MODAL ANALYSIS OF PIPE JOINT SPIRAL WOUND GASKET

NABIL FAHMI BIN MOHTAR

Thesis submitted in fulfilment of the requirement
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2010

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Modal Analysis of Pipe Joint Spiral Wound Gasket"* is written by *Nabil Fahmi bin Mohtar*. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Dr. Gigih Priyandoko

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature

Name of Supervisor : Muhammad Hatifi b. Hj. Mansor

Position : LECTURER

Date : 6 DECEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name : NABIL FAHMI BIN MOHTAR

ID Number : MA07057

Date : 6 DECEMBER 2010

For my beloved Family Members,

Especially my Parents,

And unforgettable all my friends...

May Allah bless you...!!

ACKNOWLEDGEMENTS

Praise be to Allah S.W.T, the Most Gracious, the Most Merciful for all the blessings and guidance upon me through my study. Thank you so much dear Allah for giving me strength and answering my prayers.

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this research.

First and foremost, I would like to record my sincere gratitude to my supervisor, Mr. Muhammad Hatifi b. Hj. Mansor for his supervision, advice and guidance from the very early stage of this research as well as giving me extraordinary experiences throughout the work. Above all and the most needed, he provides me unflinching encouragement and support in various ways. I am indebted to him more than she knows. One simply could not wish for a better or friendlier supervisor.

Many thanks go to all FKM laboratory instructor and technicians who are willingly landing their hands in laboratory and experimental work and all these staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay in UMP pleasant and unforgettable. Special thanks from me also go to my friends who are under same supervisor. I would like to acknowledge their comments and suggestions which were crucial for the successful completion of this study.

Where would I be without my family? My parents deserve special mention for their inseparable support and prayers. My father, Mohtar bin Kasim, in the first place is the person who put the fundament by learning character, showing me the joy of intellectual pursuit ever since I was a child. My mother, Maimunah binti Tompang, is my special one who sincerely raised me with her caring and gentle love. Brothers and sisters, thanks for being supportive and caring siblings.

Finally, I would like to thank everybody who was important to the successful realization of this thesis, as well as expressing my apology that I couldn't mention personally one by one.

ABSTRACT

This project report deals with dynamic behaviour of spiral wound gasket using theoretical and experimental analysis method. This project report is to study the dynamic properties and behaviour of spiral wound gasket by using modal analysis and compare with the finite element analysis. The structural three-dimensional solid modelling of spiral wound gasket was developed using the SOLIDWORK drawing software. The finite element analysis was then performed using ALGOR (FEA). The finite element model of the components was analyzed using the linear modal analysis approach. Finally, the experimental modal analysis was performed using Impact Hammer Testing method. The natural frequency of the mode shape is determined and comparative study was done from both method results. The comparison between natural frequencies of finite element modelling and model testing shows the closeness of the results. From the results, the percentage error had been determined and the limitation in the natural frequency of the spiral wound gasket is observed.

ABSTRAK

Laporan projek ini berkaitan dengan perilaku dinamik *spiral wound gasket* menggunakan kaedah analisis teori dan eksperimen. Laporan ini adalah untuk mempelajari sifat dinamik dan perilaku *spiral wound gasket* dengan menggunakan analisis modal secara eksperimen dan membandingkannya dengan analisis elemen secara teori. Pemodelan struktur tiga-dimensi *spiral wound gasket* dilukis menggunakan perisian melukis SOLIDWORK. Analisis elemen modal kemudian dijalankan dengan menggunakan perisian ALGOR. Analisis di dalam perisian ini menggunakan pendekatan analisis linier modal. Kemudian, analisis modal secara eksperimen dilakukan dengan menggunakan kaedah Hammer Kesan Ujian. Frekuensi dan bentuk mod ditentukan dan kajian perbandingan dilakukan dari kedua-dua keputusan kaedah. Perbandingan antara frekuensi dari pemodelan elemen secara teori dan ujian model secara eksperimen menunjukkan keputusan yang hampir sama. Dari hasil tersebut, peratus perbezaan antara kedua kaedah telah direkod dan had frekuensi asas *spiral wound gasket* telah diamati.

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSIONS

CHAPTER 5 CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

f	Frequency
F	Force
D	Diameter
P	Pressure
t	Thickness

LIST OF ABBREVIATIONS

ASME	American Society of Mechanical Engineers
SWG	Spiral Wound Gasket
CAD	Computer Aided Diagram
IGES	Initial Graphics Exchange Specification
3D	3 Dimensional
DOF	Degree of Freedom
DAS	Data Acquisition System
FEA	Finite Element Analysis
PTFE	Polychlorotrifluoroethylene
ANSI	American National Standard Institute
DIN	German Institute for Standardization
BS	British Standard
NPS	Nominal Pipe Size
FFT	Fast Fourier Transform
FYP	Final Year Project
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

In the Oil & Gas industry, pipes are widely used in refinery piping, exploration, crude oil transmission, line pipe, flow lines, injection lines (water and gas), gas transmission lines, offshore platform piping, floating production storage and off-loading, sub-sea piping and piping on vessels. There are many types of pipe joints used in the piping system. Some of them are push-on joints, mechanical joint, flanged joint, restrained joints, restrained push-on gasket, field-welded restrained joints, ball and socket joints and grooved and shouldered joints. In the pipe joints field, spiral wound gaskets are commonly used as their connecter. This kind of gasket had been improved and modified to give assurance of the safety of the distribution system.

Spiral wound gaskets are very efficient as sealing devices, not least because of the high loads which are used to compress and retain them in the place. Spiral wound gaskets comprising alternate turns of a profiled metal strip and softer filler material strip are commonly used in industrial sealing applications where they are positioned, for example, between a pair of pipe flanges and compressed by the use of bolts to hold the flanges together. Basic type spiral wound gasket consists of a thin metallic strip and soft non-metallic filler (graphite, asbestos, ceramic, polychlorotrifluoroethylene (PTFE), etc.) that are simultaneously wound on a rotating mandrel. The metal hoop is pre-formed with a V or W shaped profile which allows the gasket to act as a spring between the flanges. Further, the hoop provides the basic structural element for the gasket while the non-metal filler material seals small imperfections on the flange surfaces. They are available in all standard flanges of sizes.

Spiral wound gaskets have good compressibility and rebound elasticity. It can keep very good sealing performance under some tough conditions of circulating alternation such as high temperature, low temperature, high vacuum and impact vibration. In this project, we will investigate the stability and detect the vibration that occurred in the spiral wound gasket. The vibration occurred is obtained by performing dynamic analysis using ALGOR Finite Element Analysis (FEA).

1.2 OBJECTIVES OF STUDY

The purpose of this research is to study the dynamic properties and behavior of spiral wound gasket by using modal analysis and compare with the finite element analysis.

1.3 SCOPES OF PROJECT

This projects focus on the following points:

(i) The plan of spiral wound gasket is created using SOLIDWORK.
(ii) The theoretical data from dynamic analysis using ALGOR will be taken.
(iii) Experimental analysis which is modal analysis is performed to the spiral wound gasket.
(iv) Comparative study will be conduct between the previous result and the result from modal analysis.

1.4 PROBLEM STATEMENT

In the piping system, high vibration levels occurred frequently in the fields. Vibration has been identified as the dominant cause of piping failures. Excessive piping vibration can cause real problems. Threaded connections can loosen. Flanges can start leaking. Pipes can be knocked off their supports. Gasket will be defected. And in extreme cases, a pipe fatigue failure can occur. Gaskets are the weakest link in the piping system of a process plant. Therefore, it is important not to ignore the design and selection of the gaskets to prevent flange-leakage problems and avoid costly shutdowns.

In Simonen and Gosselin (2001) piping vibration fatigue was reported as the cause of piping failures 29 percent of the time in US nuclear plants between 1961 and 1996. In small bore pipes, 2 inch and less, vibration fatigue accounted for 45 percent of the piping failures. With such a high failure rate it is important that the cause of the vibration be eliminated and studied whenever possible (Herbert, 2001).

During the last three decades considerable advances have been made in the applications of numerical techniques to analyze pressure vessel and vibration piping problems. Among the numerical procedures, finite element methods and modal analysis are the most frequently use (Jaroslav, 2004).

Modal analysis is done to obtain the actual dynamic properties. The dynamic properties which consist of natural frequency, mode shape and damping are unknown on the design. The frequency of vibration of the spiral wound gasket is directly related to the stiffness and the mass of it while the mode shapes are related to the defect location. Therefore vibration testing needs to be carried out to obtain the data of those dynamic properties. The parameters that describe each mode are natural frequency or resonance frequency (modal) damping mode shape; these are called the modal parameters. By using the modal parameters to model the structure, vibration problems caused by these resonances (modes) can be examined and understood (Inman, 2007). The purpose of this project is to determine the natural frequencies of the spiral wound gasket for structural health monitoring and evaluation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A significant of this chapter is based on preliminary of piping system, vibration in piping system, spiral wound gasket characteristic and ALGOR finite element analysis. Basics understanding in the study must be recognizable before running the finite element analysis of the spiral wound gasket in ALGOR.

The review of this study is based on preceding work of vibration in piping system and briefly elaborated about the spiral wound gasket performance, their functional requirements and selecting material, application of spiral wound gasket, how they are manufactured, studying of each element in spiral wound gasket, several potential gasket-related problems, the cause of the leakage in piping system and the technique that will be used to analyzed are ALGOR finite element analysis and experimental analysis which is modal analysis.

2.2 BASIC VIBRATION THEORY

Any system has certain characteristics to be fulfilled before it will vibrate. To put in simple words, every system has a stable position in which all forces are equivalent, and when this equilibrium is disturbed, the system will try to regain its stable position. To remain stable, structure exhibits vibration at different magnitude when excited, the degree of vibration varies from point to point (node to node), due to the variation of dynamic responses of the structure and the external forces applied.

Therefore, vibration may also be described as the physical manifestation of the interchange between kinetic and potential energy. (Silva, 2005)

The majority of structures can be made to resonate, i.e. to vibrate with excessive oscillatory motion. Resonant vibration is mainly caused by an interaction between the inertial and elastic properties of the materials within a structure. Resonance is often the cause of, or at least a contributing factor to many of the vibration and noise related problems that occur in structures and operating machinery. To better understand any structural vibration problem, the resonant frequencies of a structure need to be identified and quantified. (Inman, 2007)

2.3 PIPING SYSTEM

Piping systems are generally can be defined as interconnected piping subject to the same set or sets of design conditions. Piping refers to assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping components refers to mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components of the piping systems are include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, in-line portions of instruments, and separators. Systems and components of the piping system do not include any equipment excluded from ASME B31.3 or B31.9 or ASME Boiler and Pressure Vessel Code. (ASME B16.20, 1993.)

2.4 GASKET

A gasket is a mechanical seal that fills the space between two mating surfaces, may also be called a seal, generally to prevent leakage from or into the joined objects while under compression. Gaskets are commonly produced by cutting from sheet materials, such as gasket paper, rubber, silicone, metal, cork, felt, neoprene, nitrile rubber, fiberglass, or a plastic polymer such as polychlorotrifluoroethylene (PTFE). Gaskets for specific applications may contain asbestos. It is usually desirable that the gasket be made from a material that is to some degree yielding such that it is able to deform and tightly fills the space it is designed for, including any slight irregularities. A few gaskets require an application of sealant directly to the gasket surface to function properly. (Daniel, 1996) Gaskets come in many different designs based on industrial usage, budget, chemical contact and physical parameters:

2.4.1 Spiral Wound Gasket (SWG)

Spiral wound gaskets are special semi-metallic gaskets. They are made of a preformed metallic strip and a soft filler material, wound together in a V-shaped under pressure, and optionally with an inner and/or outer guide ring. The metal strip holds the filler, resulting in excellent mechanical resistances, resilience and recovery, therefore they are very suitable for application featuring heavy operating conditions. The outer centering ring controls the compression and holds the gasket centrally within the bolt circle. The inner retaining ring increases the axial rigidity and resilience of the gasket. Spiral wound gasket should always be in contact with the flange and should not protrude into the pipe or project from the flange. Europiping Industrial Technologies (EIT, 2000).

Spiral wound gaskets are very efficient as sealing devices, not least because of the high loads which are used to compress and retain them in the places. It would be desirable to use a spiral wound gasket in applications such as in vehicle exhausts at junctions between pipes and catalytic converters for example. However, the available clamping loads are very low due to the relatively flimsy securing flanges which are normally available, the low number of clamping bolts (usually four or less) and the relatively small section and thread areas of those bolts that are available. The established sealing systems for such exhausts are mica foil on a tanged core or exfoliated graphite on a tanged steel core. Due to the relatively low bolt load available and the contact area of these gaskets, the surface stress achieved on these gaskets is low and the sealing unsatisfactory. The Flexitallic Group (TFG, 2000). Figure 2.1 shown is a spiral wound gasket manufactured according to standard ASME B16.20 and Figure 2.2 is the cross section of the spiral wound gasket that shows the v-shaped profile in the sealing elements.

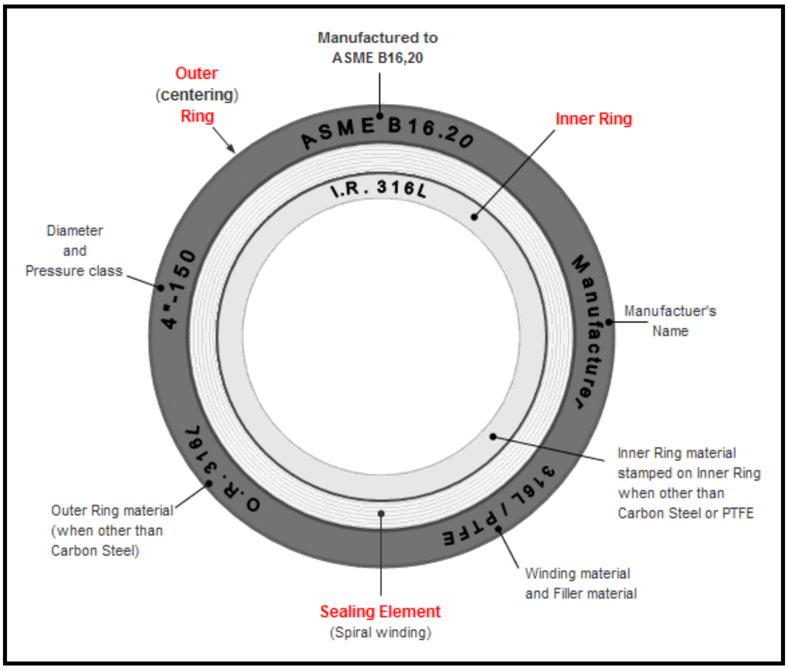


Figure 2.1: ASME B16.20 Spiral wound gasket

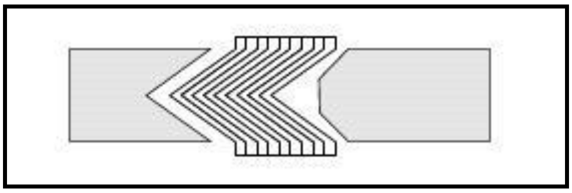


Figure 2.2: Cross section of spiral wound gasket; V-shaped profile

Source: The Flexitallic Group (2000)

2.4.2 Spiral Wound Gasket Styles

Basically, there are four basic types of spiral wound gasket that has been manufactured widely in the market as shown in Figure 2.3. Four basic types of spiral wound gaskets are plain gaskets, outer ring gaskets, inner and outer ring gaskets, and inner ring gaskets. Each design of spiral wound gaskets has a specific application in the pipe flange industry.

i. Plain gasket - Spiral winding only. This style of gasket consists of the winding/sealing element only. It has no guide ring (centering ring) or inner ring. It is most commonly used in tongue and groove and male/female flanges.

ii. Inner ring gasket - This gasket is similar to the plain gasket, however, it has an inner ring. Its application is similar to the plain gasket.

iii. Outer ring gaskets - The outer ring gasket is the most common profile of spiral wound gasket and used extensively in ANSI B16.5 flanges. The gaskets consist of a metal guide ring (or sometimes referred to as a centering ring) and a spiral wound sealing element. This profile is normally used in raised and flat faced flanged. The outer ring is often made of carbon steel (painted or zinc plated to prevent corrosion) but can be made of alloys for higher temperature and more severe medium applications.

iv. Inner and outer ring gaskets - This gasket is identical to the outer ring gasket, however an inner ring has been inserted to enhance gasket performance. The inner ring is added to prevent the possibility of the gasket imploding into the pipe during installation, to protect the sealing element from extreme temperatures and mediums, fill the void between flanges to prevent erosion of the flange, and to reduce the possibility of failure. The inner ring is normally made of the same alloy as the winding. The DIN 2699 standard (German) specifies inner rings in all spiral wound gaskets. Inner rings are required for gasket with PTFE filler according to ASME B16.20 standards, and considered important for graphite fillers. This profile is normally used in raised and flat faced flanges. TianYi Chemical Industrial (TCI, 2006).

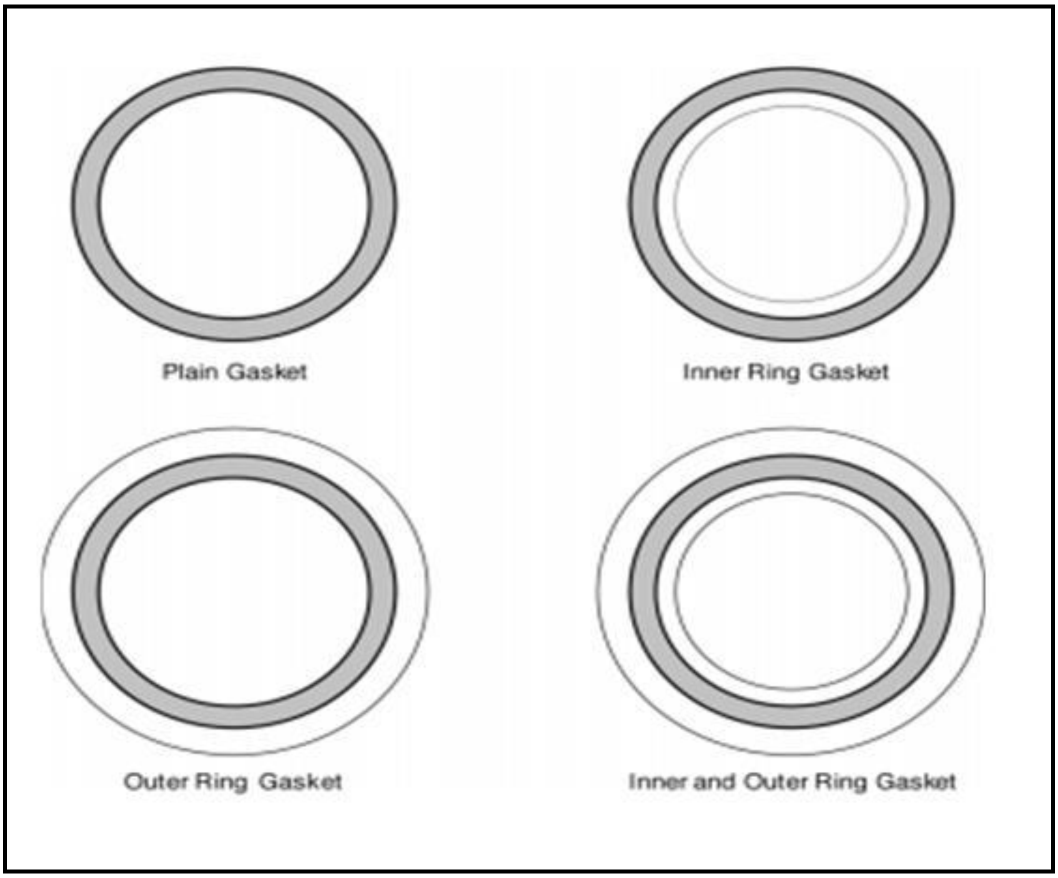


Figure 2.3 Spiral wound gasket styles

Source: TianYi Chemical Industrial (2006)

2.4.3 Selecting Material of Spiral Wound Gasket

With the diversity of gasket materials available in the marketplace, it becomes challenging to find the product that will meet the specific demands of any given application. More effective selection of the best product begins with an initial assessment of conditions. Four basic conditions must be considered when selecting a gasket material:

- Operating conditions
- Nature of the media and chemical compatibility
- Flange design
- Environmental or regulatory issues

The operating conditions include parameters such as pressure and temperature, as well as their fluctuations. If the system is subject to severe pressure spikes or thermal cycling, these things can adversely affect the performance of a gasket material that otherwise would perform adequately. Vibration also has to be considered.

The gasket material must not contaminate or be chemically attacked by the sealed product. The affect of temperature fluctuations on dew point excursions also may have to be considered, since they can increase the aggressiveness of the media. In critical applications, it may be necessary to perform laboratory tests to simulate the operational conditions and thereby assure chemical compatibility

The flange design plays a very important role in selection of the gasket material. Plastic, FRP, glass or other fragile flange material will require a gasket material that seals with low bolt loads. Gasket selection for these flanges differs from that for metal flanges at high pressures where the bolt load must be high to assure sealability. Flange geometry is another important consideration. Tongue-and-groove flanges can apply high seating stress when compared with full-face flanges. The sealing surface finish and its condition, such as the existence and extent of pitting or corrosion, warping or rotation, also can determine the selection of the best gasket material. The number of bolts, bolt material and, consequently, the bolt load also will influence selection.

Environmental and regulatory issues must be carefully analyzed. There might be standards or regulations that prevent the use of certain types of gasket materials in a given application.

Many gasket failures result because these four basic steps were not considered. With proper analysis of the application, a major step will be made toward selection of a gasket material that will perform reliably in service. (Arthur, 2006).

