certain parameters of the specimen. At the end of the research, a new procedure to predict the attached and detached forces of two fitted cylinders has been established. This procedure guides the designer to use either mathematical equations or FEA simulation. The mathematical equations and the FEA simulation become the design tools to replace the trial-and-error method on the testing. The design time spent in such a design work was considerably reduced to 113 minutes through the proposed design method.

ABSTRAK

Dalam proses reka bentuk, penentuan daya dipengaruhi dimensi geometri dan toleransi yang sesuai yang akan dimuktamadkan dalam lukisan kejuruteraan. Secara khususnya, apabila dua silinder dipasang, tujuannya adalah untuk memastikan daya memasang dan menanggal berada dalam lingkungan 70-220 N. Daya ini merupakan keupayaan manusia untuk memasang dan membuka aksesori tanpa menjejaskan fungsi peralatan rumah seperti pembersih vakum. Pada masa ini, ujian menentukan daya memasang dan menanggal pada silinder dijalankan untuk menentukan toleransi yang sesuai dalam pemasangan dua silinder. Walau bagaimanapun, kaedah ini lazimnya memakan masa selama 162 minit untuk menyempurnakan tugas tersebut. Bagi menangani isu ini, satu kajian telah dijalankan dengan mencadangkan penggunaan persamaan matematik dan simulasi untuk mengesahkan model Analisis Unsur Terhingga (FEA) untuk menggantikan ujian asal yang memakan masa. Satu prosedur yang mempunyai empat fasa ini telah dijalankan. Dalam fasa pertama, rig ujian dibangunkan dan data eksperimen dikumpulkan. Dalam fasa kedua, data dianalisis dengan menggunakan kaedah analisis statistik dan penggunaan persamaan matematik untuk data daya memasang dan menanggal yang telah dikumpulkan. Dalam fasa ketiga, model FEA telah dibangunkan dan perbandingan telah dibuat antara data simulasi dengan eksperimen. Akhirnya, dua kes kajian yang dijalankan untuk memantau tingkah laku daya memasang dan sekiranya terdapat perubahan parameter tertentu pada spesimen. Pada akhir kajian, satu prosedur baru untuk meramalkan daya memasang dan menanggalkan dua silinder terpasang telah dihasilkan. Prosedur ini menjadi panduan kepada pereka bentuk untuk menggunakan sama ada persamaan matematik atau simulasi FEA. Persamaan matematik dan simulasi FEA menjadi alat reka bentuk untuk menggantikan kaedah percubaan dalam ujian. Masa yang dihabiskan dalam kerja reka bentuk tersebut dapat dikurangkan kepada 113 minit dalam kerja reka bentuk dapat dicapai melalui kaedah reka bentuk yang dicadangkan.

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LIST OF SYMBOLS

Ø, d	-	Diameter
E	-	Young's modulus
F	-	Force
L	-	Length
N	-	Normal force
p	-	Pressure
r	-	Radius
T	-	Temperature
μ	-	Coefficient of friction
ν	-	Poisson ratio
ε	-	Strain
σ	-	Stress

LIST OF ABBREVIATIONS

FEA	-	Finite Element Analysis
I.D	-	Internal Diameter
O.D	-	Outer Diameter
CAD	-	Computer Aided Design
Att	-	Attach
Dett	-	Dettach
GD&T	-	General Dimensioning & Tolerancing
CMM	-	Coordinate Measuring Machine
SW	-	Solid Work
I.P	-	Intellectual Property

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CHAPTER 1

RESEARCH BACKGROUND

1.0 Introduction

The interest in tolerance analysis is increasing in industry. The needs for quality have focused the attention on the effects of variation on cost and performance of manufactured products. Excess cost due to poor performance will eventually result in a loss of market share. Therefore, the specification of tolerance limits on each dimension and feature is reflected on the engineering drawing that is considered vital design function. Engineering design and manufacturing profession are concerned about the effects of tolerances. Engineers prefer tight tolerances to ensure fit and function intended designs are met. Manufacturers prefer loose tolerances which makes components and assemblies easier and less expensive to produce. (Kenneth and Alan, 1991)

In another word, tolerance specifications become critical ties between engineering and manufacturing. In the last twenty years, companies have established comprehensive programs in quality management. Among them are the efforts of Motorola, IBM, and Xerox, who have initiated formal, corporate-wide programs for improved tolerance specification, monitoring, and control. The success in reducing waste, while cutting on development lead time and cost and reclaiming lost market share has received United States acknowledgement.

