Study of Low Stiffness Resilient Shaft (LSRS)

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2015

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CERTIFICATION OF APPROVAL

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14818

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi Petronas
In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

____

(Mr Mui'nuddin b Maharun)

CERTIFICATION OF ORIGINALITY

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

____

(MUHAMAD FARITH BIN PAUZI)

ABSTRACT

This dissertation mainly covers various chapters upon the design and modeling of Low Stiffness Resilient Shaft (LSRS) using wire rope as the main component. The use of flexible LSRS to replace the conventional steering shaft is discussed. The proposed steering system configuration is similar to a conventional electrical power-assisted steering with the replacement of the rigid steering shaft with a LSRS. The flexible LSRS should be able to carry the main task of the conventional steering shaft where it can allow active control of the vehicle. The steering system developed has a fail-safe functions that can respond to failures in steer-by-wire (SBW) steering system. The advantages of LSRS in comparison SBW and other conventional systems are discussed. This dissertation also discuss on the best wire rope configuration that should be used to build the LSRS. A single wire rope is compared with a four strand wire rope in ANSYS™ simulation. From the simulation, Total Deformation, Equivalent Stress, Maximum Principal Stress, Equivalent Elastic Strain, and Total Angle Deflection for both wire ropes are compared. The results show that wire rope that are configured using four strand where it is arranged in two of the wire ropes are in a right hand lay and the other two in a left hand lay to counter the force, give higher torsional stiffness.

ACKNOWLEDGEMENT

My completion of Final Year Project will not be a success without many peoples. Hereby, I would like to acknowledge my heartfelt gratitude to those I honor.

I would like to deliver my utmost gratitude to my direct supervisor, Mr Mui'nuddin b Maharun, lecturer of Mechanical Engineering Department, Universiti Teknologi PETRONAS for his continuous support, exemplary guidance, monitoring and constant encouragement throughout this thesis. Apart from technical aspects, he is also provides me with valuable guidance on my self-development in order to have mental preparation in the future working conditions and teach me the importance of passion and putting your heart into your work in order to produce outstanding result.

Subsequently, I would like to thank my friends who are giving me suggestions and comments on my work for further improvements. Last but not least, I would like to thank almighty and my family for their support and keep me motivated during my final year study. With their support, I managed to perform well for my final year of undergraduate.

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, a lot of technologies have been developed in automotive industry. One of the developments is on the steering system of the vehicles which has attracted a lot of attention recently. [1-4]. All those research and studies have the same objective, which is to improve the stability and maneuverability of a vehicle under all driving conditions. At the same time, the vehicle steering control should improve the safety of critical cornering behaviors in an emergency [6].

Steer-by-wire (SBW) is a system that has been introduced in vehicle steering technology. A SBW system is expected to improve both passive and active safety. The use of electrical control unit in the SBW system improves vehicle stability and steering maneuverability while reducing the impact of the mechanical linkage to the driver during front-end collision. [5].

However, despite the improvement in terms of safety factor and maneuverability, SBW is still prone to a failure. SBW system relies mostly on the Electrical Control Units (ECU) to receive and send signals. Like every other ECUs, there will be a possibility for them to be malfunctioned. In a case where SBW failed to function, a fail-safe design is introduced whereby a Low Stiffness Resilient Shaft (LSRS) replace the mechanical shaft used in conventional steering system. Design of the wire rope is discussed for the LSRS.

1.2 Problem Statement

SBW technology in the automotive industry is the use of electrical or electro-mechanical systems for performing vehicle functions which traditionally achieved by mechanical linkages. This technology replaces the traditional mechanical control systems with electronic control systems using electromechanical actuators and human-machine interfaces. In 2013, Nissan applied this system in their Nissan Infinity model by using three ECUs. In this case, if one fails, the other will serve as a back-up system. If it's happen to be all three are failed to function, a magnetic type of clutch which rely on electronic system will be activated thus restore a traditional mechanical steering system. The magnetic clutch however also has a tendency to a failure since it is electronically controlled. If this happens, it would mean that the driver will no longer have any sort of controls of the steering. To avoid this from happening, Low Stiffness Resilient Shaft (LSRS) is proposed. The use of LSRS will eliminate any connection in between compared to mechanical steering shaft where it needs a clutch to connect. LSRS also can be bendable, can be shaped and have more advantages in packaging wise.