2.4.4 Spiral Wound Gasket Installation

Once adequate attention has been given to all aspects of gasket selection, proper installation is necessary for the ultimate success of this component in a bolted joint. One of the most common causes of leaky joints is improper gasket installation. Figure 2.4 shows how spiral wound gasket is installed in the system. The following gasket installation procedures can be useful for all bolted flange connections:

(i) Inspect the gasket. It is important that the correct gasket has been chosen. Verify that the material and design is as specified, and visually inspect the gasket for any obvious defects or damage.

(ii) Inspect the gasket seating surfaces. Look for tool marks, cracks, scratches or pitting by corrosion. Radial tool marks on gasket seating surfaces are virtually impossible to seal, regardless of the type gasket used. Therefore, every attempt should be made to minimize these.

(iii) Use only new studs or bolts, nuts and washers. Make sure they are of good quality and appropriate for the application.

(iv) Lubricate all thread contact areas and nut facings. The importance of proper lubrication cannot be overstated. A proper lubricant will provide a low coefficient of friction for more consistent bolt stress. An anti-seize compound, when used as a bolt and nut lubricant, will facilitate subsequent disassembly.

(v) Loosely install stud bolts. With raised-face and flat-face installation, loosely install the stud bolts on the lower half of the flange. Insert the gasket between the flanges to allow the bolts to center the gasket on the assembly. Install the remaining bolts and nuts and bring all to a hand-tight or snug condition. In a recessed or grooved installation, center the gasket midway into the recess or groove. (If the joint is vertical, it may be necessary to use a minimum amount of cup grease, gasket cement or some other adhesive compatible with the process fluids, to keep the gasket in position until the flanges are tightened.) Then, install all bolts and nuts to a hand-tight or snug condition.

(vi) Identify the proper bolting sequence and number bolts accordingly. Each bolt should be numbered so that bolt torque sequences can be easily followed. Failure to follow proper bolt torque sequences can result in cocked flanges.

Then, regardless of the amount of subsequent torquing, flanges cannot be brought back to parallel. This can contribute heavily to a leaky joint.

(vii) Torque the Bolts. Bolts should be torqued in a proper bolting sequence, in a minimum of four stages, as specified in Steps 8, 9, 10 and 11.

(viii) Torque the bolts up to a maximum of 30% of the final torque value required following the recommended bolt torque sequence.

(ix) Repeat Step 8, increasing the torque to approximately 60% of the final torque required

(x) Repeat Step 8, increasing the torque to the final torque value.

(xi) Retorque all studs. All studs should be retorqued with a rotational pattern at the final value of torque until no further rotation of the nuts can be achieved. This may require several passes, as torquing of one stud typically causes relaxation in adjacent studs. Continue torquing until equilibrium has been achieved.

(xii) Some flange joints should be retightened just before being put in operation, to compensate for bolt and gasket relaxation. Success also has been reported with heat exchangers, with certain gasket types and flange facings, when bolting is retightened during initial heat-up, before loss of lubricant (or bolt seizing). Gasket Resource Incorporation (GRI, 2000).

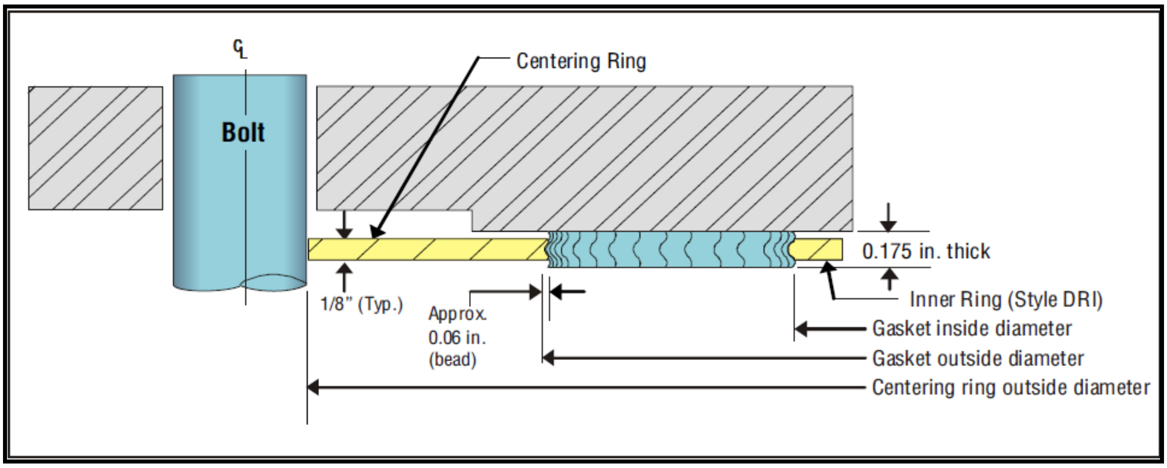


Figure 2.4: Spiral wound gasket installation

Source: Gasket Resource Incorporation (2000)

2.4.5 Gasket Material

There are many gasket materials available in the market. Selected materials should be compatible with operating temperature and chemicals.

METAL WINDING STRIP
AS STANDARD
Stainless Steel 304
type 316L

OTHERS
Stainless Steel
type 304L
309
310
316Ti
317L
321
347
430
17-7PH
ALLOY 20
MONEL®
TITANIUM®
NICKEL® 200
INCONEL® 600
625
X-750
HASTELLOY® B2
C276
INCOLOY® 800
825
DUPLEX
ZIRCONIUM®
TANTALUM®
COPPER
PHOS-BRONZE
CARBON STEEL

FILLER MATERIAL
Flexicarb® flexible graphite
Thermiculite™ 835
Thermiculite™ 735
Flexite Super®
PTFE
Mica
Ceramic
Non-sintered PTFE

Thermiculite, FLEXITALLIC'S new high-temperature, sealing material is comprised of chemically exfoliated and thermally exfoliated vermiculite.

This revolutionary new product simulates the structure of exfoliated graphite but with one notable exception... gaskets made with Thermiculite maintain their integrity, even at extreme temperatures.

Thermiculite is thermally stable, ensuring against thermal oxidation, at temperatures in excess of 1800°F (Thermiculite™ 835).

GUIDE RING MATERIAL
AS STANDARD
Carbon Steel

OTHERS
Stainless Steel
type 304
304L
316
316L
316Ti
310
321
347
410
INCONEL® 600
625
MONEL®
TITANIUM®
NICKEL
INCOLOY® 800
ALLOY 20
INCOLOY® 825
HASTELLOY® B-2
C276

Figure 2.5: Available gasket material

Source: The Flexitallic Group (2000)

2.4.6 Factors Affecting Gasket Performance

There are a number of key factors that contribute to the majority of variability in performance associated with spiral wound gasket joints. There was a prevailing assumption shared by many plant engineering and maintenance personnel. This assumption was that the American Society of Mechanical engineers (ASME) B16.20 certification stamped upon the outer guide ring of most spiral wound gaskets indicated that a gasket so stamped met common and relatively uniform dimensional and performance criteria. (ASME B16.20, 1993.) Gasket performance is depends on a number of factors, including:

(i) Surface finish: The surface finish of a gasket, which consists of grooves or channels pressed or machined onto the outer surface, governs the thickness and compressibility required by the gasket material to form a physical barrier in the clearance gap between the flanges. A finish that is too fine or shallow is undesirable, especially on hard gasket materials, because the smooth surface may lack the required grip, which will allow extrusion to occur. On the other hand, a finish that is too deep will yield a gasket that requires a higher bolt load, which may make it difficult to form a tight seal, especially when large flange surfaces are involved. Fine machining marks applied to the flange face, tangent to the direction of applied fluid pressure can also be helpful. Flange faces with non-slip grooves that are approximately 0.125 mm deep are recommended for gaskets more than 0.5 mm thick; and for thinner gaskets, grooves 0.065 mm deep are recommended. Under no circumstances should the flange-sealing surface be machined with tool marks extending radially across the gasket-sealing surface; such marks could allow leakage.

(ii) Gasket thickness: For a given material, it is a general rule that a thinner gasket is able to handle a higher compressive stresses than thicker one. However, thinner materials require a higher surface finish quality. As a rule of thumb, the gasket should be at least four times thicker than the maximum surface roughness of the flange faces. The gasket must be thick enough to occupy the shape of the flange faces and still compress under the bolt load. In situations where vibration is unavoidable, a thicker gasket than the minimum required should be employed.

(iii) Bolt loading: Bolt loads also affect the choice of materials thickness. Basically, the gasket material must be thick enough to deform sufficiently to accommodate any irregularities or inequalities in the flange faces under the available bolt load. The lower this load, the greater will be the required thickness, and vice versa. However, the thickness will also depend on the material's compressibility. In general, it is desirable to use multiple bolts that are equally loaded to give a uniform stress over the gasket area. Using many small-diameter bolts is preferable to using few large-diameter bolts. (Jenko and Hunt, 2000).

(iv) Gasket width: In order to reduce the bolt load required to produce a particular gasket pressure, it is advisable not to have the gasket wider than is necessary. For a given gasket stress, a raised face flange with a narrow gasket will require less pre-load, and thus less flange strength than a full-face gasket. In general, high-pressure gaskets tend to be narrow.

(v) Stress relaxation: This factor is a measure of the material's resiliency over a period of time, and is normally expressed as a percentage loss per unit of time. All gasket material will lose some resiliency over time, due to the flow or thinning of the material caused by the applied pressure. After some initial relaxation, the residual stress should remain constant for the gasket.

(vi) Gasket external diameter: For two gaskets made of the same material and having the same width, the one with a larger outer diameter will withstand a higher pressure. Therefore, it is advisable to use a gasket with an external diameter that is as large as possible.

(vii) Temperature: An increase in temperature will degrade the strength of the gasket material, causing it to deform. This will change the bolt load and thus modify the residual stress. A poor gasket material that suffers high deformation with increasing temperature will show high relaxation and collapse or extrude at high temperatures under moderate internal pressure.

(viii) Fluid properties: The gasket material must be resistant to corrosive attack from the fluid. It should chemically resist the system fluid to prevent serious impairment of its physical properties. (Trinath, 2008).

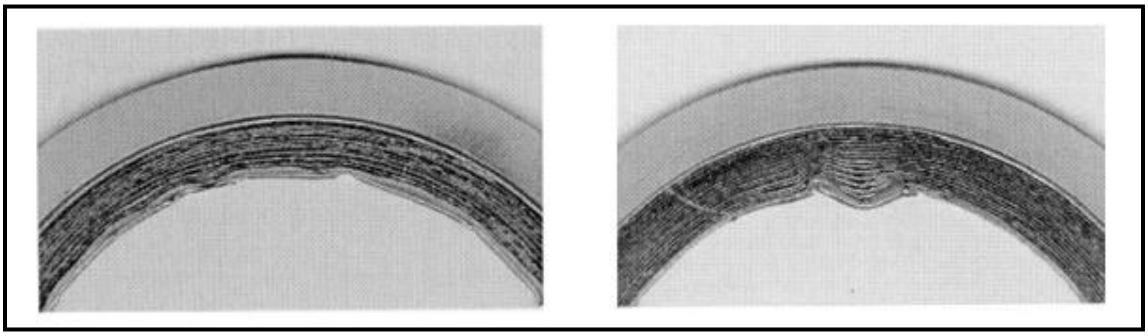
2.4.7 Failure of Spiral Wound Gasket

Graphite filled spiral wound gaskets are not new and have developed from asbestos filled types. They are commonly found in refineries, gas and other petrochemical processing plants and are generally manufactured to either ASME or BS standards. Most nominal bore sizes and classes (class refers to pressure rating) are affected. The problem of spiral buckling, which appears to have been exacerbated with the move away from asbestos to graphite filler, is now well understood by most leading manufacturers.

Spiral wound graphite filled gaskets are made up from alternate plies of pre-formed metal winding and filler, tightly wound spirally and contained within a metal centering ring. The metal and filler material can be varied to suit practically any service condition. In the case of higher pressure gaskets a metal inner ring is also included. The use of supporting rings on the inside and outside of the spiral wound portion, permits the application of the gaskets to be extended to flat or raised face flanges in high pressure lines. (James, 2008).

Failure of spiral wound gaskets rarely occurs because of quality problems. The most likely reasons for failure is the selection of an incorrect gasket for the application conditions, gasket was damaged in storage, handling or on installation, gasket was crushed by excessive load during assembly (buckling), gasket was reused, or gasket failed due to corrosion. (Daniel, 1996). The damage predominantly extended to:

(i) Buckling of the inner ring
(ii) Detachment of the inner ring
(iii) Delamination of spiral windings
(iv) Severe distortion of the centering ring
(v) Damage to flange faces



(a) (b)

Figure 2.6: (a) Uniform radial buckling. (b) Localized buckling.

Source: Jenko and Hunt (2000)

Figure 2.6 shows the inward radial gasket buckling of the spiral wound gasket. The other example of the spiral wound gasket failure can be referred to Figure 6.1 in Appendix A.

2.5 FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis is a technique for modeling a complex structure. When the mathematical model is subjected to known loads, the displacement of the structure may be determined. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. (Pelosi, 2007).

FEA is commonly used as a design tool for product design. FEA requires the management of simplification assumptions in order to simulate a real complex system. Usefulness of the FEA result depends highly on the pre-processing stage. Thus, defining an appropriate physical model (mathematical model, geometrical simplifications, material properties, boundary conditions and loads) and an adapted mesh in accordance with simulation goals is a very difficult and time-consuming task. (Bellenger et al., 2008).

2.6 EXPERIMENTAL MODAL ANALYSIS

The history of experimental modal analysis began in the 1940's with work oriented toward measuring the modal parameters of aircraft so that the problem of flutter could be accurately predicted. At that time, transducers to measure dynamic force were primitive and the analog nature of the approach yielded a time consuming process that was not practical for most situations (Huang, 2001). With the advent of digital mini-computers and the Fast Fourier Transform (FFT) in the 1960's, the modern era of experimental modal analysis began. Today, experimental modal analysis represents an interdisciplinary field that brings together the signal conditioning and computer interaction of electrical engineering, the theory of mechanics, vibrations, acoustics, and control theory from mechanical engineering, and the parameter estimation approaches of applied mathematics. (Seybert, 2002).

The experimental determination of natural frequencies, mode shapes, and damping ratios is called experimental modal analysis and is based on vibration measurements that fall within the general designation of modal testing. The objective of this form of vibration testing is to acquire sets of frequency response functions (FRFs) that are sufficiently accurate and extensive, in both the frequency and spatial domains, to enable analysis and extraction of the dynamic properties for all the required modes of vibration of the structure. Prior knowledge of areas such as vibration analysis, instrumentation, signal processing, and modal identification, to state just a few, is required to understand modal testing. The basic aim of modal testing is to obtain FRFs relating output vibration responses at a number of coordinates of interest, usually under the form of accelerations (or velocities, or displacements), to input vibration excitations, usually under the form of driving forces, applied at a given coordinate. (Robert, 1981).

Every piping system has natural characteristics. When impose vibration on a piping system, the piping system takes deformation patterns when the vibration frequency approaches the natural frequency of the piping system. The deformation pattern at the natural frequencies takes on variety of shapes depending on which frequency is used to excite the piping system. The deformation patterns are referred to as mode shapes of the piping system.

The natural frequency and mode shape depend on the mass and stiffness distribution in the piping system. Basically, there are three sequences of steps in a modal test:

(i) Measurement of the test structure's vibration response to a controlled and known excitation.
(ii) Analysis of the resulting response functions to identify the underlying modal properties (natural frequencies and mode shapes) of the test structure;
(iii) Construction of a mathematical model from these modal properties, suitable for the intended application. (Jaroslav, 2004).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In general, methodology means a set or system of methods. This chapter is about how the research is carried out. The research is to study about the dynamic characteristic of spiral wound gasket by doing the experimental modal analysis and performing ALGOR (FEA) method. All the result and data from the ALGOR will be compared with the data collected from the experimental modal analysis. The flow chart of the methodology is as shown in Figure 3.1.

This study begins with the problem statement, determine the project objectives and scopes, literature review on previous work and theoretical study on spiral wound gasket and modal analysis. After gathering the information, the model of spiral wound gasket is sketch using SOLIDWORK software. Then, a simulation is conducted to observe the dynamic characteristic of spiral wound gasket such as natural frequency and mode shape. In this project, the simulation is performed using ALGOR Finite Element Analysis software. After that, an experimental modal analysis is performed and lastly, after gathering information from both results, a comparative study will be done and discussed on performance and stability of spiral wound gasket.

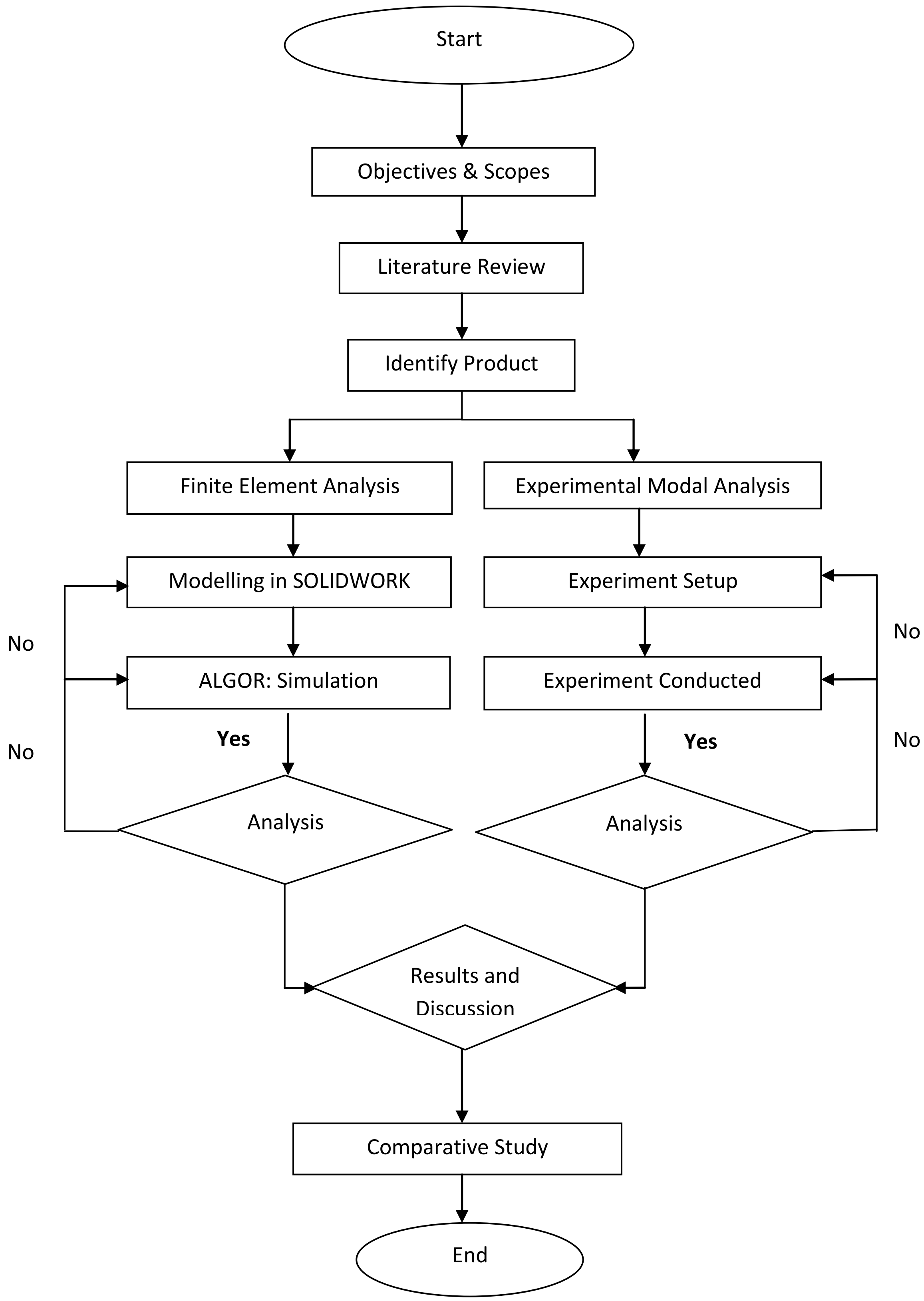


Figure 3.1: Flowchart methodology

3.2 GEOMETRY

The material, diameter and thickness of spiral wound gasket must be determined before running the experiment. These considerations are important to make sure the experiment and simulation run smoothly.