Despite the fact, the issue on tolerance may diverge between engineering design and manufacturing as shown in Figure 1.1 in determining the magnitude, assignment, and build up of tolerances. The need to have a balance in costing and the specification of a product resulting from tolerancing is important. The indication of the growing interest in tolerancing is the Mechanical Tolerancing Workshop sponsored by US National Science Foundation (NSF) and American Society of Mechanical Engineers (ASME) in 1988 which brought together an international experts in tolerancing to discuss the state of the art and identify research opportunities. This has been followed by special theme sessions at several American Society of Mechanical Engineers conferences, such as the Design Technical Conference in Montreal in 1989, the Design Show in Chicago in 1990, and the Computers in Engineering Conference in Boston in 1990. (Kenneth and Alan, 1991)

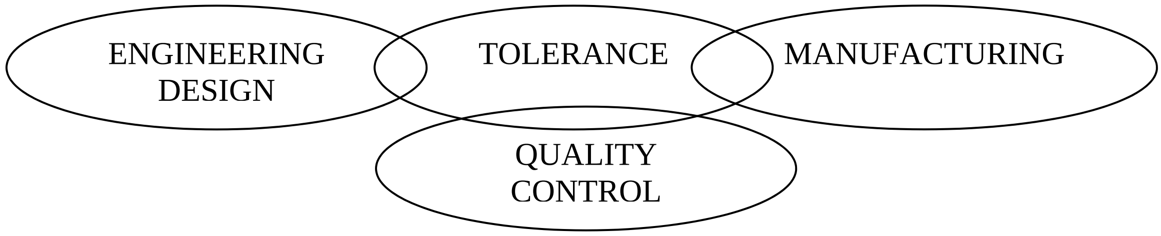

Figure 1.1: Three main groups who are constantly concerned with the tolerance problems (Kinzel and Pham, 2003)

1.1 Background Of The Research

At the moment, the process to get the appropriate tolerance to meet the product specification is usually time consuming. It requires the making the mock up samples, and testing have to be done for a few times to get desired tolerance allocation. This process is very costly. Currently, the development of a new product should be shorter in terms of time frame to secure the market share as well to lead the market trend in order to succeed in the tough competition.

Tolerance Stack Process

The flow chart of the tolerance stack verification is shown in Figure 1.2.