1.3 Objectives

The main objective of this project is to find the most suitable design for the wire rope that will be used in LSRS. In order to do that, these need to be achieved:

1.3.1 To model and simulate wire rope configuration use In LSRS

1.3.2 To investigate an idle wire rope configuration to be used in LSRS via FEA simulation

1.4 Scope of Study

This paper will focus on modeling and simulation of the wire rope that best resembles its actual construction in LSRS. As for modeling, CATIA drawing software will be used and ANSYS will be used for the simulation purpose. There are two parameters of interest when conducting simulation. Those are torsional rigidity and numbers of wire rope requires for LSRS

CHAPTER 2

LITERATURE REVIEW

2.1 Basic Principles of Vehicle Steering System

Vehicle steering system converts the rotation of the steering wheel into a swiveling movement of the road wheels in such a way that the steering wheel rims turns a long way to move the road wheels a short way [8]. The system allows a driver to use only light forces to steer a heavy car. For example, the rim of a 15 in. (380mm) diameter steering wheel moving four turns from full left to full right travels nearly 16 ft (5m), while the edge of a road wheel moves a distance of only slightly more than 12 in. (300mm) [7]. If the driver were to rotate the road wheel directly, he or she would have to push nearly 16 times as hard.

The most common type of steering system is the rack and pinion steering. It is a pretty simple mechanism where rack and pinion gear set is enclosed in a metal tube, with each end of the rack protruding from the tube. A rod called a tie rod, connects to each end of the rack. The pinion gear is attached to the steering shaft. When the steering wheel is turned, the gear spins thus moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle. (see figure 2.1)

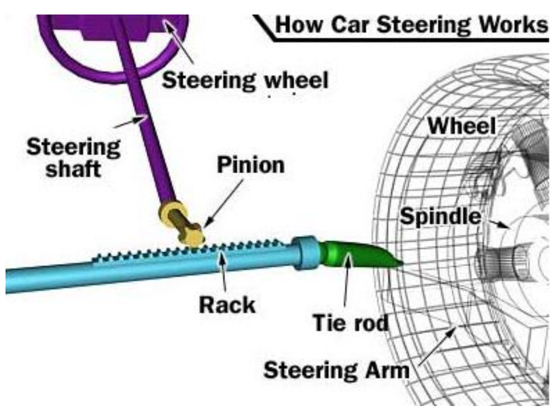

Figure 2.1: Rack and Pinion Mechanism [8]

2.2 Steer by Wire (SBW)

SBW has been held up as a "technology of the future" for well over a decade. It replaces the traditional mechanical relationship between steering wheel and tires with an electronic system. The system interprets the driver's input from force applied to the steering wheel. This information is fed to multiple electric control units (ECUs). The ECUs will receive the information and send a signal to steering angle actuator, which results in the turning of the front wheels [11]. Due to this, less effort is requires from the driver to turn the wheels. In theory, the biggest advantage of the system is that tires respond to driver input almost instantaneously. The SBW system consists of 4 main components (refer figure 2.2). These are;

2.2.1 <u>Steering-force sensor</u>

- It has two roles. First to send commands to the ECUs and second is to act as the driver's feedback source by varying resistance to the wheel

2.2.2 <u>Clutch</u>

- This clutch will be open on most of the times, unless if there is a failure in the ECUs, it will be automatically closed to create a solid mechanical connection between the steering wheel and the rack.

2.2.3 <u>Electronic Control Modules</u>

- These three ECUs controls the electric-assist motors and the steering force sensor. They also act as redundancies in case where one of the ECUs failed to function, the other will step up to replace it.

2.2.4 <u>Steering-Assist Motors</u>

- This motor will receive signal from the ECU and transfer the signal to mechanical movement to turn the wheels.

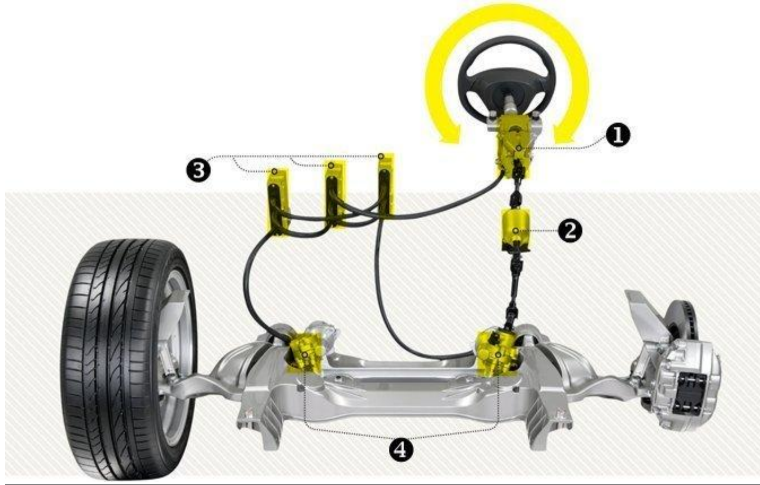

Figure 2.2: SBW main components [11]

Other than instantaneous response time, the advantage of SBW is that it also helps the driver to drive in straight line [6]. With the camera install within the system, it will constantly giving road feedback to the ECUs. This feature helps in a way where driver will no longer need to make constant small corrections to the steering. In addition to that, this system will filter out distracting feedback from bumps and uneven pavement from being felt by the driver. This is due to the electronic steering wheel/tire relationship.