The Figure 3.2 below show the spiral wound gasket after separated from the piping system, while Figure 3.3 is the cross section of spiral wound gasket which indicates the measurement of d1, d2, d3, and d4. The diameter of sealing element, outer and inner ring was measured. The measurement was done using the automatic vernier caliper as it can increase the accuracy of the dimension. The details then are checked with the ASME B16.20 criteria. The material is figured out from the label on the spiral wound gasket. From the measurement, the data collected as shown in Table 3.1 and Table 3.2 below:

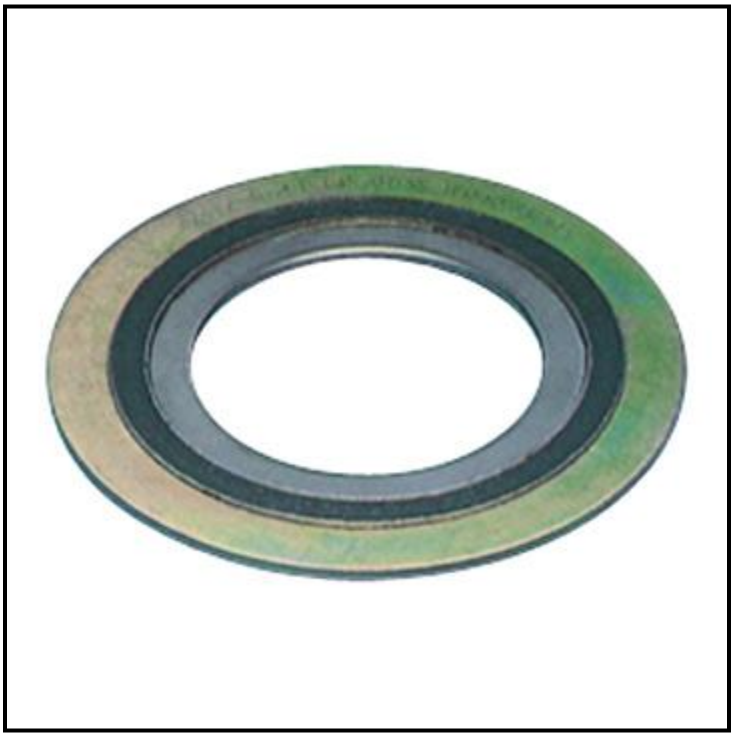


Figure 3.2: Spiral wound gasket

Source: The Flexitallic Group (2000)

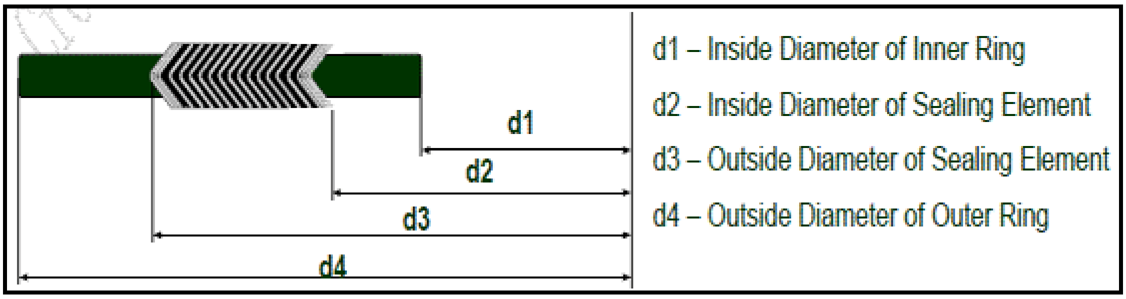


Figure 3.3: Diameter of the spiral wound gasket

Source: The Flexitallic Group (2000)

Table 3.1: Dimension of spiral wound gasket

Pressure (lbs)	NPS (in)	D1 (mm)	D2 (mm)	D3 (mm)	D4 (mm)
2500	8	215.9	233.5	263.7	308.1

Table 3.2: Spiral wound gasket thickness and material

Part	Thickness (mm)	Material
Inner Ring	3.2	Stainless Steel 316 L
Sealing Element	4.5	Flexible Graphite
Outer Ring	3.2	Stainless Steel 316 L

3.3 MODELLING

3.3.1 Modelling Method

From the data measured, the spiral wound gasket (SWG) model is drawn using SOLIDWORK. The design of the model is shown in Figure 3.4 to 3.7. The SWG consists of 3 parts that is inner ring, sealing element and outer ring. The sealing elements consist of many joint winding materials which each of them have thickness around 0.18-0.2 mm. For this SWG, it contains 68 parts of winding elements that joint together.

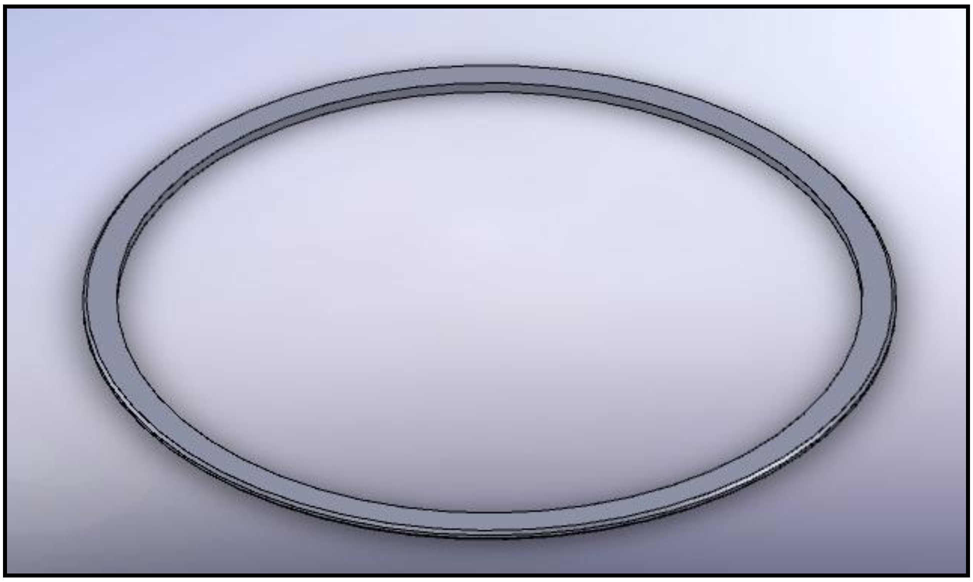


Figure 3.4: Isometric view of inner ring

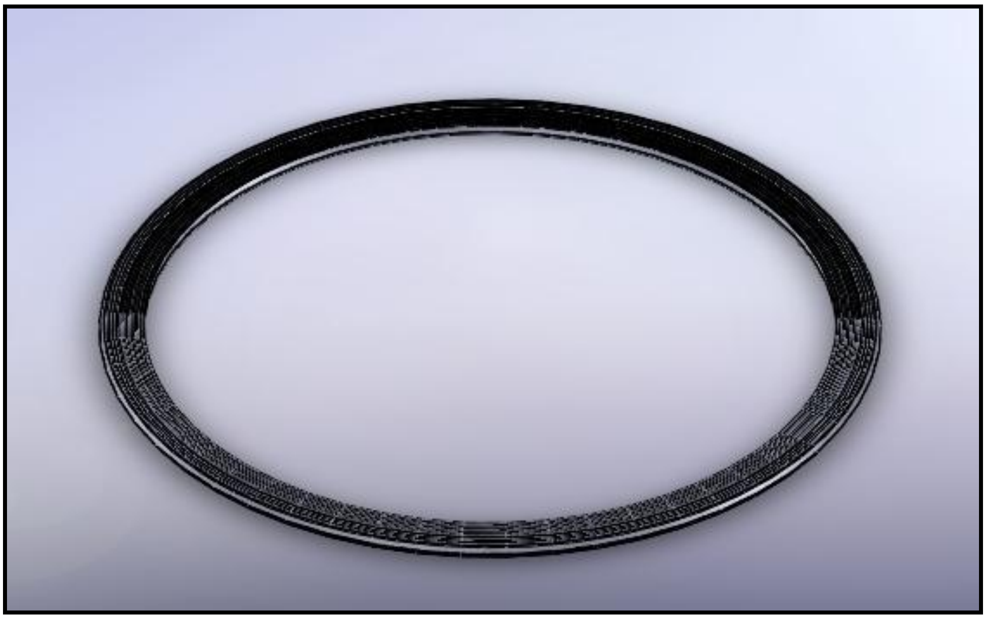


Figure 3.5: Isometric view of sealing element

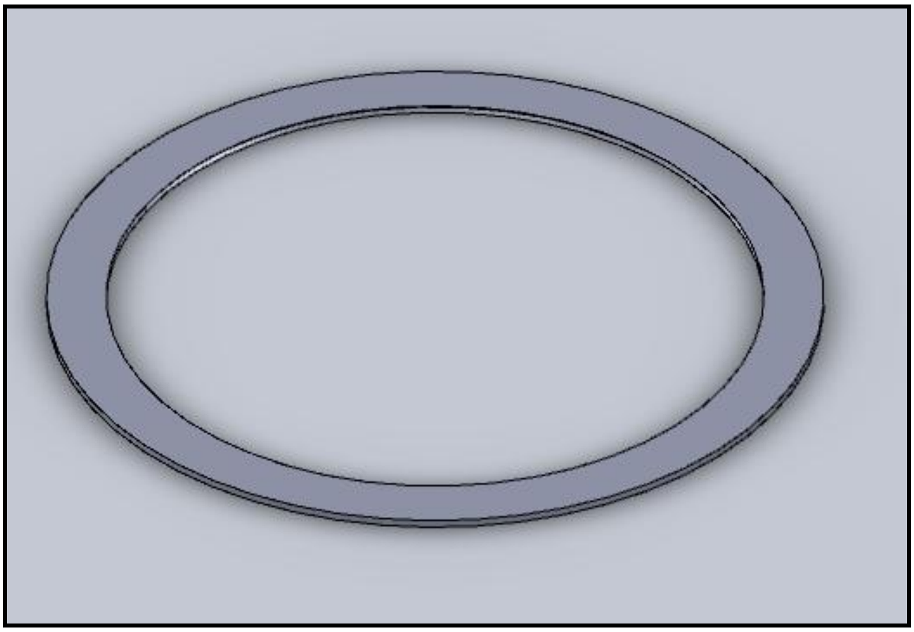


Figure 3.6: Isometric view of outer ring

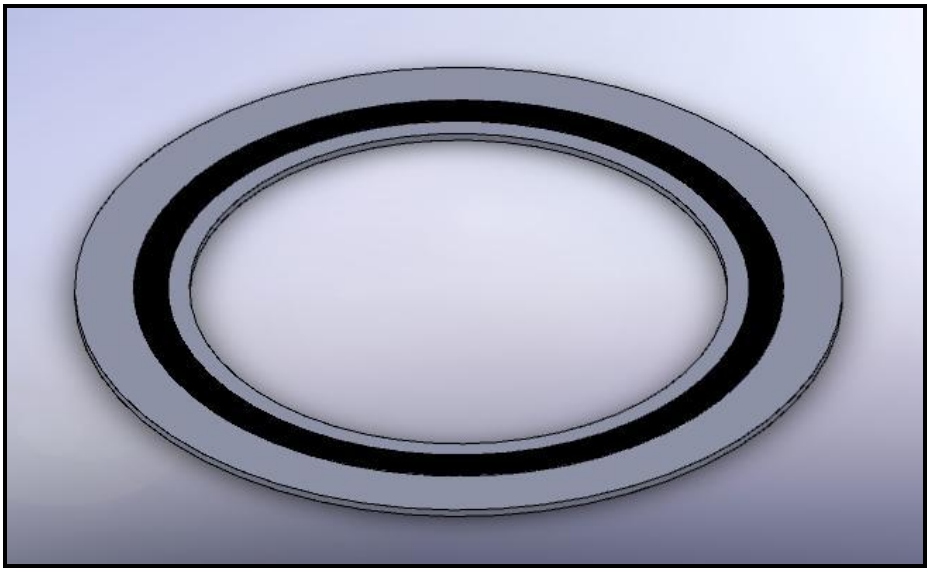


Figure 3.7: Isometric view of assemble part

Figure 3.4 to Figure 3.6 shows the isometric view of the parts in SWG and Figure 3.7 shows the isometric view of the complete assemble part. The drawing is made from SOLIDWORK software. The details of the drawing can be referred in Figure 6.2 to 6.5 in Appendix B1 to B4.

3.4 SIMULATION

3.4.1 Simulation Method

The finite element analysis is carried out using ALGOR FEMPRO 23.1. ALGOR is capable of generating meshes automatically because it support for multi-CAD environments and also an extensive finite element modeling tools that help manufacturers study initial design intent and accurately predict product performance. It also allows user to validate and optimize designs before manufacturing which can increase efficiency, minimizing reliance on physical prototypes, reducing costs, and decreasing errors. It also allows complex geometries to be generated easily and support mesh types for 2D and 3D simulation.

ALGOR FEMPRO 23.1 software is used to conduct the analyzing of spiral wound gasket. ALGOR Finite Element Analysis (FEA) uses a complex system of points called nodes which make a grid called a mesh. Natural frequency (modal analysis) in ALGOR determined a part's natural frequencies and mode shapes to avoid frequencies that are disruptive or harmful in the design. The software use studies of oscillating modes to determine if a part resonates at the frequency of an attached power-driven device such as a motor. It makes design changes to reduce the amplitude of oscillations and account for stiffening effects from applied loads. (Helms, 2005).

3.4.1.1 Transferring Model

The 3D model of spiral wound gasket by SOLIDWORK is transferred into the ALGOR software in the type of IGS file. IGS file is a 2D/3D vector graphics format based on the Initial Graphics Exchange Specification (IGES) used by many CAD programs as a standard ASCII text-based format for saving and exporting vector data which can store wireframe models, surface or solid object representations, circuit diagrams, and other objects. The IGES format was introduced in 1979 and has since become a standard for transferring three-dimensional models between CAD programs. (Helms, 2005).

3.4.1.2 Grid generation

The mesh was constructed using three parts that represent the inner ring, sealing element and outer ring. The element type for inner and outer ring is set to stainless steel 316L specification as in Figure 3.8 while the sealing element is set to graphite. The mesh structure for the spiral wound gasket outer ring part is shown in Figure 3.12. The other meshing diagram of the spiral wound gasket parts is shown in Figure 6.6 and Figure 6.7 from Appendix C1. The simulation is done part by part so then it can be compared to the experimental analysis later. The experiment is carried out by setting the analysis type to Natural Frequency (modal), change the units from metric mks (SI) to custom unit and change the length to millimeter (Figure 3.9). The element definition is set to tetrahedron and defines the mesh size to 70% (Figure 3.10 and Figure 3.11). The result will be better if higher percentage of mesh size is set up but it need super computer to perform the analysis. For this experiment, 30-50 mode shapes were analyzed and there are no loading and boundary conditions were imposed on the test specimen. The free boundary condition is simulated by supporting the structure with soft materials such as sponge.

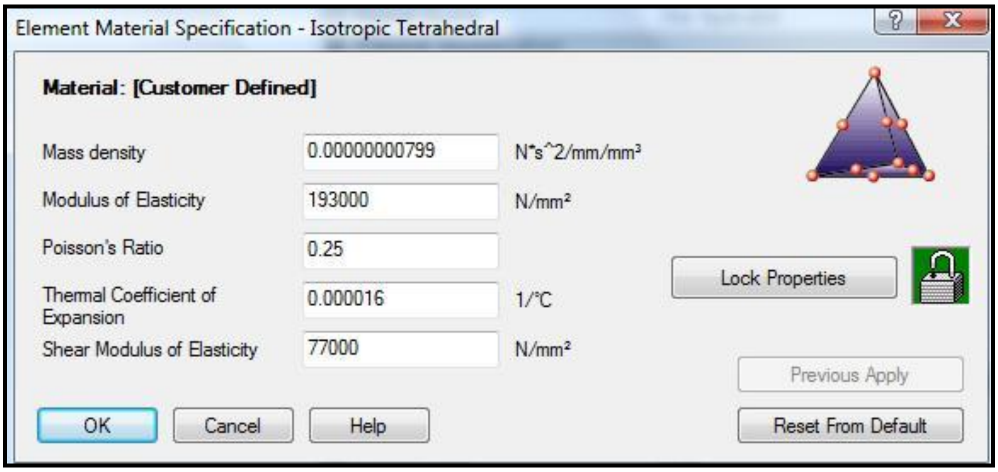


Figure 3.8: Material Specification

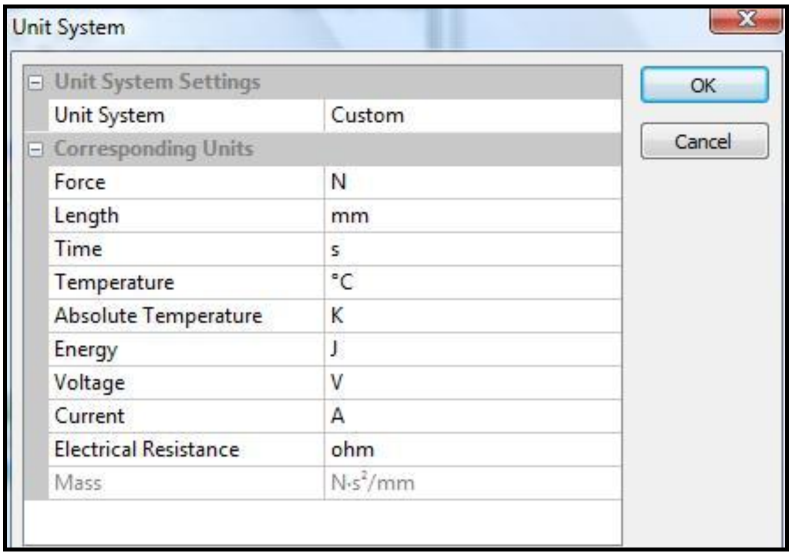


Figure 3.9: Custom unit system; length in mm

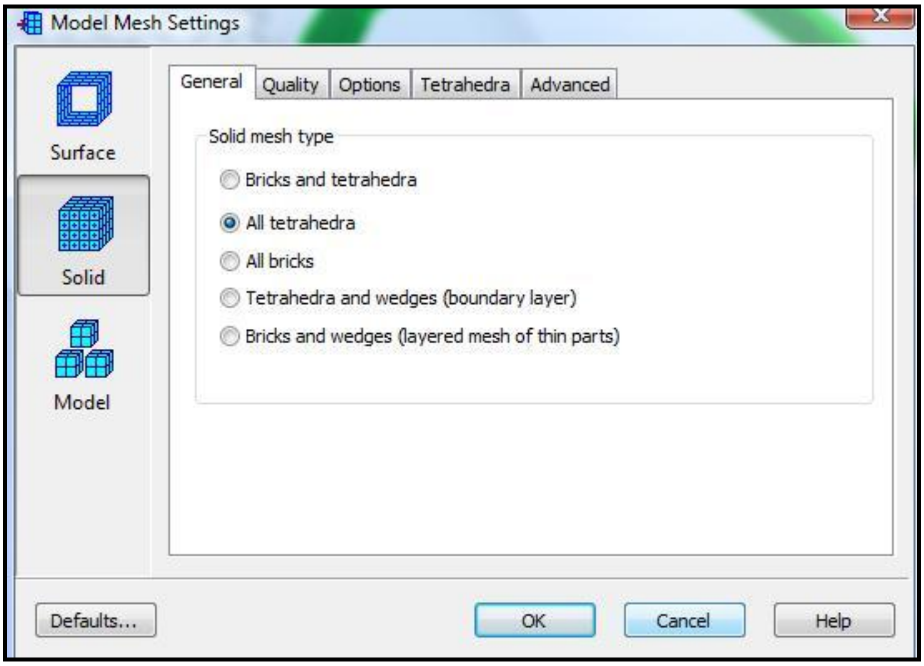


Figure 3.10: Solid mesh type selected; all tetrahedral

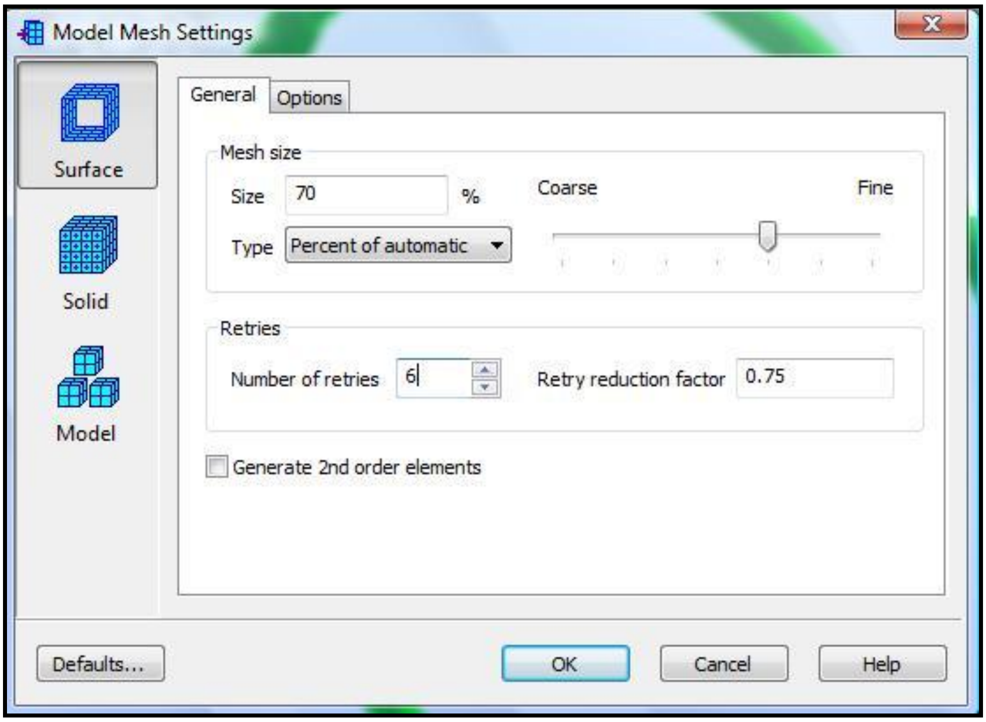


Figure 3.11: Mesh size selected; 70%

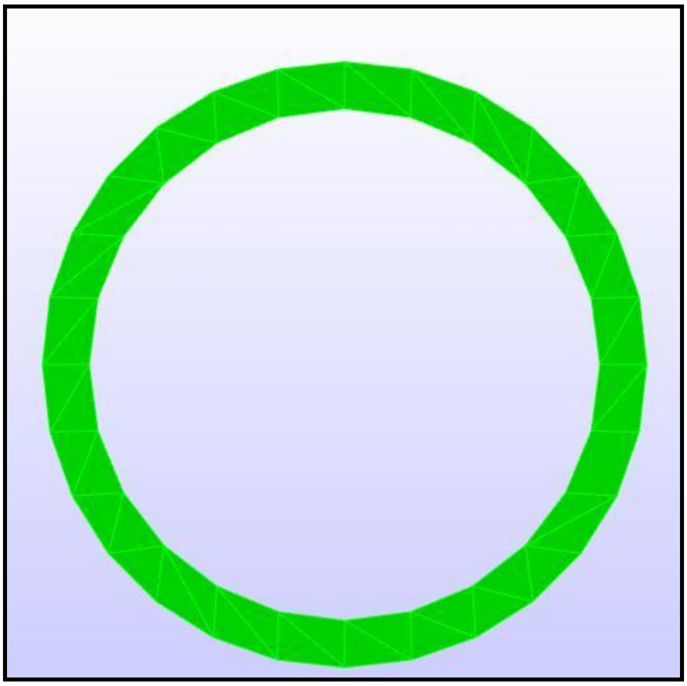


Figure 3.12: Mesh diagram of outer ring

3.4.1.3 Natural Frequency

The first step in any dynamic analysis should be the determination of the frequencies and shapes of the natural vibration modes. In a 3-D structure there are three dynamic degrees of freedom (DDOF) for every unrestrained node with non-zero mass and there is potentially a natural vibration mode for each DDOF. Thus, there are usually many potential vibration modes in a typical structure, but usually only a small number of vibration modes with the lowest frequencies that are of interest. If a dynamic load is applied to a model close to its natural frequency, the model exhibits a larger than normal oscillation. Without proper damping, the oscillation can become uncontrollable and cause the model to collapse. To prevent this problem, FEA predicts the natural frequency of the model so it can analyze the model under specific, dynamic constraints. The result of a modal analysis helps determine whether a model requires more or less damping to prevent failure.