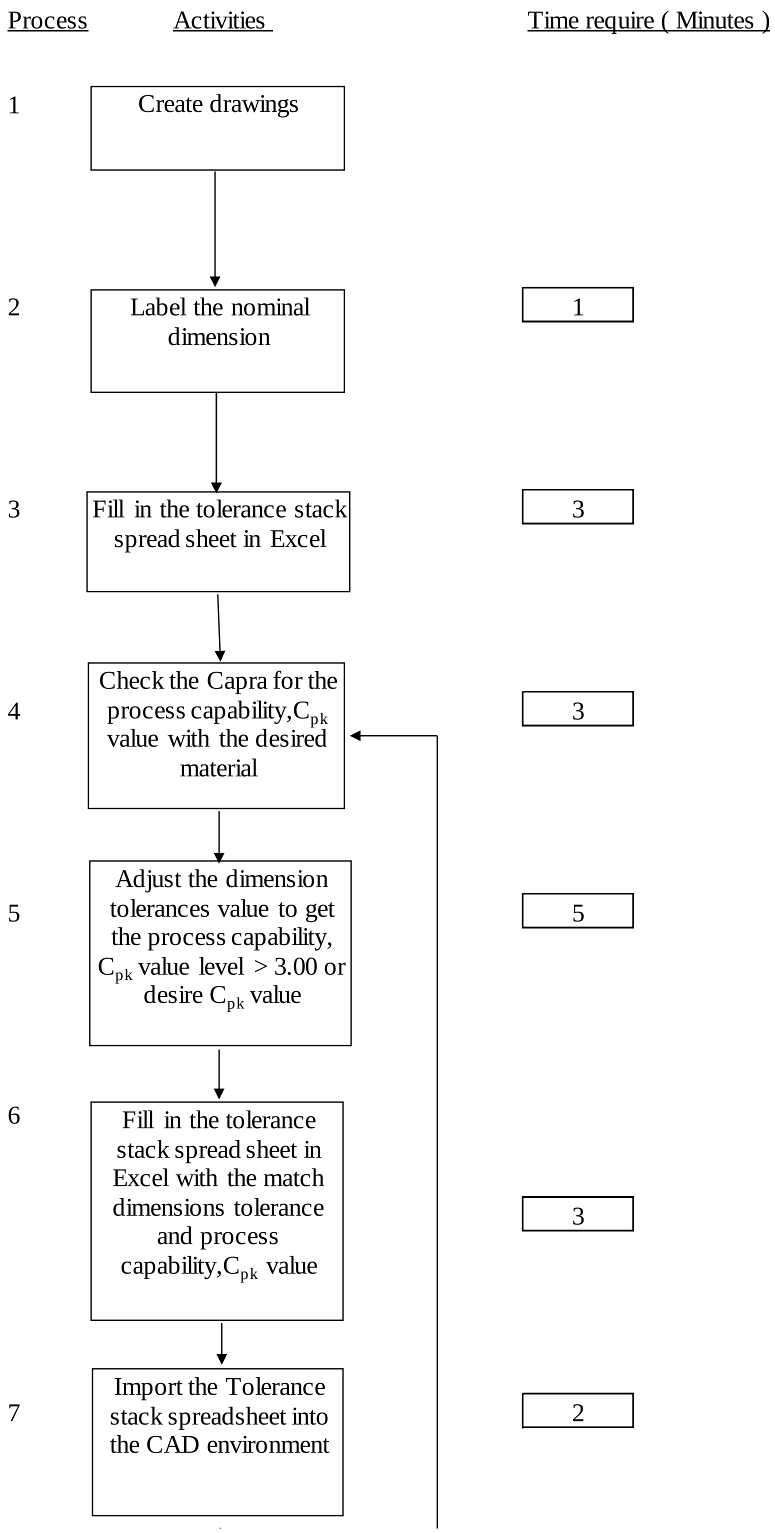

Figure 1.2 : Tolerance Stack Process in a typical product development from company A