3.4.1.4 Mode shape

By determining mode shapes, the vibration of the spiral wound gasket can be known. A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different mode shapes will be associated with different frequencies. Understanding both the natural frequency and mode shape helps to design structural system for noise and vibration applications. In this experiment, five mode shapes are picked from the analysis. The mode shapes shows the deformation pattern on the structure at each one of the natural frequencies. (Peter, 2001).

3.5 MODAL TESTING

3.5.1 Impact Hammer Testing

In order to perform modal testing a number of hardware components must be available. In this experiment, impact hammer is used to run modal testing. The components are interfaced with a host computer allowing for coordination of the operation of the overall system and enhancing the data-processing capabilities.

An impact hammer test is the most common method of measuring FRFs (Frequency Response Functions). The hammer imparts a transient impulsive force excitation to the device. The impact is intended to excite a wide range of frequencies so that the DAS (data acquisition system) can measure the vibration of the device across this range of frequencies. In the experiment, Accelerometer is used as the sensor to connect with the DAS. Accelerometer is a device for measuring vibration of a structure, producing an output signal proportional to acceleration. They work by having some kind of force-measuring sensor, with a mass attached to it so that when the device is forced to vibrate a force is produced by Newton's law, proportional to acceleration. There are two types: the force measuring element can be either a piezoelectric crystal or a cantilever beam fitted with a strain gauge (Huikai et al., 2008). The bandwidth or frequency content of the excitation input depends on the size and type of impact hammer that is used. The dynamic force signal is recorded by the DAS. After the impact, the device vibrations are measured with accelerometers or other sensor and recorded by the DAS. The DAS then computes the FRF by comparing the force excitation and the response acceleration signals. Figure 3.13 shows a typical set-up for a measurement system. Basically, there are three main measurement mechanisms:

- The excitation mechanism
- The sensing mechanism
- The data acquisition and processing mechanism

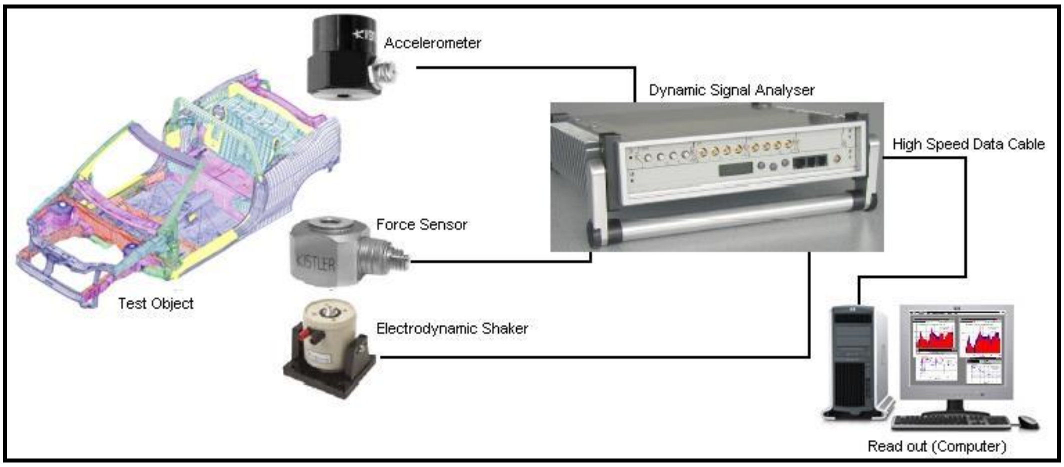


Figure 3.13: Modal testing system

3.5.2 List of Apparatus

Below are the lists of the apparatus used for this experimental method.

Table 3.3: List of apparatus

No	Apparatus	Function
1	Modal Hammer Model: Endevco Type: 2302-10	i. Excites the system. Impact all the DOF's point on the SWG.
2	8 Channel FFT Analyzer	i. Collect time data and convert it to FRF measurement. ii. Response will displayed in PC
3	Computer with PULSE-Lite software version 10.2, ME's Scope version 4.0,	i. PULSE-Lite – display the collected data ii. ME's Scope – simulate or analyze the data converted from the analyzer.
4	Tri-Axial Accelerometer Model: Bruel & Kjaer Type: 4507B	i. Measure signal response in each DOF from impact hammer test. Measurement includes 3 Axis (X,Y,Z)

Figure 3.14: Modal hammer

Model: 2302-10, Endevco

Figure 3.15: Data acquisition system

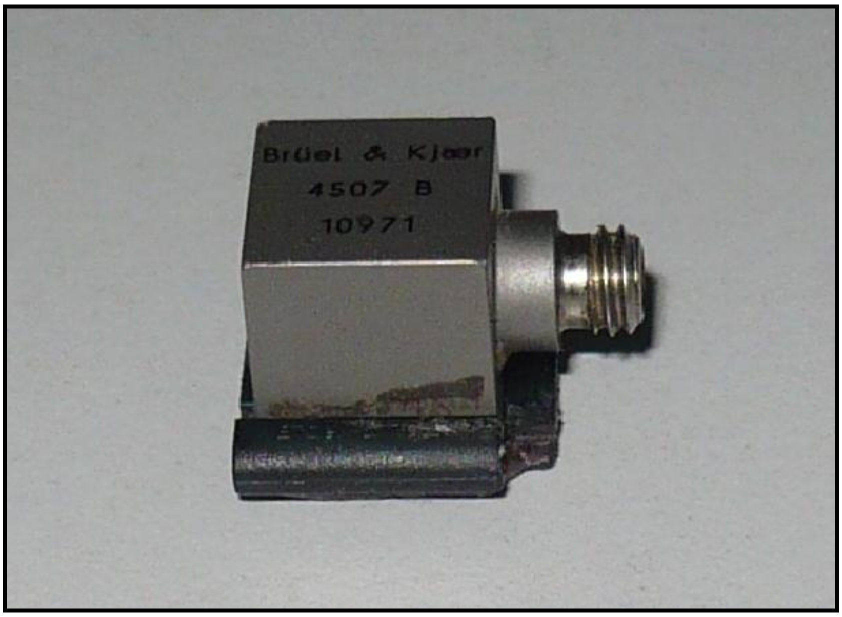


Figure 3.16: Accelerometer

Model: Bruel & Kjaer, type 4507B

3.5.3 PULSE-Lite Software

In the experiment, PULSE-Lite software is used in measuring the vibration system using Fast Fourier Transform (FFT). In impact hammer testing, it analyzes the resonance and export data for modal analysis. To start the analysis, PULSE Lite button in the start menu is clicked to get the interface of the software. The first step after software is opened is to click on the Hardware Setup on taskbar. After that, the table for hardware setup will be appearing as shown in Figure 3.17.

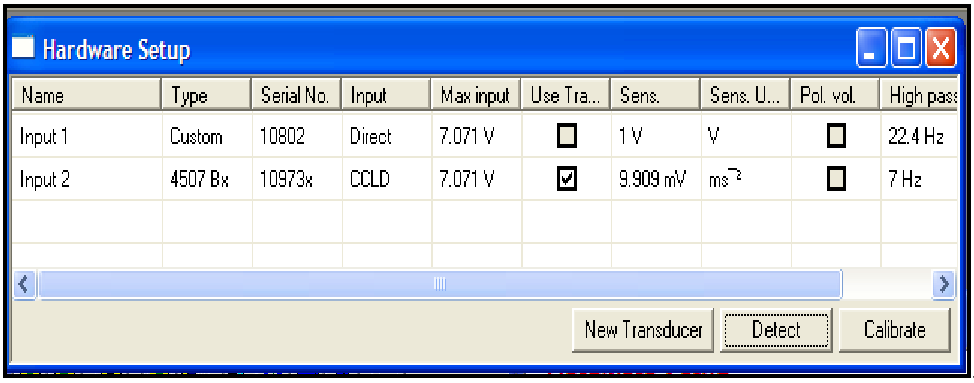


Figure 3.17: Windows for hardware setup

Hardware Setup Table is used to select the transducers that can be used in the experiment. After that, the correct input voltage for each channel is determined using the Level Meter. The table for FFT Analyzer is opened after finish setup the hardware. Windows for FFT Analyzer is shown in the Figure 3.18.

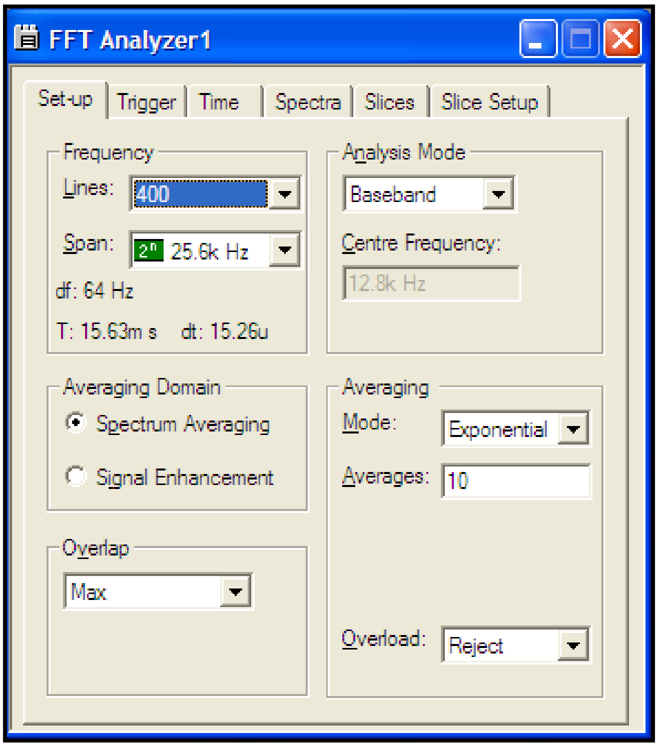


Figure 3.18: Window for FFT Analyzer

This window is used to set the sampling frequency and the resolution for the FFT analyzer. For this experiment, the frequency span that been used is 5 kHz. It determines the range of frequency that being analyze in the analysis.

Before doing the impact hammer testing on the specimen, graphical setup must be set to obtain the force of the hammer to the spiral wound gasket in each part. Figure 3.19 is graphical setup for sealing element of spiral wound gasket. The force of the hammer impact will be set up to 65 N.

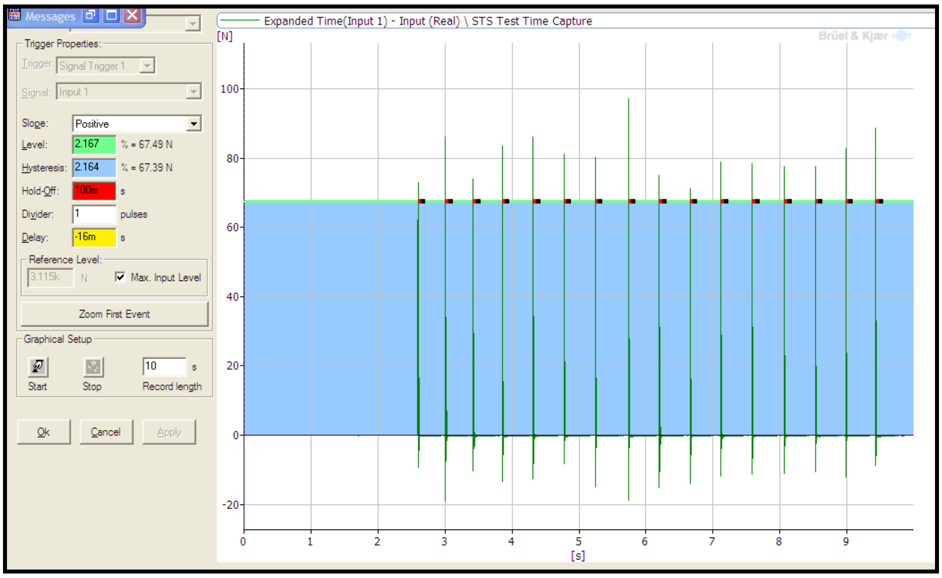


Figure 3.19: Graphical setup for sealing element

3.5.4 Procedures of Experiment

As a summary, there are several steps to conduct impact hammer testing:

i. Open software PULSE Lite.
ii. Load save file of 'hammer 2_2.pls'.
iii. Click 'organizer' tab and click measurement.
iv. Choose setup and click properties.
v. Click on graphical setup and click on start.
vi. Hit the specimen at desired point until 10 sec-press Apply-OK
vii. Click on FFT Analyzer-click properties.
viii. Set line (800-1600)-set span (5 kHz).
ix. Click run and start hit the specimen 2 times and observe the graph

In this experiment, 12 points is set in the SWG specimen to determine its natural frequency. 4 points is divided in each of the 3 parts as shown in Figure 3.20. The experiment is run on top of a sponge to simulate in free boundary condition.

Figure 3.20: Impact hammer testing on a spiral wound gasket

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the result from the experiment and simulation will be discussed. The study is carried out using the experimental analysis (Impact Hammer Testing) and finite element analysis using ALGOR (FEA). There will be discussion about properties and comparative study between experimental and numerical analysis.

4.2 ALGOR FINITE ELEMENT ANALYSIS RESULTS

Modal analysis is done by using ALGOR Finite Element Analysis to determine the natural frequencies and mode shapes of spiral wound gasket. The natural frequencies and mode shapes of each part of spiral wound gaskets are shown in the Figure 4.1 to 4.3 below. From the natural frequencies and mode shapes, resonance in the system can be neglected. Hence, it will save a lot of cost from shutting down. The other mode shape of the spiral wound gasket can be referred to Figure 6.8 to 6.18 in Appendix C.

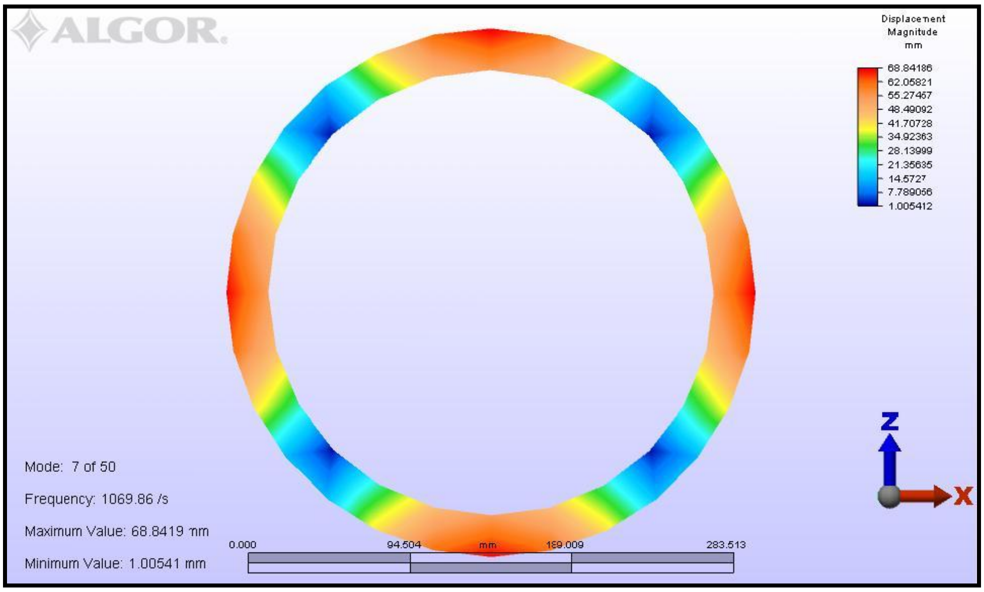


Figure 4.1: Outer ring mode shape

Figure 4.1 shows the first mode shape of the outer ring spiral wound gasket. The frequency of the mode is 1069.86 Hz. The maximum displacement of the mode is 68.8419 mm and the minimum displacement is 1.00541 mm. The red color indicates the maximum displacement occurred in the mode and blue color is the minimum displacement. The data from all the mode shape is shown in Table 4.1.

Table 4.1: Frequency and displacement for outer ring

Mode	Frequency (Hz)	Max. Displacement (mm)	Min. Displacement (mm)
1	1069.89	68.8419	1.00541
2	1569.61	62.3608	0.5434
3	2576.01	59.9461	24.3855
4	3536.39	74.0818	2.4677
5	3957.07	55.3842	28.6861

Table 4.1 shows the natural frequency and displacement of 5 mode shapes for the outer ring spiral wound gasket. Mode shape 4 has the highest maximum displacement magnitude of deformation that is 74.0818 mm, while mode shape 5 has the lowest maximum displacement magnitude.

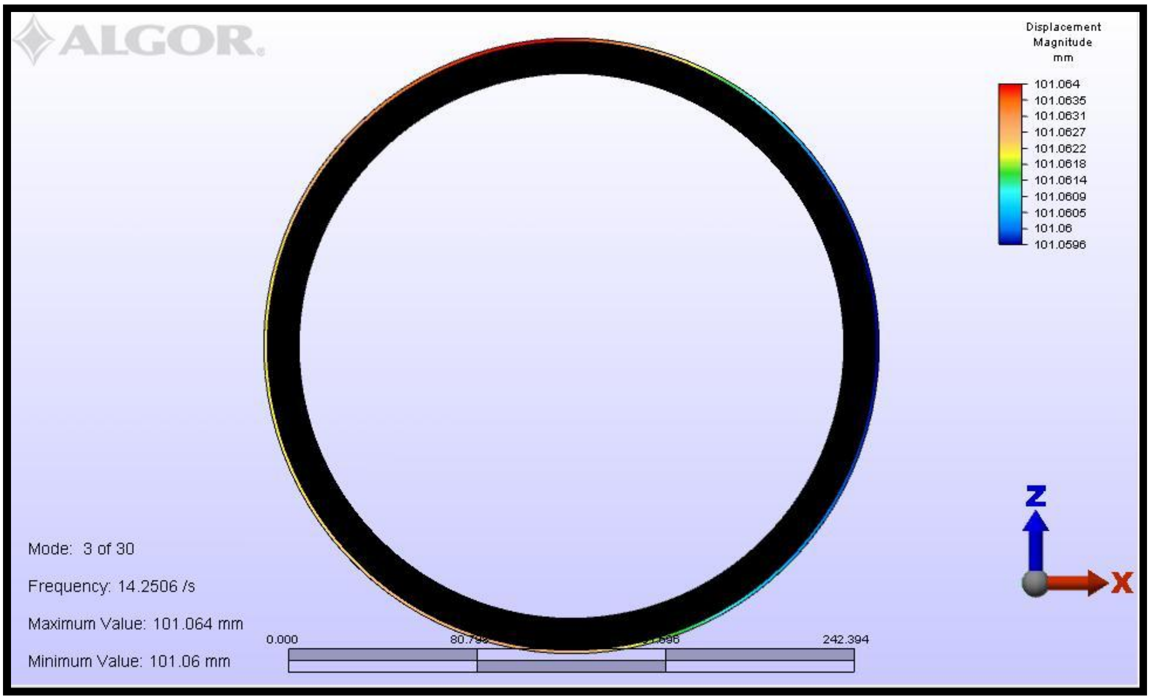


Figure 4.2: Sealing element mode shape

Figure 4.2 shows the first mode shape of the sealing element spiral wound gasket. The frequency of the mode is 731.585 Hz. The maximum displacement of the mode is 131.761 mm and the minimum displacement is 9.70875 mm. The red color indicates the maximum displacement occurred in the mode and blue color is the minimum displacement. The data from all the mode shape is shown in Table 4.2.

Table 4.2: Frequency and displacement for sealing element

Mode	Frequency (Hz)	Max. Displacement (mm)	Min. Displacement (mm)
1	14.2506	101.064	101.0600
2	731.85	131.761	9.7087
3	742.963	127.799	22.6366
4	1332.02	183.781	63.3562
5	1341.98	209.552	38.6836

Table 4.2 shows the natural frequency and displacement of 5 mode shapes for the sealing element spiral wound gasket. Mode shape 5 has the highest maximum displacement magnitude of deformation that is 209.552 mm, while mode shape 1 has the lowest maximum displacement magnitude that is 101.064 mm.