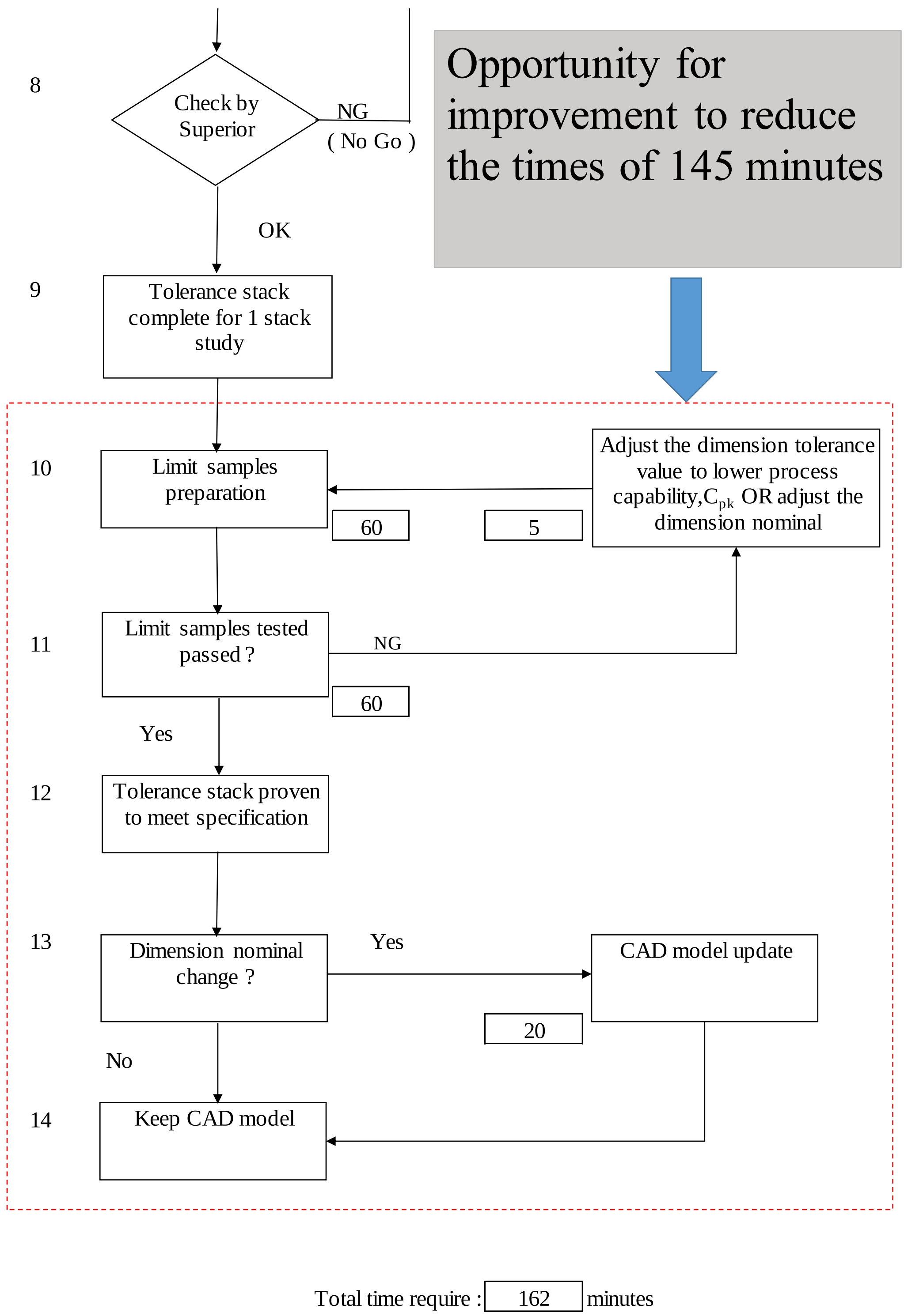

Figure 1.2 : Tolerance Stack Process in a typical product development from company A (continued)

The tolerance stack study which is define the tolerances to ensure the components are able to work within the limits, namely the maximum and minimum limits of the component. The dimension confirmation is required to perform the tolerance stack study. The flow chart shows a typical design process to confirm the dimensions on the drawings. The software call Capra is then used to predict the C_{pk} value based on different type of manufacturing processes, in this case is the plastic injection process. The higher the C_{pk} value, the process capability is better, but maximum at 4.0. The C_{pk} value is based on the value with the tolerance assigned, the wider the tolerance, the better of the C_{pk} value due to the component will be easier to produce. Once the dimension assigned with tolerance, a limits samples will be mock up and go for comprehensive testing. When the testing passed, the intended dimensions will be kept otherwise, the C_{pk} value or dimensions need to be revised and prototype need to be mock up again. The making of the prototype samples might have differences from different designers. Thus, the variation from the prototype samples also contributes to the testing results variation. Hence it is difficult for designer to conclude the test results from the testing.

Figure 1.2 shows that 162 minutes is the time consumed to verify a single tolerance stack from engineering drawings for the purpose of dimensions confirmation. To produce a product, such as vacuum cleaner accessories on the fitting of the two components with user interaction, tolerance stacks are required to be examined. This is very time consuming and costly as the number of mock ups are required. Not to mention, the testing on the limits is a must. It would not be an efficient way to design. The opportunity for the improvement is from process 10 to 14, which is boxed with red dotted line. The time used for these processes is expected to be 145 minutes or more if multiple testing are repeated to get the intended results.

1.2 Problem Statement

In order to be cost effective in terms of time on human personnel in design, the tolerance stack verification should be represented as mathematical representation. Therefore, this research is carried out, to develop the mathematical representation of the tolerance stack using the statistical approach on the experimental data. The mathematical representation is then verified using FEA model.

1.3 Objective of the research

The objectives of the research are:

(a) To develop a procedure to replace the experiment
(b) To develop the new mathematical model for prediction of force in the interference fits for cylindrical components
(c) To develop analytical method with FEA model for prediction of force in the interference fits for cylindrical components

1.4 Scope of the research

The scopes of the research are as follow:

(a) The assembled part is shown in Figure 1.3 and the main parameters to be studied on attach and detach force.

(b) Tolerance is between two cylindrical parts. The parts are made of different materials. The materials are as follows:
Material 1: Polycarbonate (PC) for hollow brush housing (Cylinder 2)
Material 2: High Impact Acrylonitrile-Butadiene-Styrene (ABS) for hollow lower tube (Cylinder 1)