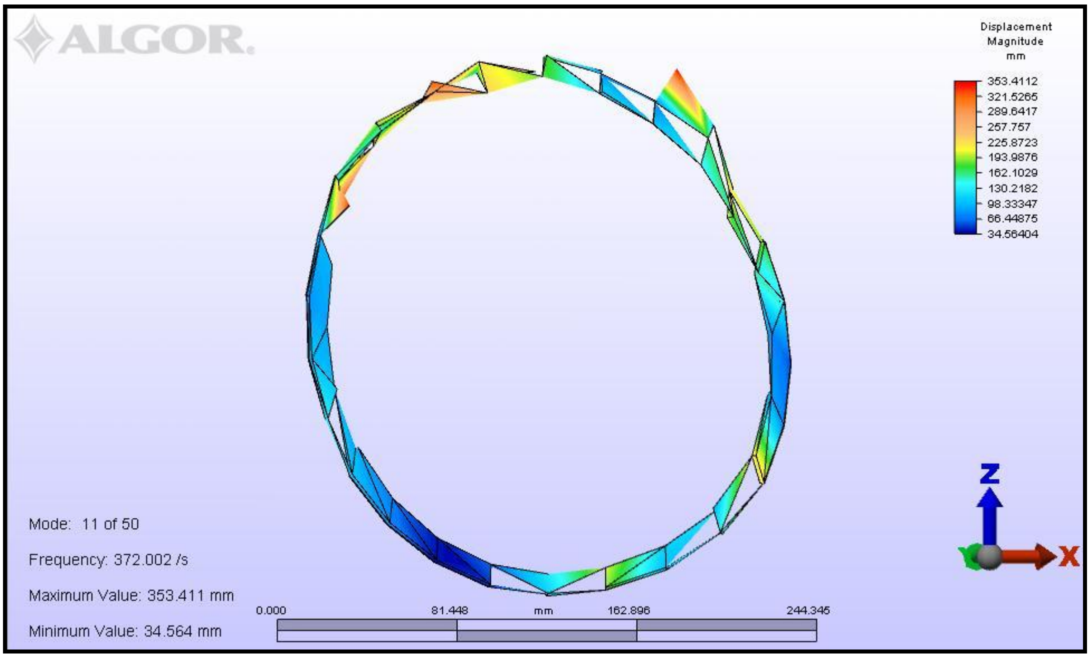


Figure 4.3: Inner ring mode shape

Figure 4.3 shows the first mode shape of the sealing element spiral wound gasket. The frequency of the mode is 372 Hz. The maximum displacement of the mode is 353.411 mm and the minimum displacement is 34.564 mm. The red color indicates the maximum displacement occurred in the mode shape and blue color is the minimum displacement. The data from all the mode shape is shown in Table 4.3 below.

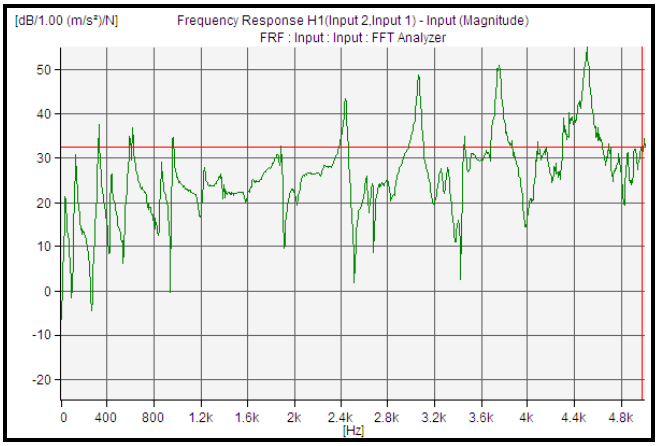
Table 4.3: Frequency and displacement for inner ring

Mode	Frequency (Hz)	Max. Displacement (mm)	Min. Displacement (mm)
1	372.002	353.411	34.5640
2	661.005	551.256	43.9973
3	1071.1	741.348	7.2661
4	1573.27	507.472	14.3211
5	1952.99	349.690	35.8973

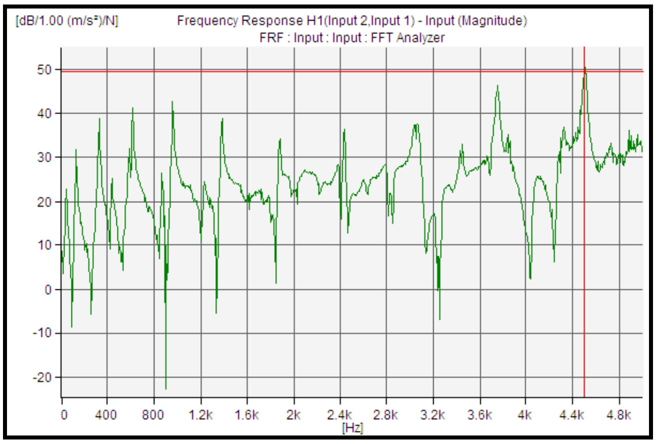
Table 4.3 shows the natural frequency and displacement of 5 mode shapes for the inner ring spiral wound gasket. Mode shape 3 has the highest maximum displacement magnitude of deformation that is 741.348 mm, and mode shape 5 has the lowest maximum displacement magnitude that is 349.690 mm.

4.3 EXPERIMENTAL ANALYSIS RESULT

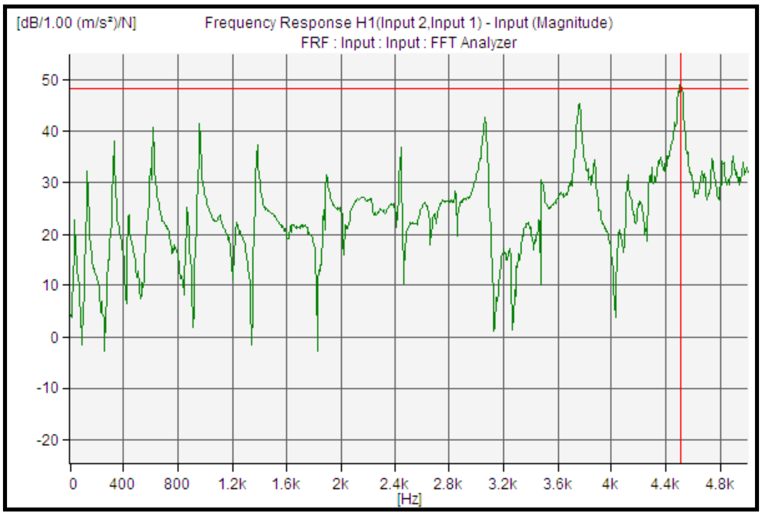
From the experimental analysis, a set of data is collected in the Impact Hammer Testing. The testing is made within 12 points selected at the spiral wound gaskets which consists of 4 points in outer ring, 4 points in sealing element and 4 points in inner ring. The graphs obtained from the experiment are shown in the figures below and then the values are placed in Table 4.4, 4.5 and 4.6.



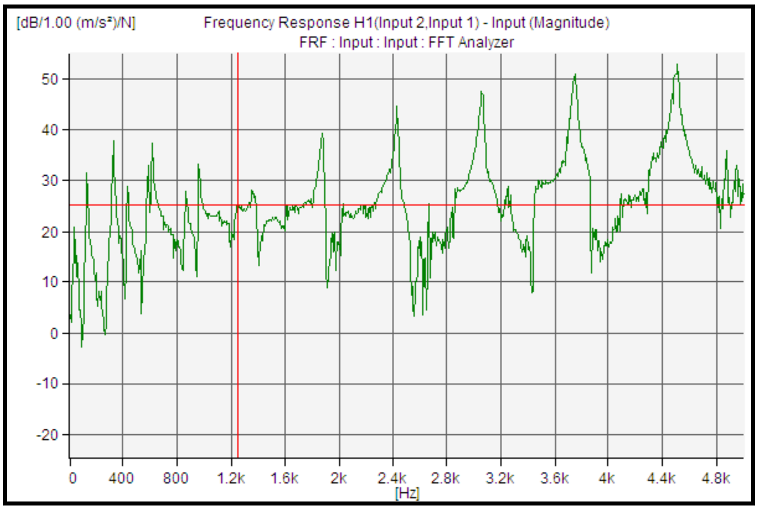
(a) Frequency Response 1



(b) Frequency Response 2



(c) Frequency Response 3



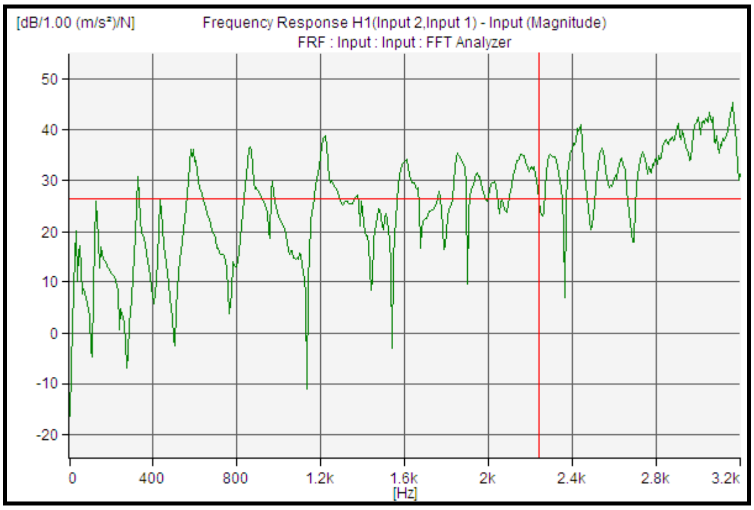
(d) Frequency Response 4

Figure 4.4: (a)-(d): Frequency response of outer ring

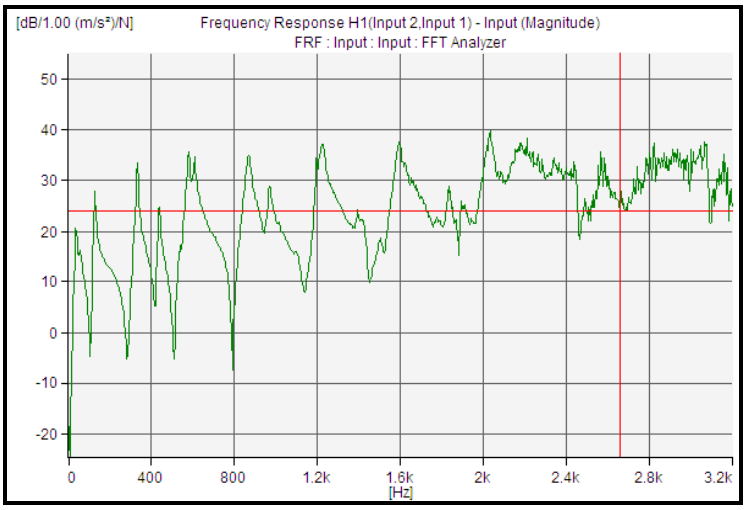
Figure 4.4 shows the frequency response function graph of the outer ring at point 1-4 that had been determined from the PULSE Lite software. Every peak of the graph indicates the natural frequency of the parts. Table 4.4 shows the average natural frequencies of the outer ring spiral wound gasket.

Table 4.4: Experimental Results of natural frequencies for outer ring

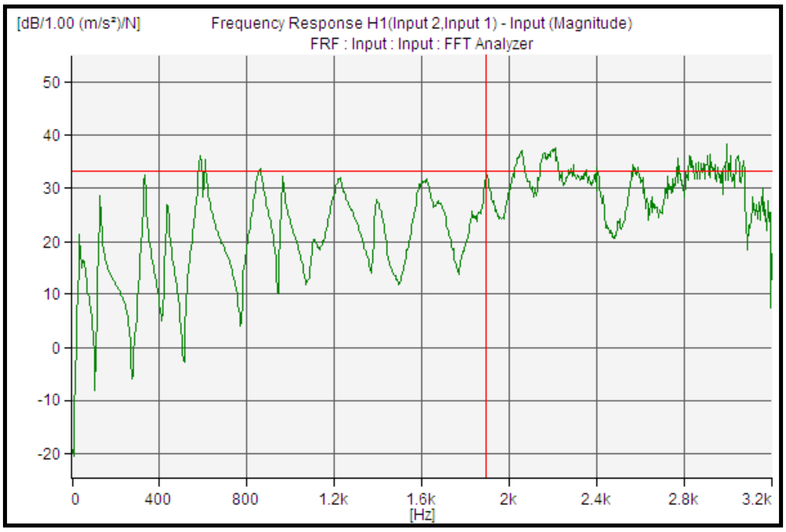
Point	Natural Frequency (kHz)				
1	0.962	1.881	2.431	3.056	3.750
2	0.956	1.875	2.431	3.038	3.750
3	0.956	1.869	2.425	3.050	3.744
4	0.959	1.877	2.429	3.044	3.748
Average	0.958	1.876	2.429	3.047	3.748



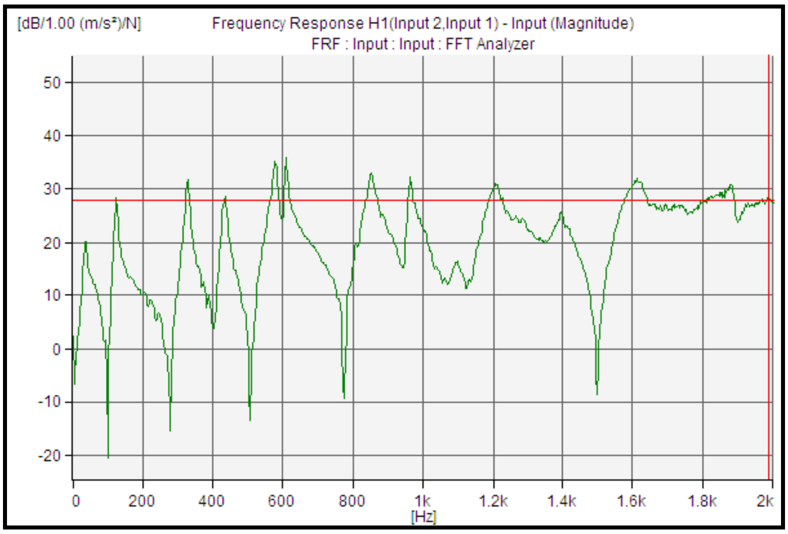
(a) Frequency Response 5



(b) Frequency Response 6



(c) Frequency Response 7



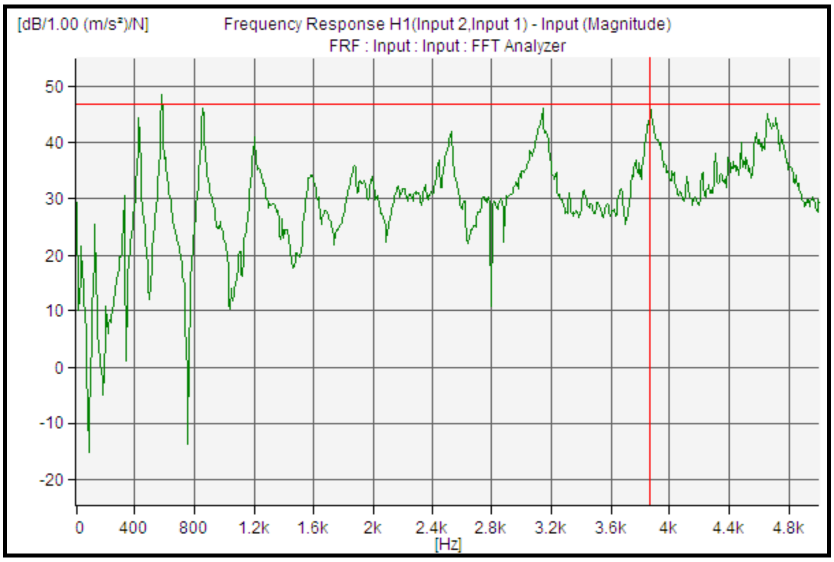
(d) Frequency Response 8

Figure 4.5: (a)-(d): Frequency response of sealing element

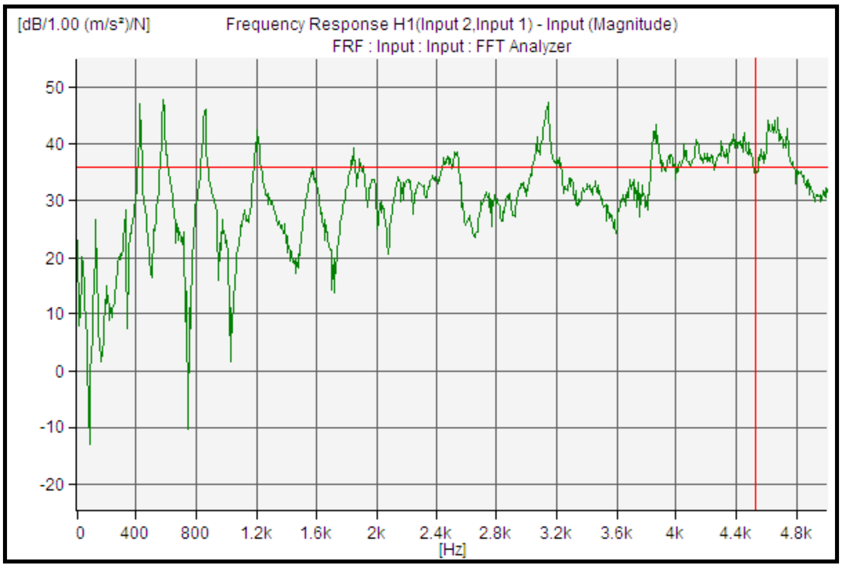
Figure 4.5 shows the frequency response function graph of the sealing element at point 5-8 that had been determined from the PULSE Lite software. Every peak of the graph indicates the natural frequency of the parts. Table 4.5 shows the average natural frequencies of the sealing element spiral wound gasket.

Table 4.5: Experimental results of natural frequencies for sealing elements

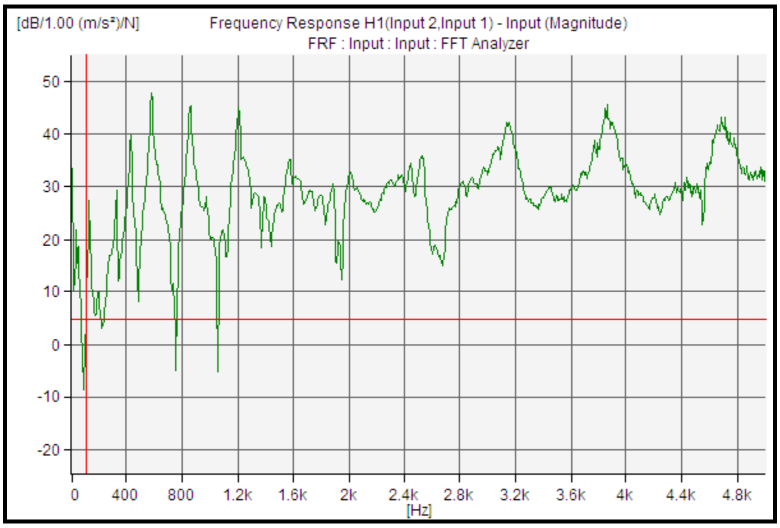
Point	Natural Frequency (kHz)				
5	0.025	0.432	0.584	0.860	1.219
6	0.027	0.434	0.580	0.857	1.224
7	0.020	0.440	0.587	0.868	1.222
8	0.019	0.432	0.594	0.862	1.220
Average	0.023	0.435	0.586	0.862	1.221



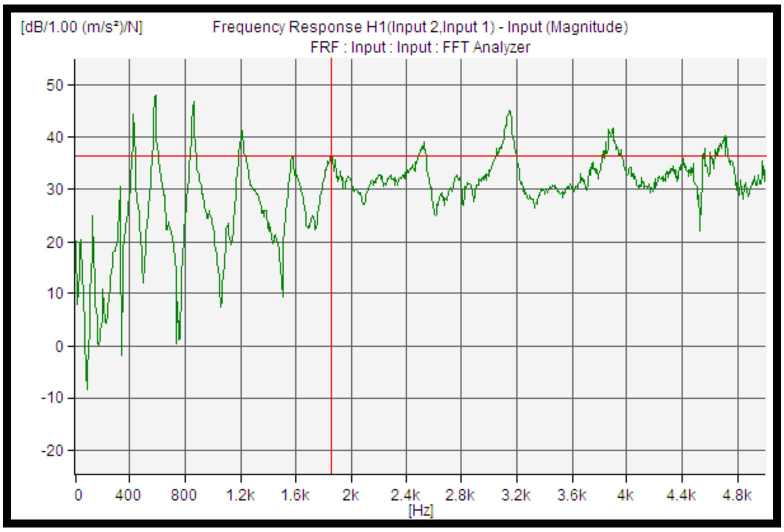
(a) Frequency Response 9



(b) Frequency Response 10



(c) Frequency Response 11



(d) Frequency Response 12

Figure 4.6: (a)-(d): Frequency response of inner ring

Figure 4.6 shows the frequency response function graph of the inner ring at point 9-12 that had been determined from the PULSE Lite software. Every peak of the graph indicates the natural frequency of the parts. Table 4.6 shows the average natural frequencies of the sealing element spiral wound gasket.