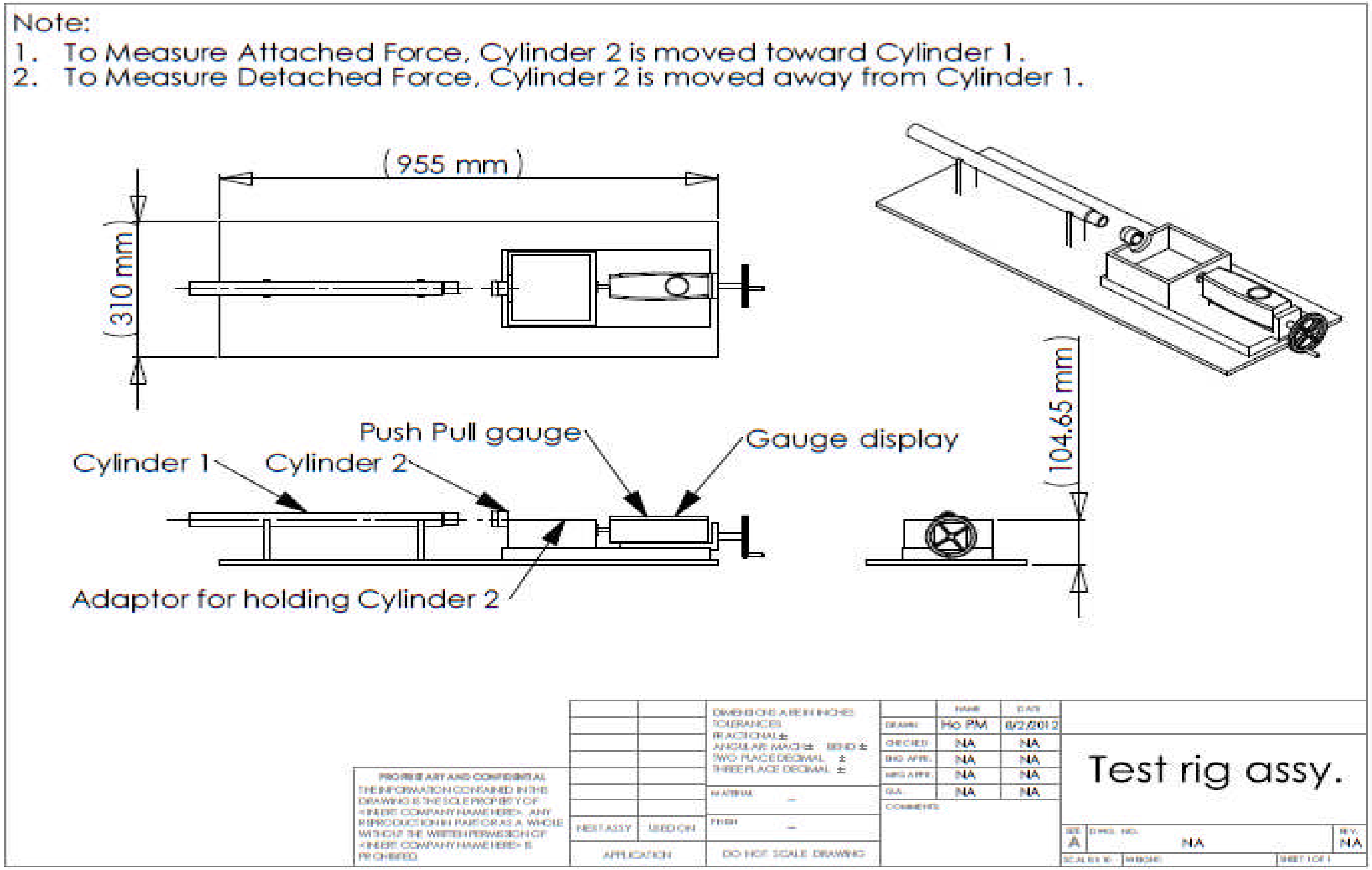

Figure 1.3: Test Rig Assembly

1.5 Significance of the study

The significances of the study are as follows:

(i) The mathematical representation can be used to predict attach and detach force required on the cylindrical parts. Therefore, it will reduce the time taken during the tolerance stack process.

(ii) The FEA model can also be used to study the parametric effect if design parameters need to be changed.

(iii) Both mathematical representation and FEA model together bring the requirement of comprehensive testing to be done on the desktop via stimulation software

1.6 Thesis Summary

The following is the summary of the chapters

Chapter 2: This chapter reviews the related literature. It will then discuss on the relevant theory, tools, and methods on the interference fits study.

Chapter 3: Methodology on how to conduct the research is discussed in this chapter.

Chapter 4: In this chapter, the results and data from the experiment were analyzed to develop the mathematical representations. Then, data were verified using FEA model. Finally, case studies are carried out.

Chapter 5: This chapter outlines the conclusion of the research and give recommendation for future research.

REFERENCE

Battison E., (1973). A New Look at the Whitney Milling Machine. *Technology and Culture*. 14 (4), 592-598.