Table 4.6: Experimental results of natural frequencies for inner ring

Point	Natural Frequency (kHz)				
Point 9	0.433	0.597	0.856	1.200	1.590
Point 10	0.422	0.602	0.850	1.260	1.581
Point 11	0.440	0.614	0.856	1.220	1.569
Point 12	0.428	0.612	0.850	1.200	1.584
Average	0.431	0.606	0.853	1.220	1.581

4.4 COMPARISON

Table 4.7: Natural frequencies analysis of outer ring

Mode	Theoretical (kHz)	Experimental (kHz)	Error (%)
1	1.069	0.958	**10.38**
2	1.569	1.876	**19.57**
3	2.576	2.429	**5.7**
4	3.563	3.047	**14.48**
5	3.957	3.748	**5.28**

Table 4.7 shows natural frequencies obtained from the modal analysis of finite element models and modal testing results of outer ring and the amount percent of their errors in the different cases. Mode shape 5 had the lowest percentage error while mode shape 2 had the highest percentage error in the result. Figure 4.7 shows the graph for the comparison between theoretical and experimental result

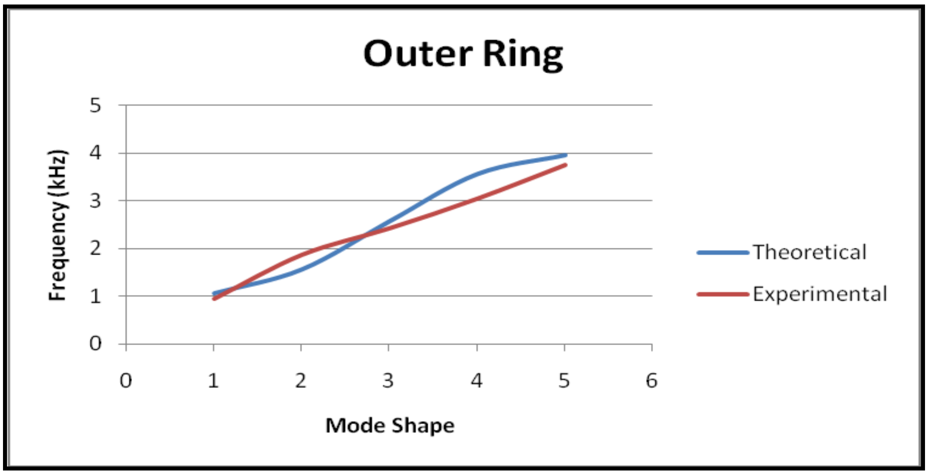


Figure 4.7: Comparison result for outer ring

Table 4.8: Natural frequencies analysis of sealing element

Mode	Theoretical (kHz)	Experimental (kHz)	Error (%)
1	0.014	0.025	**78.57**
2	0.731	0.435	**40.49**
3	0.742	0.586	**21.02**
4	1.332	0.862	**35.28**
5	1.341	1.221	**8.94**

Table 4.8 shows natural frequencies obtained from the modal analysis of finite element models and modal testing results of sealing elements and the amount percent of their errors in the different cases. Mode shape 5 had the lowest percentage error while mode shape 1 had the highest percentage error in the result. Figure 4.8 shows the graph for the comparison between theoretical and experimental result.

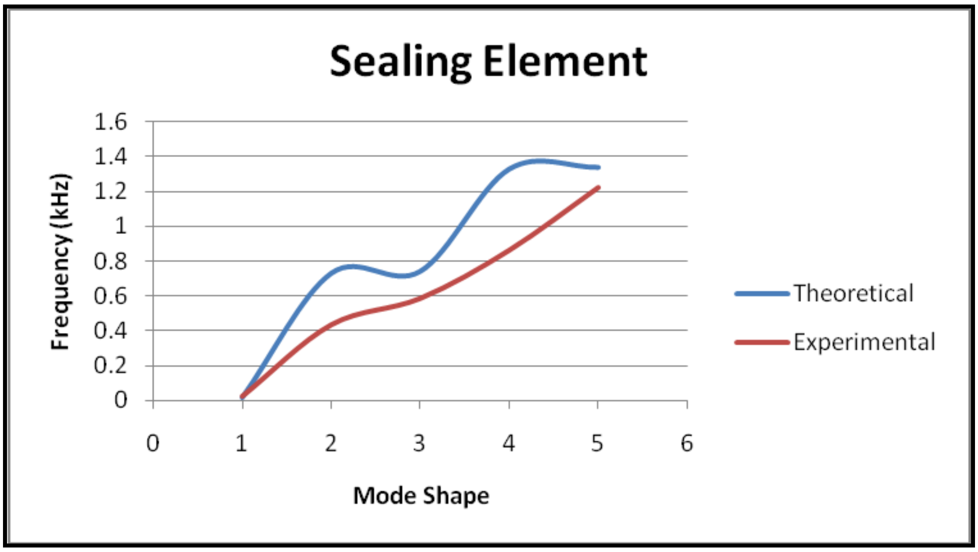


Figure 4.8: Comparison result for sealing element

Table 4.9: Natural frequencies analysis of inner ring

Mode	Theoretical (kHz)	Experimental (kHz)	Error (%)
1	0.431	0.372	**13.69**
2	0.606	0.661	**9.07**
3	0.853	1.071	**25.5**
4	1.220	1.573	**28.93**
5	1.581	1.953	**23.53**

Table 4.9 shows natural frequencies obtained from the modal analysis of finite element models and modal testing results of inner ring and the amount percent of their errors in the different cases. Mode shape 2 had the lowest percentage error while mode shape 4 had the highest percentage error in the result. Figure 4.9 shows the graph for the comparison between theoretical and experimental result.

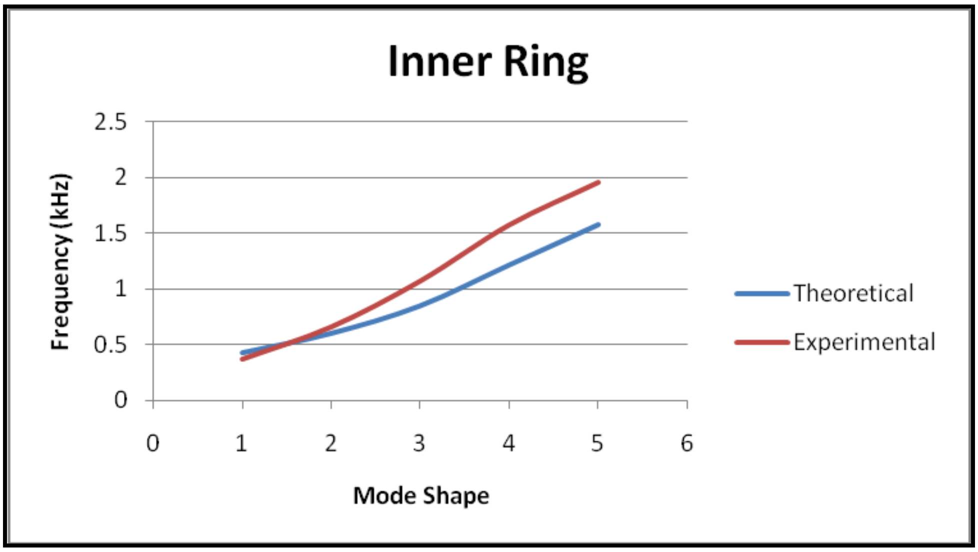


Figure 4.9: Comparison result for inner ring

4.5 DISCUSSION

The vibration frequency region of outer ring is much higher than the vibration frequencies of inner ring even though they made of same materials. The frequency region of sealing elements part are the lowest among them because it made of flexible materials. So it will deform in a lower natural frequencies. The percentage error levels for all the parts are within the accepted ranges and the high error in some of them might be referred to the boundary conditions specification, because it is not easy to simulate the realistic boundary conditions for such complicated system and it is impossible to imitate perfect free boundary condition in the experiment. These conditions can only be approximated in the laboratory with reasonable accuracy.

Other reason that may be caused the high percentage error levels in the comparative study is the experimental modal analysis is conducted with all 3 parts of the spiral wound gaskets are joined together while in simulation, the parts were separated in order to get the results in each part. Since the conditions are different, there will be slightly error in the results.

The spiral wound gasket that being used in the experiment is also not a new one which means that the specimen maybe had a little corrosion or some defects and it will affect the gasket performance in the experiment a little bit.

While doing the experiment, the room is also not completely silent. Even though the room is sound proofed, but the door is left open and there will be noise come from the outside by accident and affect the results of experiment.

Besides that, there's the different between theoretical and experimental modal analysis. Jimin and Ze (2001) have proposed that theoretical approach looks for frequencies of a system that perfectly balance internally stored energy and kinetic energy. At these frequencies, exchange between the two energies is triggered by any external input at the same driving frequency as the natural frequency. In other words, the theoretical approach doesn't need an external excitation. The energy balance is calculated by considering inertial and stiffness terms in isolation. While in experimental, the system needs an input to get a response. Physical testing for normal modes excites the system and measures the response. So there will be energy loss in experimental analysis while theoretical analysis assumed they are perfectly stored in their simulation. The energy loss may occur because of the frictional rubbing between the parts and it is also can be carried away as sound waves. Some energy is also lost to viscosity of the air because of the local air flow around the edges of the structure.

CHAPTER 5

CONCLUSION

5.0 INTRODUCTION

This chapter will conclude the research and briefly discussed about the recommendation that can be applied for the future work. The conclusion were done according to the result obtain from Chapter 4. In order to study the dynamic behavior of spiral wound gasket, other aspects of future work also will be discussed.

5.1 CONCLUSION

The aim of this research is to determine the dynamic properties and behavior of spiral wound gasket by using modal analysis and compare with the finite element analysis.

In this paper a finite element model is used to analyze the mode frequencies and shapes of different parts of spiral wound gasket and hence compare the results with the experimental one. This model is analyzed in ALGOR software based on the real dimensions of spiral wound gasket and experimental analysis was done by impact hammer testing method. From the modal analysis, the natural frequencies and vibration modes shape of the model in outer ring, sealing element and inner ring were determined and evaluated. The comparison between natural frequencies of finite element modeling and modal analysis testing shows the closeness of the results. From the results, it has been observed that the suitable frequency ranges for spiral wound gasket will be up to 4000 Hz. This research work will help to find out the natural frequencies of the equipment and hence predicting the chatter formation zone as resonance phenomena and that resonance can be avoided. In other words, the natural frequency of the piping system should be set lower or higher than the natural frequency of the equipment so resonance can be avoided. The natural frequency of the system can be change either by piping layout or support function.

5.2 RECOMMENDATION

There are few improvements need to be done for the future research. This is to improve the accuracy of the predicted dynamic properties of spiral wound gasket. Some of the recommendations are:

(i) The research is carried out in a completely sound proofed room and only the person doing the experiment is allowed to be in the room while doing the experiment.

(ii) Actual thickness of spiral winding materials must be calculated properly. In this experiment. It is assumed that each of the winding materials have a thickness at 0.2 mm since no proper instrument can be used to measure the thickness of winding materials while they are already joint.

(iii) The spiral wound gasket that being used in the experiment should be a new one.

REFERENCES

This project is prepared based on the following references:

Arthur, L. 2006. *Materials for Architects and Builders*. 3rd ed. New York: Butterworth Heinrahmanemann: 338-350

ASME B16.20. 1993. Metallic gaskets for pipe flanges- ring joint, spiral-sound and jacketed. The American Society of Mechanical Engineers.

Bellenger, E., Benhafid, B. and Troussier, N. 2008. Framework for controlled cost and quality of assumptions in finite element analysis.

Complete gasket product range guide. 2008. James Walker & Co.

Daniel, E.C. 1996. *Gaskets Design, Selection and Testing*. McGraw Hill: 46

Gasket installation technical data sheet. 2000. Gasket Resource Incorporation.

Helms, R. 2005. ALGOR FEA predicts mechanism failure and confirms design modification.

Herbert, L.M. 2001. Technology and Standards Piping Vibration Involving Control Valves.

Huang, T.C. 1991. Modal analysis modeling, diagnostics and control-analytical and experimental.

Huikai, X., Gary, K.F., and Robert, E.S. 2008. *Comprehensive Microsystems*: 135-180

Inman, D.J. 2007. *Engineering Vibration*. Englewood Cliffs. 3rd ed. USA: Prentice-Hall.

Jaroslav, M. 2004. Finite elements in the analysis of pressure vessels and piping: 581-583.

Jenko, J.M. and Hunt, E.S. 2000. Generic issues affecting spiral wound gasket performance. *International journal of pressure vessels and piping.* **77**

Jimin, H. and Zh, F.F. 2001. *Modal analysis.* Butterworth Heinrahmanemann.

Pelosi, G. 2007. The finite-element method.

Peter, A. 2001. Experimental modal analysis - a simple non mathematical presentation.

Robert, D.C. 1981. *Concepts and applications of finite element analysis.* USA: John Wiley & Sons.

Seybert, F. 2002. Experimental modal analysis.

Simonen, F.A. and Gosselin, S.R. 2001. Life Prediction and Monitoring of Nuclear Power Plant Components for Service-Related Degradation. *ASME Journal of Pressure Vessel Technology*. **123**: 58–64.

Silva, C.W. 2005. *Vibration and Shock Hand Book*. USA: Taylor and Francis.

Spiral wound gasket catalogue. 2000. The Flexitallic Group.

Spiral wound gasket technical data sheet. 2000. Italy: Europiping Industrial Technologies.

Spiral wound gasket technical data sheet. 2006. China: TianYi Chemical Industrial.

Trinath, S. 2008. *Gaskets the weakest link.* Indian oil corporation ltd.

APPENDIX A

FIGURE OF SWG FAILURE

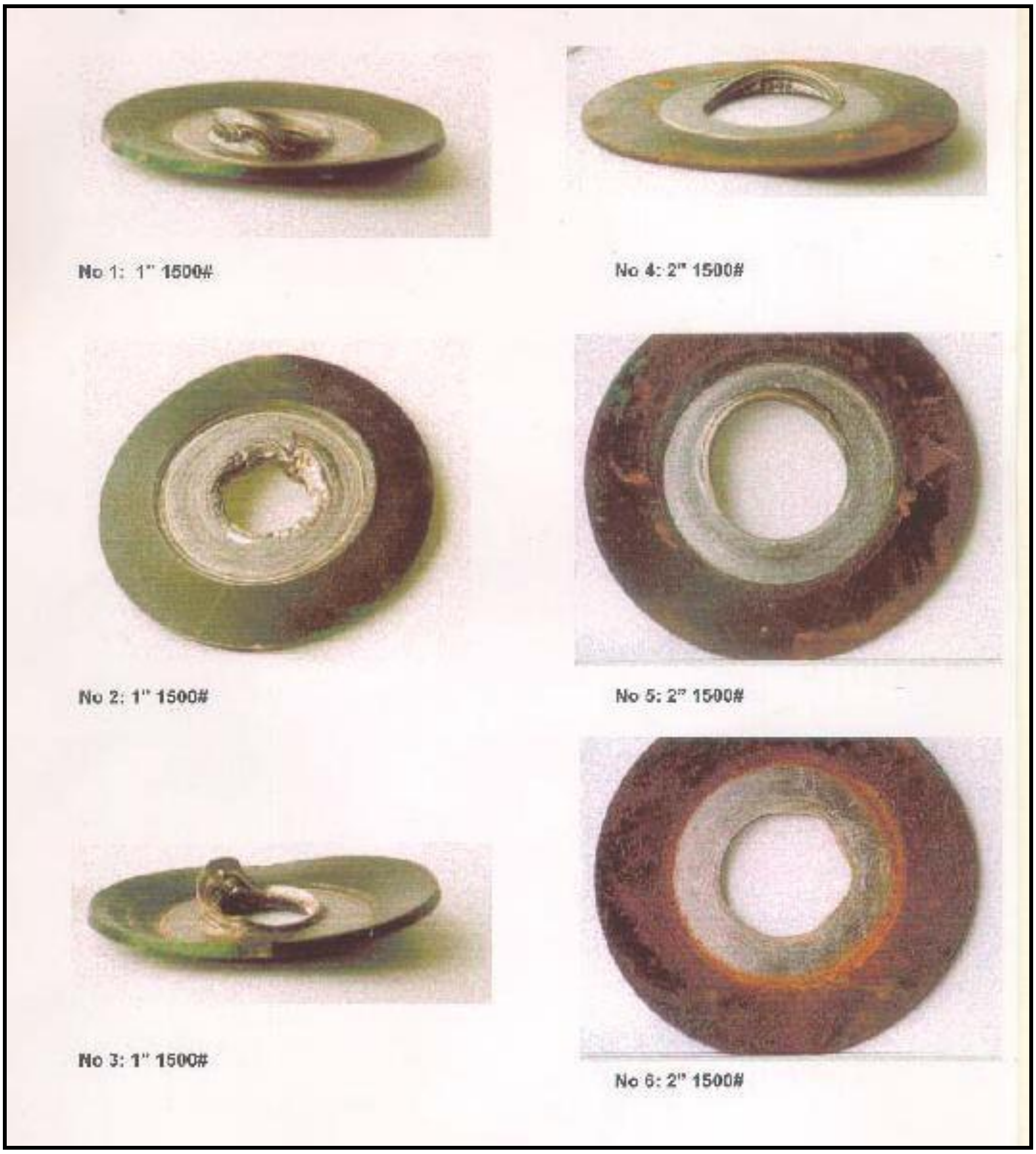


Figure 6.1: Spiral wound gasket failure

Source: Health and Safety Executive (2001)

APPENDIX B1

DRAWING ASSEMBLY OF INNER RING

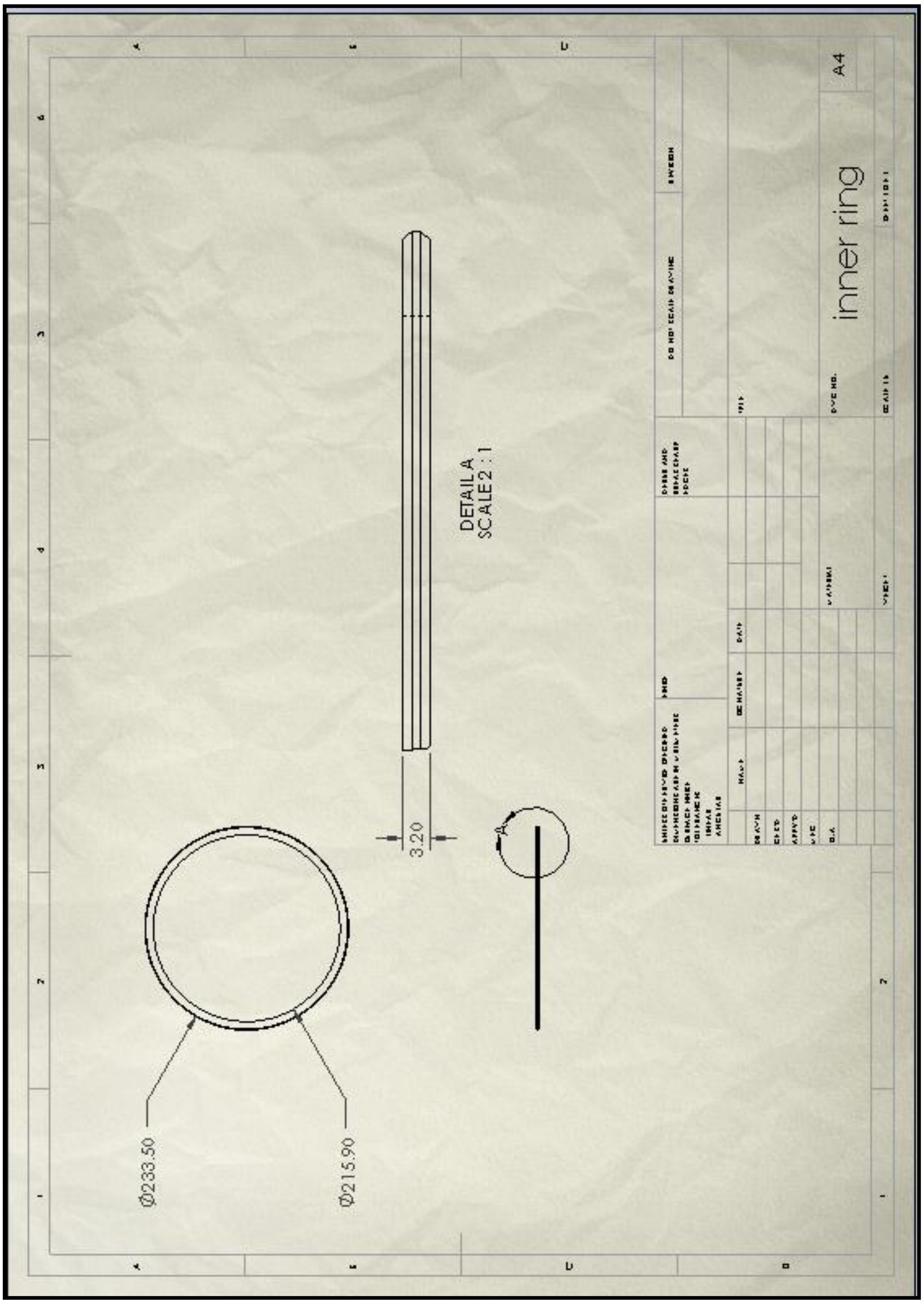


Figure 6.2: Drawing assembly of inner ring

APPENDIX B2

DRAWING ASSEMBLY OF SEALING ELEMENT

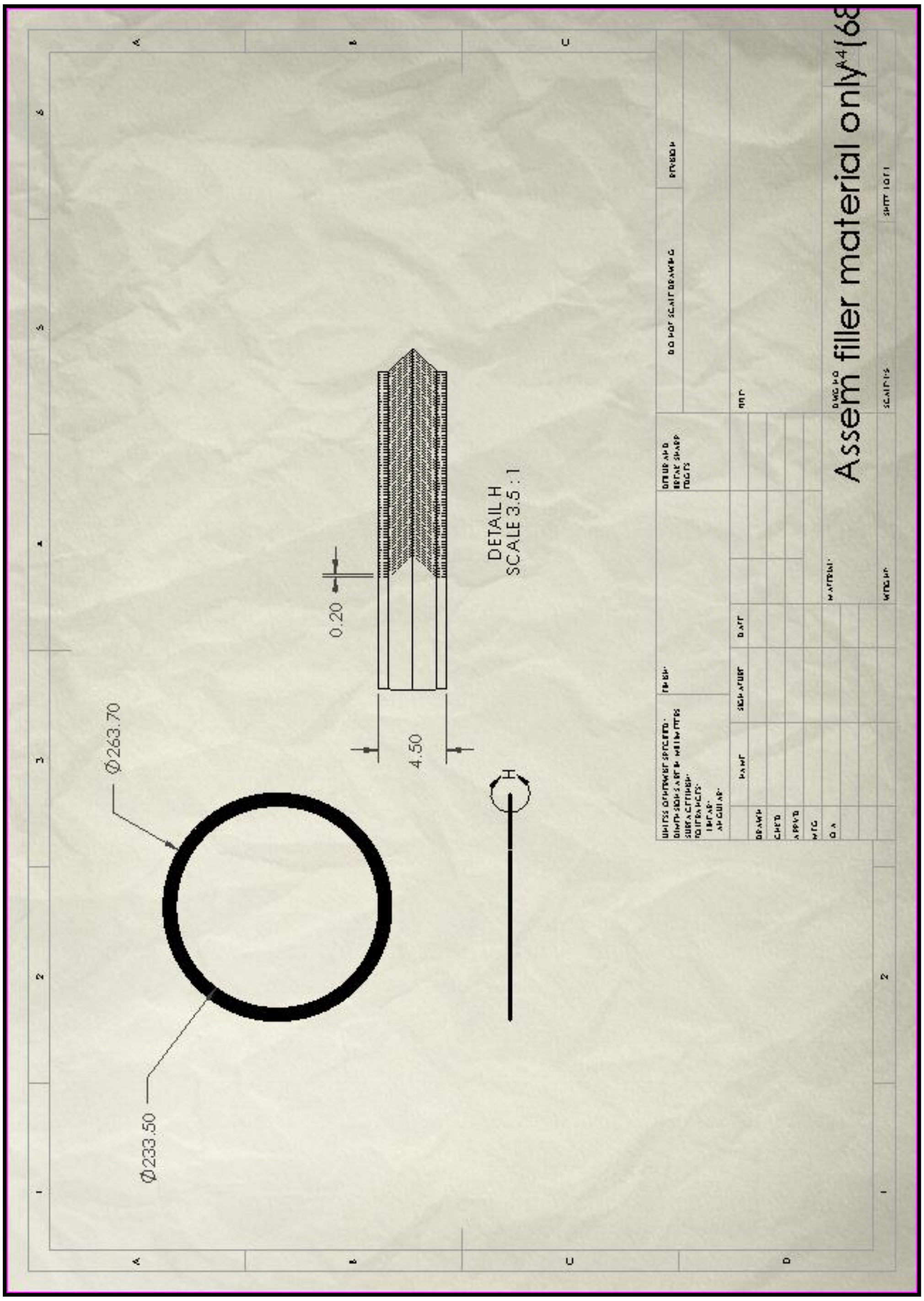


Figure 6.3: Drawing assembly of filler material

APPENDIX B3

DRAWING ASSEMBLY OF OUTER RING

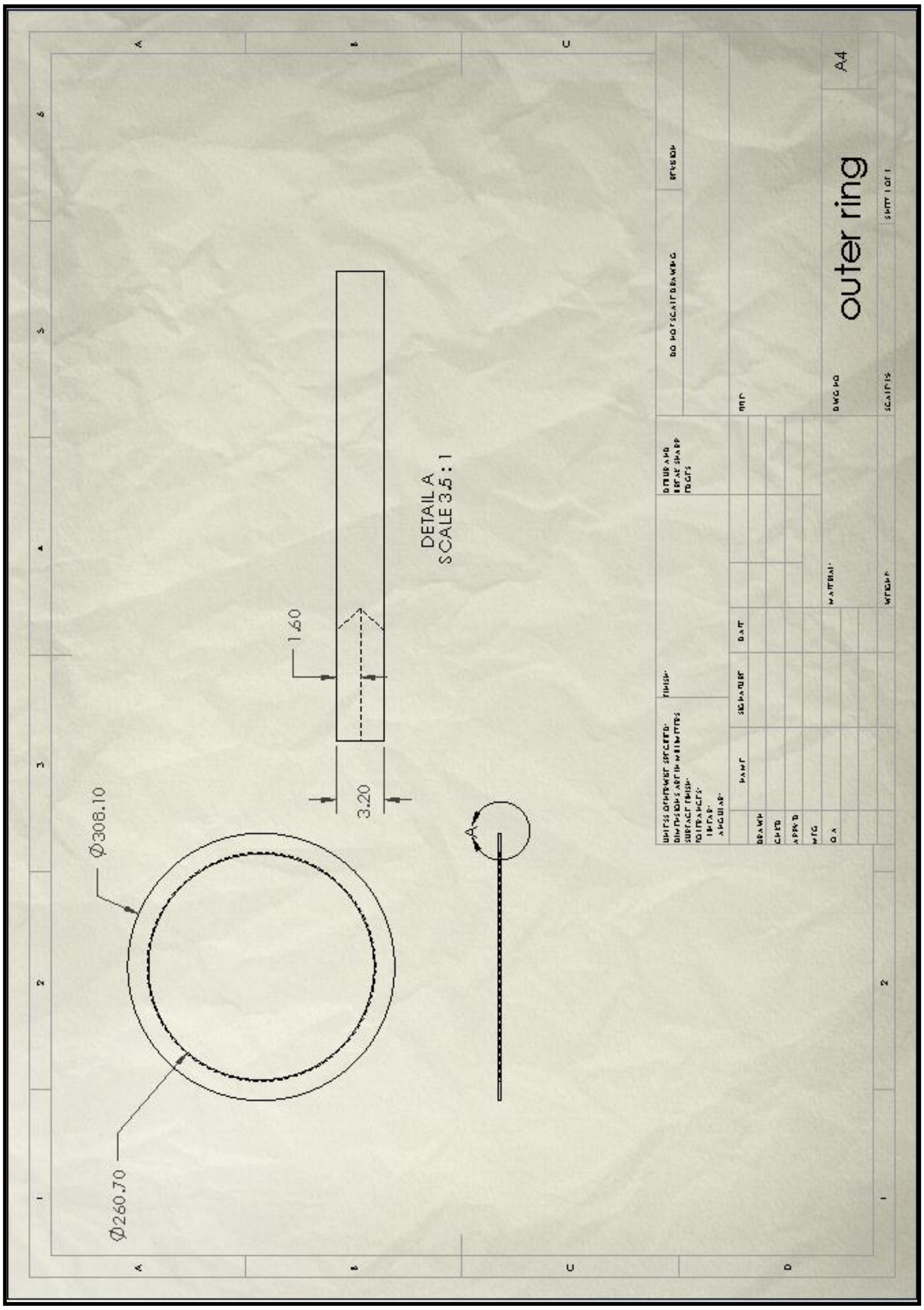


Figure 6.4: Drawing assembly of outer ring

APPENDIX B4

DRAWING ASSEMBLY OF ASSEMBLE PART

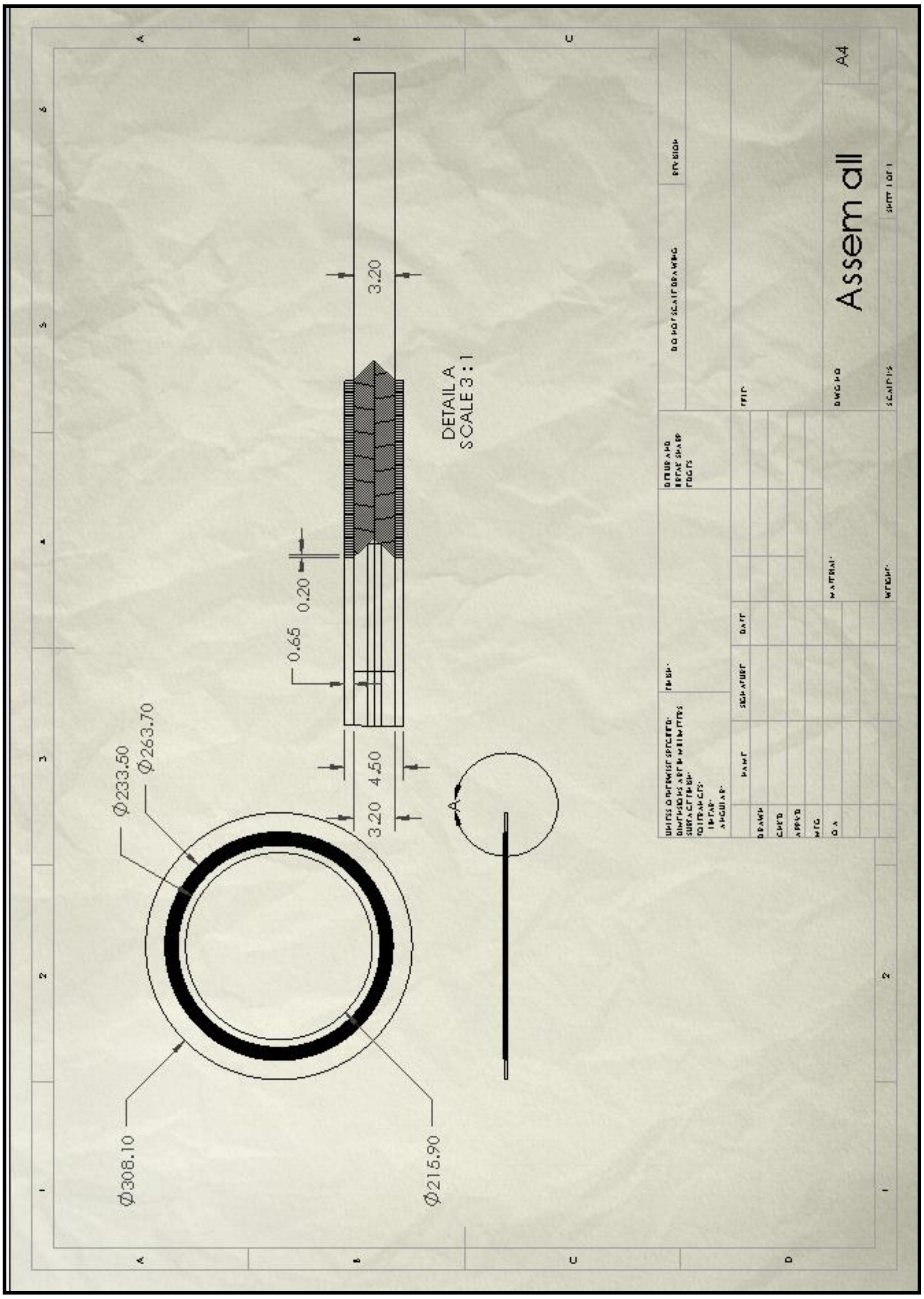


Figure 6.5: Drawing assembly of complete assemble parts spiral wound gasket

APPENDIX C1
MESH DIAGRAM

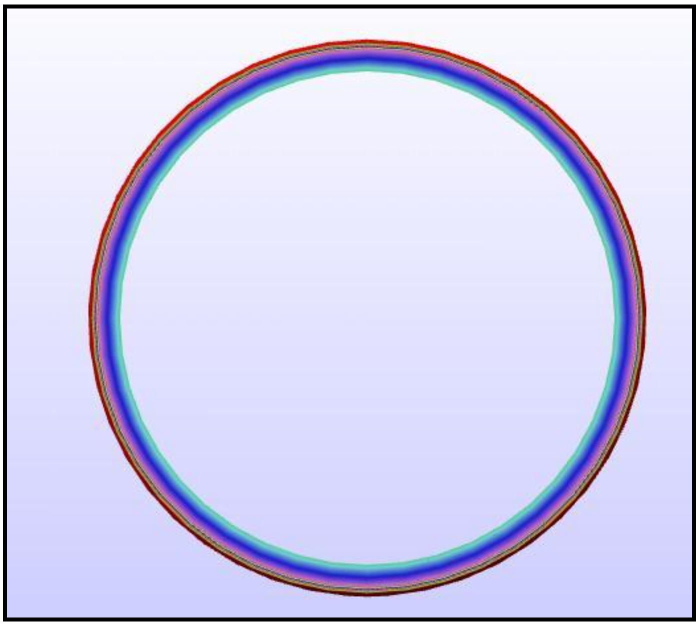


Figure 6.6: Mesh diagram of sealing element

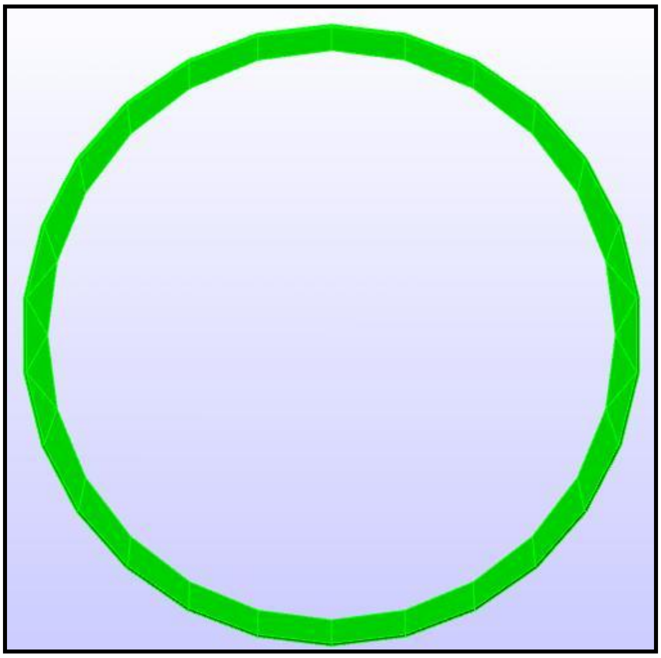


Figure 6.7: Mesh diagram of inner ring

APPENDIX C2
MODE SHAPE OF OUTER RING

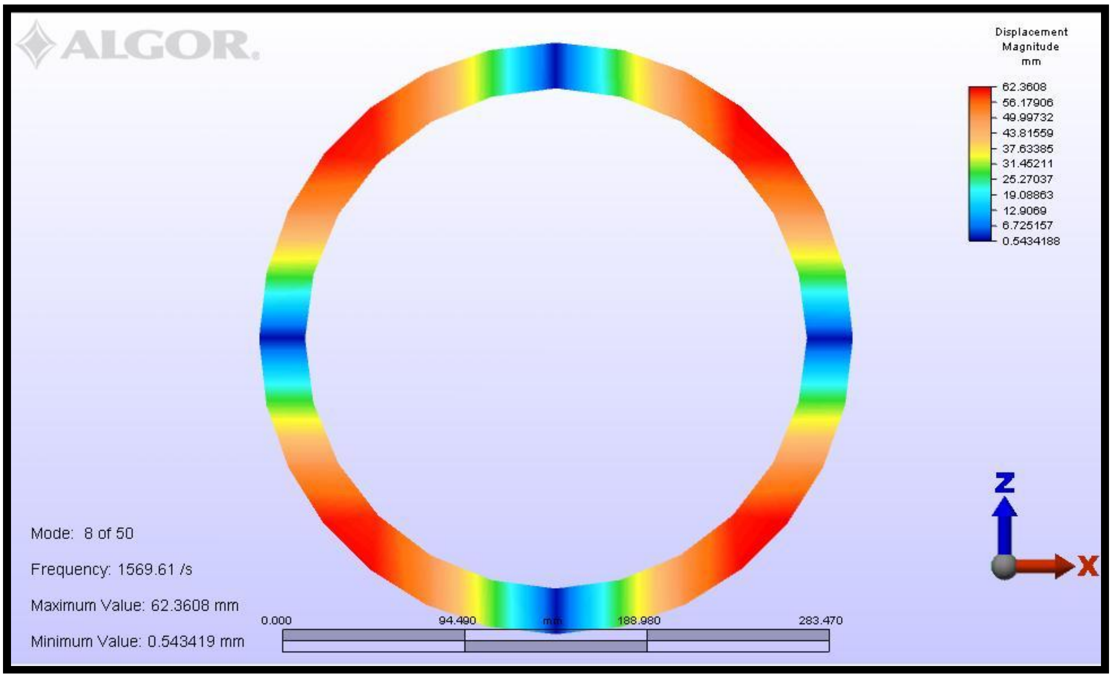


Figure 6.8: Mode shape 2 of outer ring

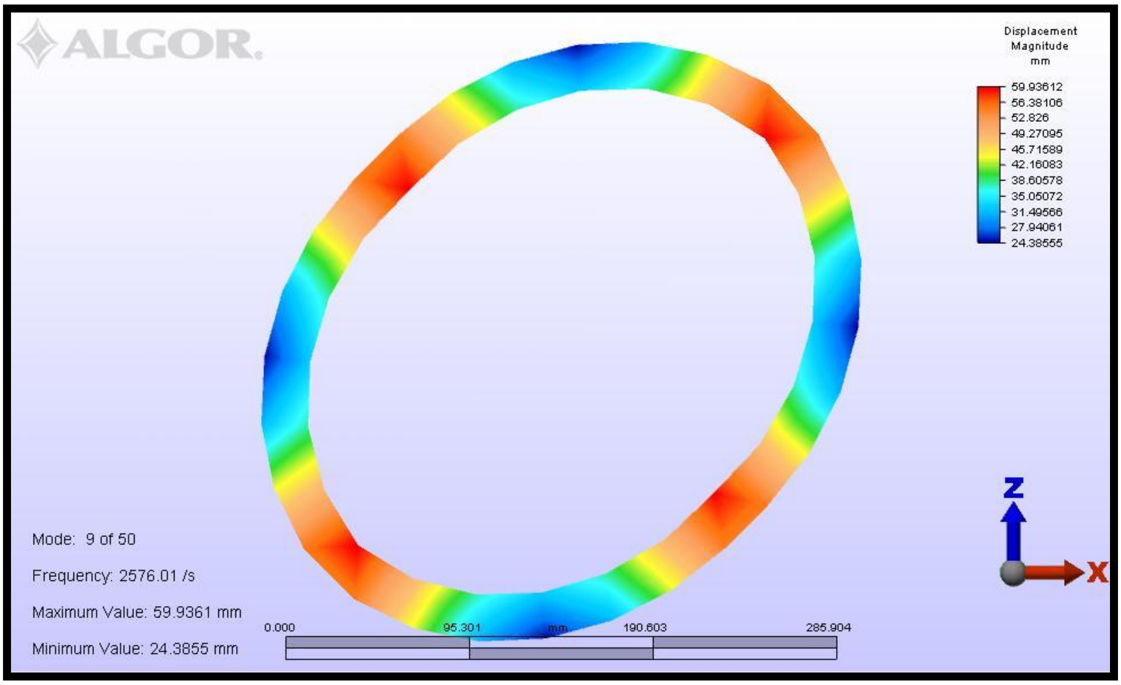


Figure 6.9: Mode shape 3 of outer ring

APPENDIX C3

MODE SHAPE OF OUTER RING

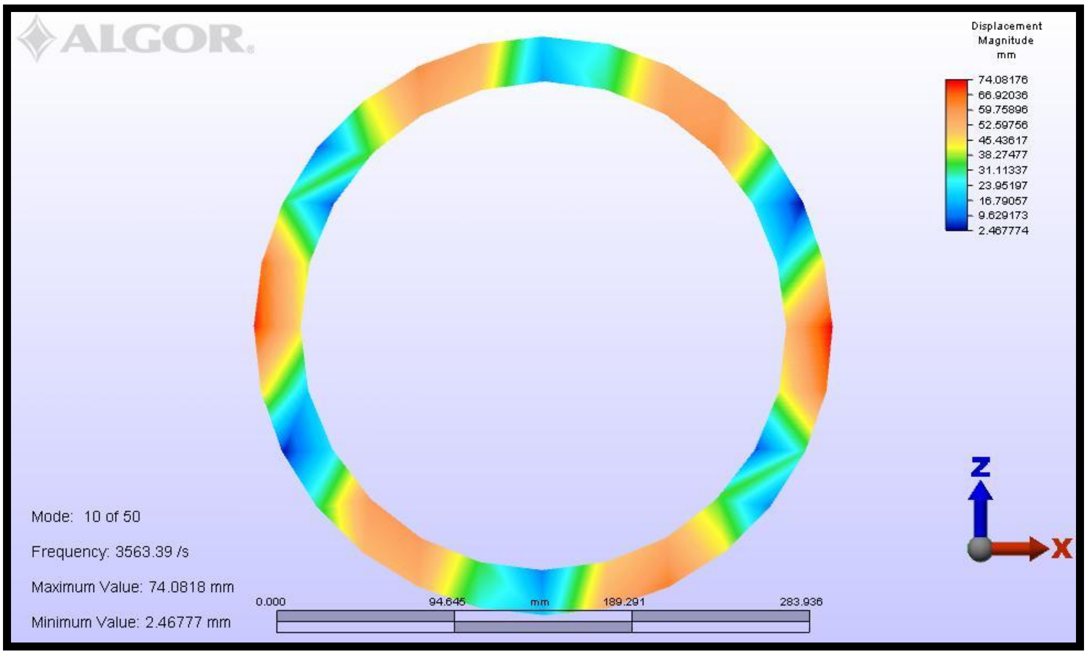


Figure 6.10: Mode shape 4 of outer ring