Booker J.D., and C. E. Truman (2011). Experimental Techniques. *Measuring the Coefficient of Friction for Use in Shrink - Fit Calculations*. 35(2),7-13.

Chase K. W. and A. R. Parkinson (1991), A Survey of Research in the Application of Tolerance Analysis to the Design of Mechanical Assemblies, *Mechanical Engineering Department. Brigham Young University Published in Research in Engineering Design*, 3(1),23-37

Changming Z, and J. Yongjie (1994). The Solutionof Frictional Contact Problems Using a Finite Element Mathematical Programming Method. *Journal of Composite Structure.* 52(1), 149-155.

Dreija Z., O. Liniņš, and Fr. Sudnieks, Influence of friction force and stresses on compression joint. *2006 IIE Annual Conference and Exhibition*. 20- 24 May, 2006. Orlando, FL. 2006 IIE Annual Conference and Exposition.2006.6.

Gadzala, J.L. (1959). *Dimensional Control In Precision Manufacturing* (1st ed.), New York: McGraw-Hill.

Hearn E. J. (2000). *Mechanics of Material 1, An Introduction To The Mechanics of Elastic and Plastic Deformation of Solids and Structural Material.* (3rd ed.), Woburn, MA: Butterworth-Heinemann.

Johnson. A.(1954). The Tool Engineer. *Index Tolerance Chart Simplified Production.* 32 (2), 53-62.

Kim J. H., H. S. Yoon, and S. H. Ahn.(2013) Effect-of-repeated-insertions-into-a mesoscale-pinhole-assembly-Case-of-interference-fit. *International Journal of Precision Engineering and Manufacturing*.14(9),1651-1654.

Kinzel G. and L. Pham, (2003). *Mechanical Design, Course Notes* , Department of Mechanical Engineering, Ohio State University under the NSF sponsored Gateway Coalition

Li, Q., S. J. Chen, Y. Zhang, and J. W. Wang (2010). An, Q, Calculation Method of Stress and Deformation of Interference Fit Conic Thread Connection. *Huadong Ligong Daxue Xuebao, Journal of East China University of Science and Technology*. 36(3), 452-457.

Mack, W., and M. Ploch (2000) Transient heating of a rotating elastic–plastic shrink fit. *International Journal of Engineering Science.* 38(8), 921-928.

Minitab Inc. (2010). *Minitab 16* [Brochure]. Pennsylvania State University, United States: Minitab Inc.

Moody J. and I. Green (2007). An Investigation of Three Dimensional Elastic-Plastic Hemispherical Sliding Contact, Part II: Results. *ASME/STLE 2007 International Joint Tribology Conference.* October 22–24, 2007. San Diego, California. ASME, 581-583.

Mooney , C.T. (1955). The Tool Engineer. *How to Adjust Tolerance Charts*. 35(4),75-81.

Perrite (2005). *Ronfalin* C PC/ABS [Brochure]. Cheshire, United Kingdom: Perrite

Pouzada A. S., E.C. Ferreira, and A.J. Pontes (2006). Polymer Testing. *Friction Properties of Moulding Thermoplastic.* Department of Polymer Engineering, Institute for Polymers and Composites. University of Minho. 25(8), 1017-1023.

Sack, Jr. C.F. (1982) *Computer Managed Process Planning-A Bridge between CAD and CAM*. The CASA/SME Autofact 4 Conference, November,7.15-7.31.

Sen, S. and B. Aksakal (2003). Stress Analysis of Interference Fitted Shaft-Hub System under Transient Heat Transfer Conditions. *Department of Mechanical Engineering. Engineering Faculty Ataturk University*.25(5), 407-417.

Vaziri. M., F.H. Stott, and R.T. Spurr (1988). Studies of the Friction of Polymeric Materials.*Wear*.122(3), 313- 327.

Vijaywargiya, R., Green, I. (2007) A finite element study of the deformations, forces, stress formations, and energy losses in sliding cylindrical contacts. *International Journal of Non-Linear Mechanics*.42(7), 914-927.

Yang, G.M., J. C. Coquille, J.F. Fontaine, and M. Lambertin (2002). Contact Pressure between Two Rough Surfaces of a Cylindrical Fit . *Journal of Materials Processing Technology*. 123(3), 490-497.

Wade O.R., (1967). *Tolerance Control in Design And Manufacturing* (1st ed.) New York: New York Industrial Press Inc.