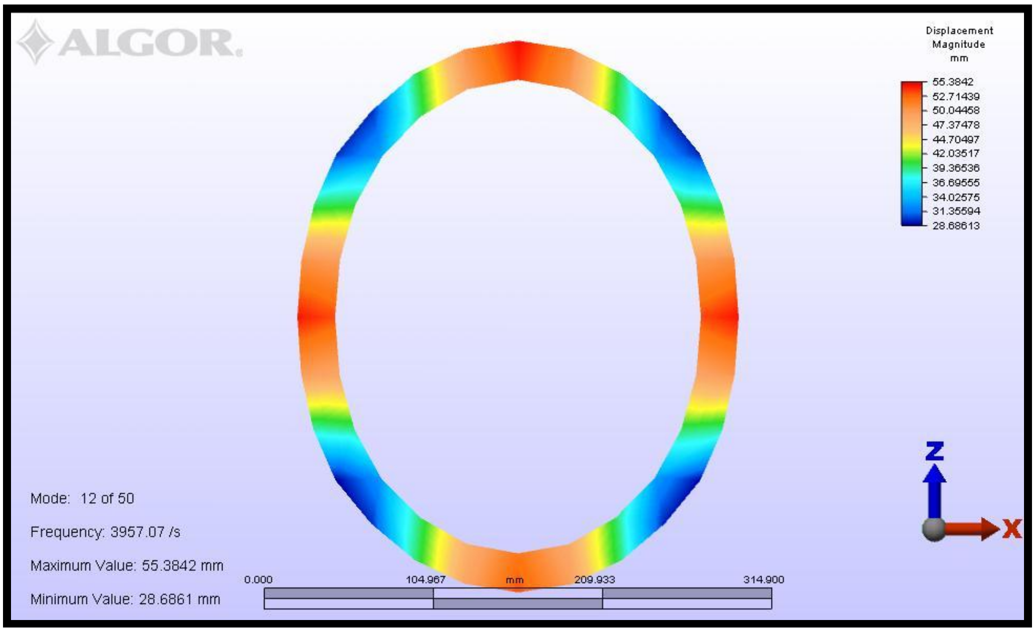


Figure 6.11: Mode shape 5 of outer ring

APPENDIX C4

MODE SHAPE OF SEALING ELEMENT

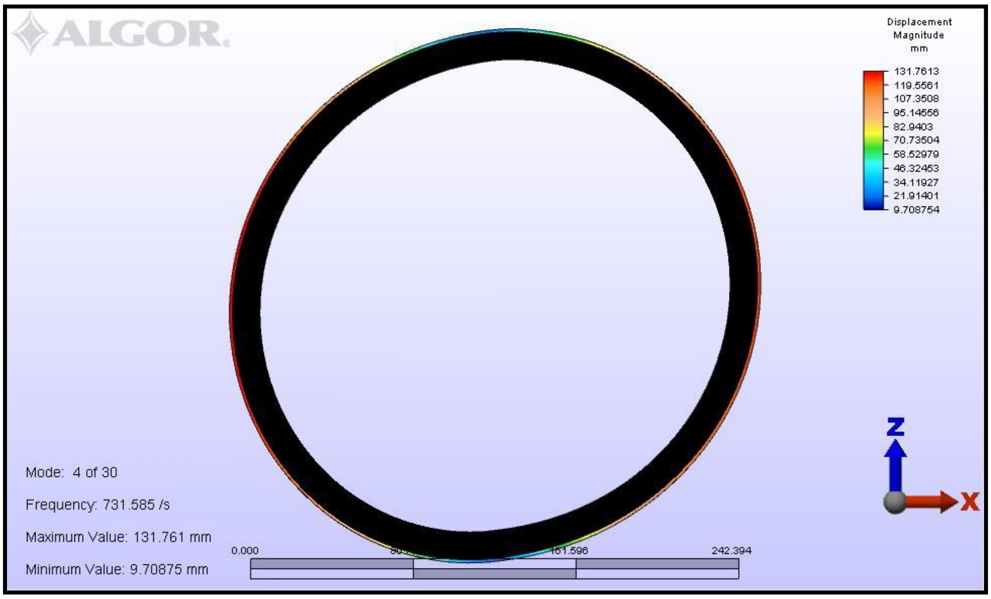


Figure 6.12: Mode shape 2 of sealing element

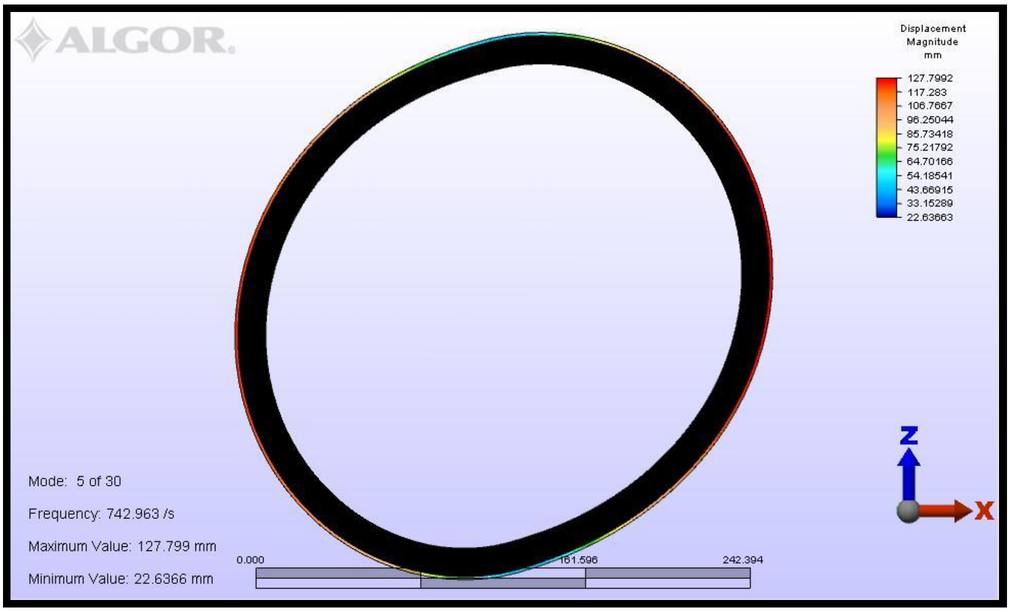


Figure 6.13: Mode shape 3 of sealing element

APPENDIX C5

MODE SHAPE OF SEALING ELEMENT

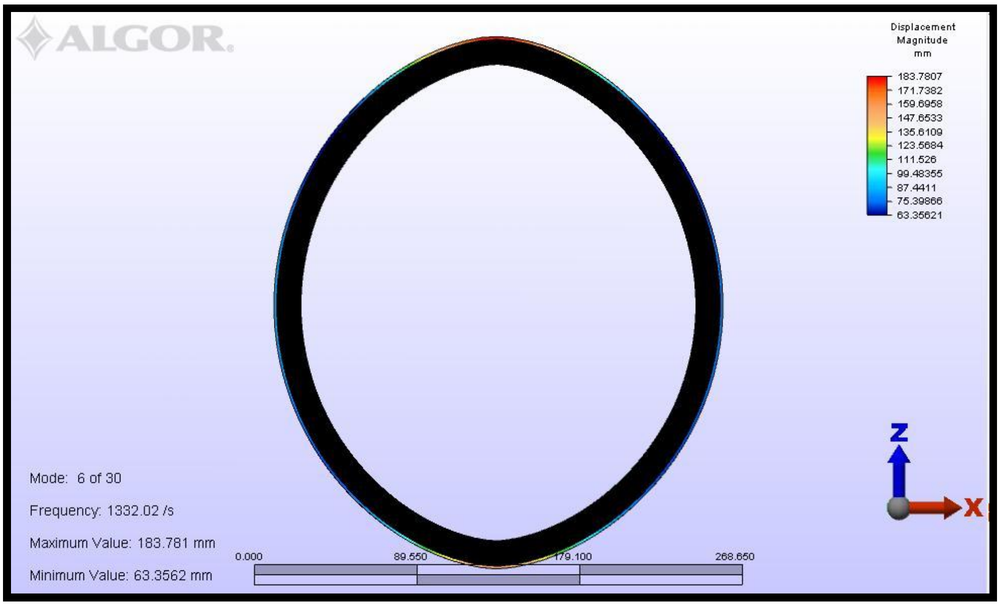


Figure 6.14: Mode shape 4 of sealing element

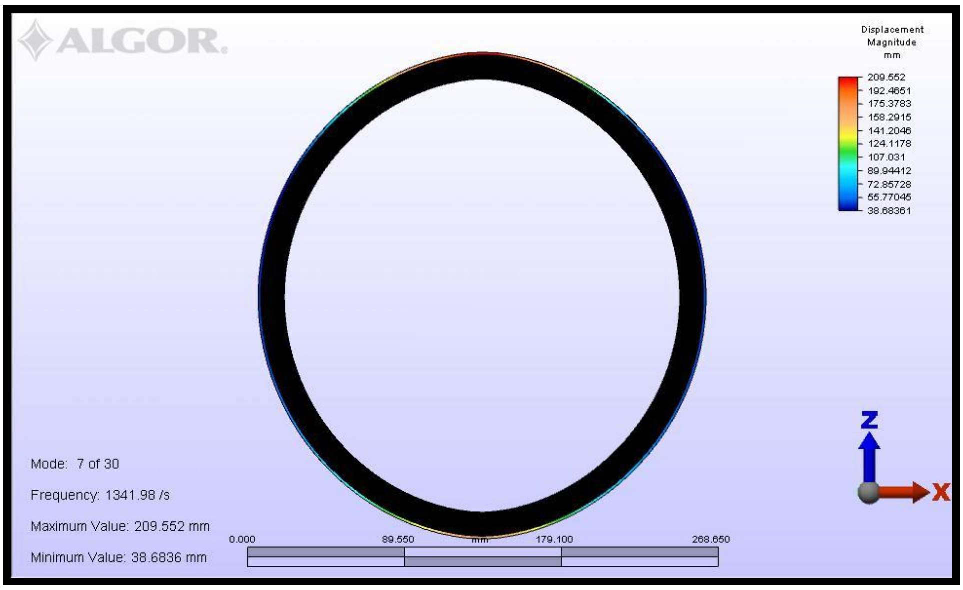


Figure 6.15: Mode shape 5 of sealing element

APPENDIX C6

MODE SHAPE OF INNER RING

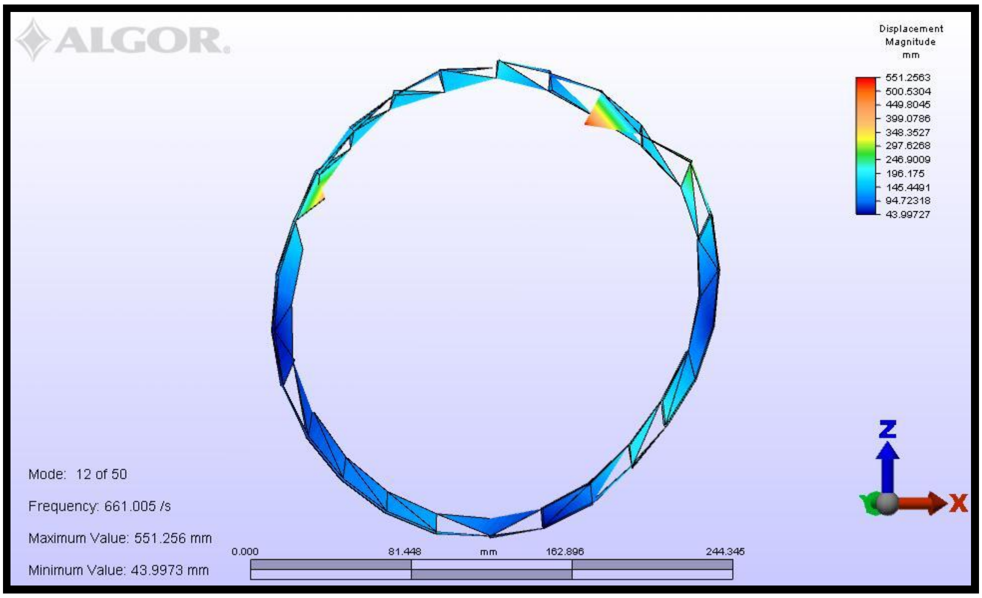


Figure 6.16: Mode shape 2 of inner ring

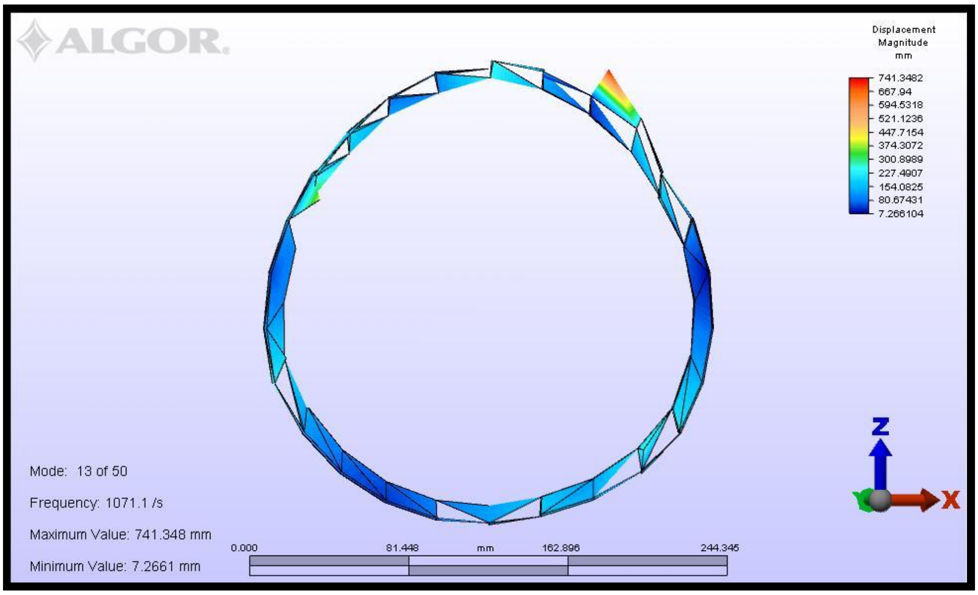


Figure 6.17: Mode shape 3 of inner ring

APPENDIX C7

MODE SHAPE OF INNER RING

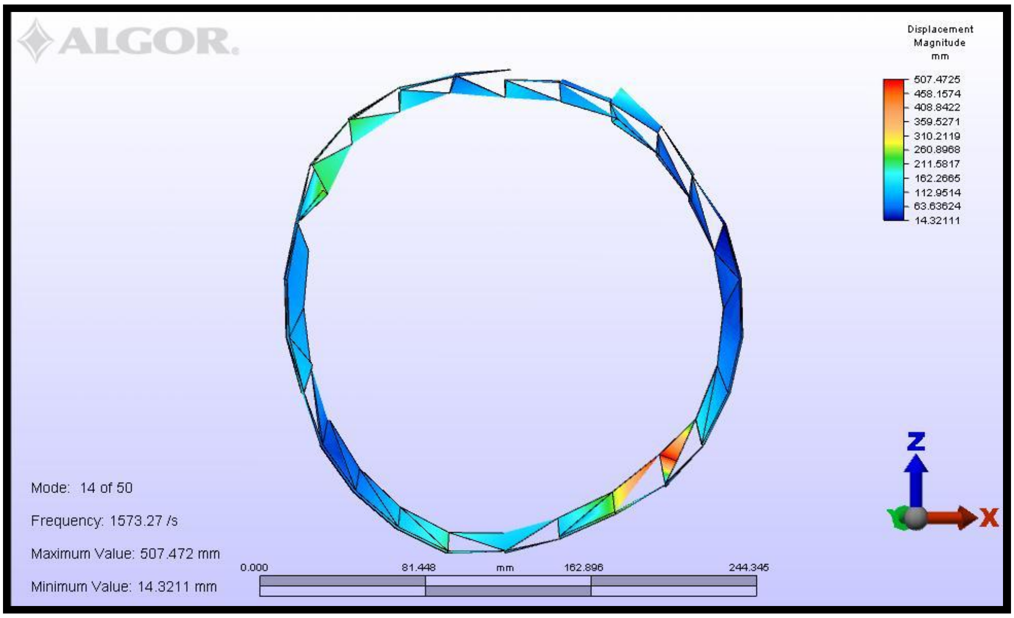


Figure 6.18: Mode shape 4 of inner ring

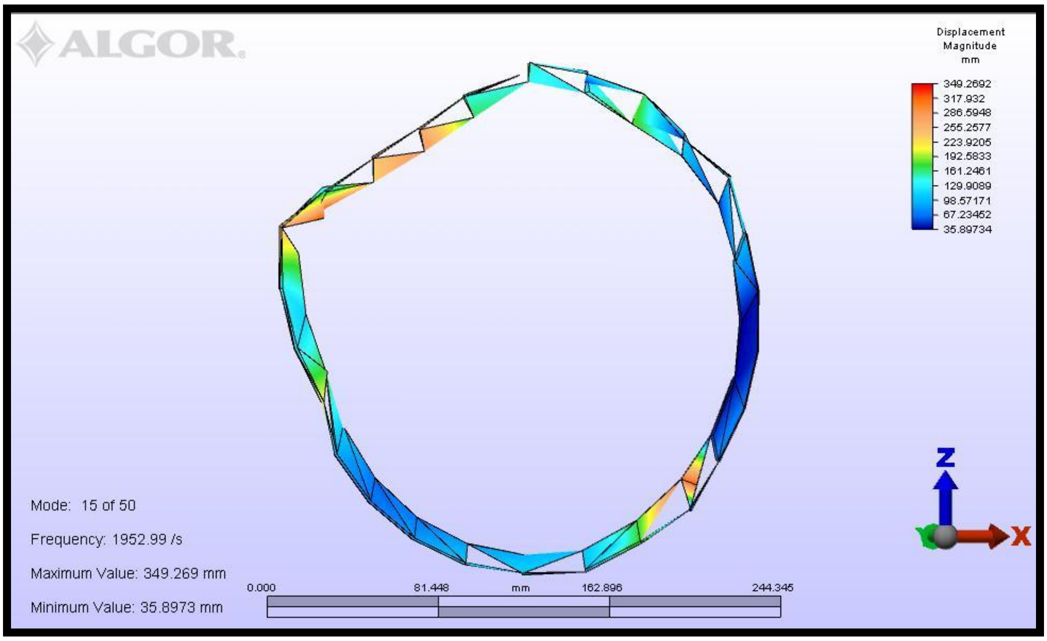


Figure 6.19: Mode shape 5 of inner ring

APPENDIX D
GANTT CHART

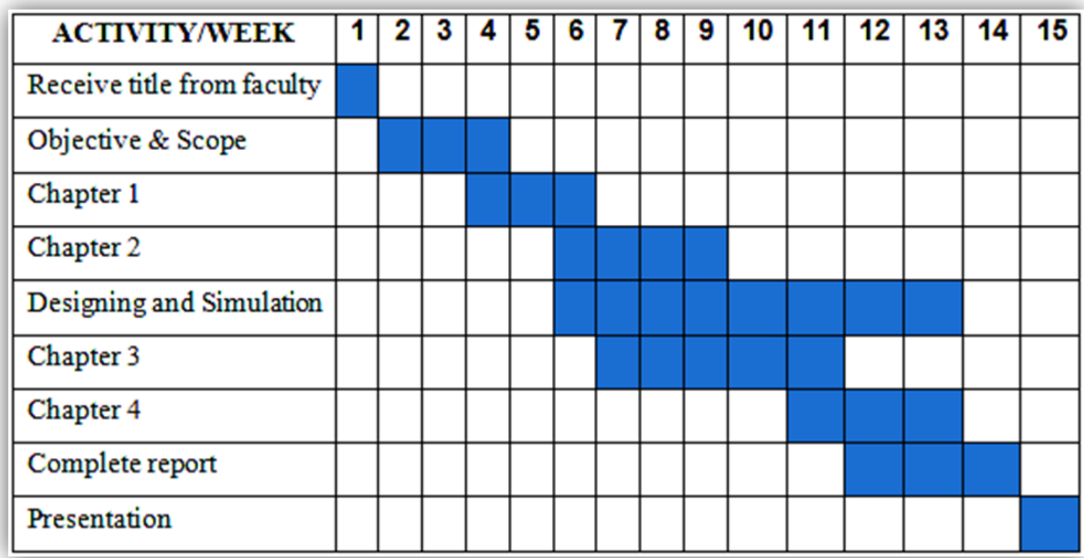


Figure 6.20: FYP 1 Gantt chart

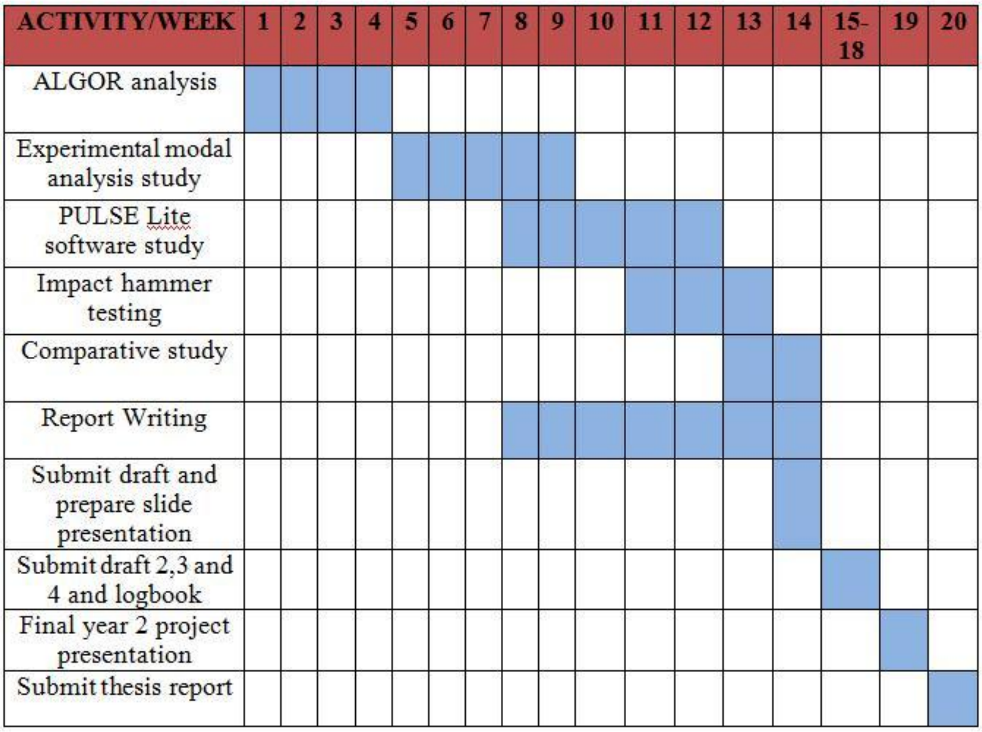


Figure 6.21: FYP 2 Gantt chart