2.3 Low Stiffness Resilient Shaft (LSRS)

LSRS is chosen to replace common mechanical steering shaft as a backup system or a fail-safe design for the SBW. This is because the characteristic of LSRS will reduce the possibility for the SBW system to fail compared to the traditional mechanical shaft. Due to its bendable characteristic, LSRS will also have more advantage in packaging wise. To construct the LSRS, a wire rope will be used. The ideal configuration of the wire rope will be further determined as stated in the objectives.

Wire ropes typically have one or more layers of helically wrapped strands, each of which is made up of one or more layers of helically wrapped wires. The core of the wire rope, if any, may be a natural or synthetic fiber rope, a strand similar to one of the main rope strands, or an independent wire rope core (IWRC) [10]. Many wire rope materials and designs are available with a variety of physical characteristics in terms of strength, flexibility, torque and rotation balance, abrasion resistance, and corrosion resistance [9]. A rope is a combination of strands formed round a core. If the direction of lay of the wires in the strands, and the strands in the rope, are the same, then it is termed Lang's lay. Lang's lay is sometimes also referred to as parallel lay. The benefit of this lay is the relatively long length of each outer wire that is exposed to the surface. When the rope wears, the wear is well distributed over the wires, which results in improved performance. The higher values of torque in Lang's lay ropes, compared with ordinary (regular) lay ropes, results in the former having a greater tendency to oscillate torsionally in service. This rotational oscillation leads to an even distribution of wear round the circumference of the rope.

Significant changes in lay length from the as-manufactured state can have detrimental effects on the endurance of hoisting ropes. One area of concern is the sheave end of the rope, where the maximum changes in lay length occur, combined with the maximum rope loads. However, severe shortening of the lay length at the front end can also lead to problems, since high levels of torque in the rope, combined with low loads, can result in the formation of abnormal defects such as kinks, waviness, and corkscrews. In Figure 2.3 are a few common wire rope configurations.

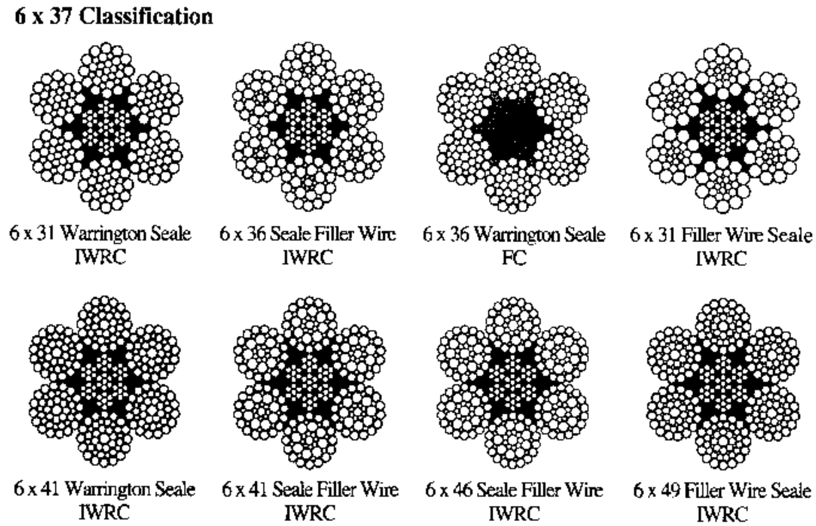

Figure 2.3: Common wire rope configurations [9]

It is important to note that reduced rope life due to the accelerated fatigue effects of operating with long lay lengths is characteristic not only of very deep shafts. In winding applications where conveyances are changed on a regular basis, large amounts of spin are released from the ropes in a short space of time. This results in significant increases in lay lengths and possible premature discards because large numbers of broken wires can be expected. Although long lay lengths can result in reduced fatigue life in bending, most ropes used on mine winders are discarded for various other reasons before the fatigue life of the rope is reached. Normal discard factors could be wear, corrosion, and wire splitting due to excessive plastic deformation of the outer wires. The overall degradation in TSRs results primarily from the interaction of plastic wear and subsequent fatigue of the outer wires. It is further complicated by the effects of torsional deformations that are inevitable in any application that involves long ropes with fluctuating loads.

The LSRS or the low stiffness resilient shaft is the feature that sets it apart from other systems. The material selection and design of the LSRS is an important task which actually influence the behavior of the LSRS itself when the steer-by-wire system fails. One of the most important parameters under consideration would be the stiffness of the LSRS so that when the electronic system fails, the stiffness of the LSRS is high enough to make the vehicle controllable and the system falls under the minimum requirements of the safety standards. On the other hand the LSRS should be resilient and flexible enough that the active control can be performed effectively without transferring most of the disturbances even on the poorest road conditions.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

Figure 3.1 below shows the methodology in conducting this project.

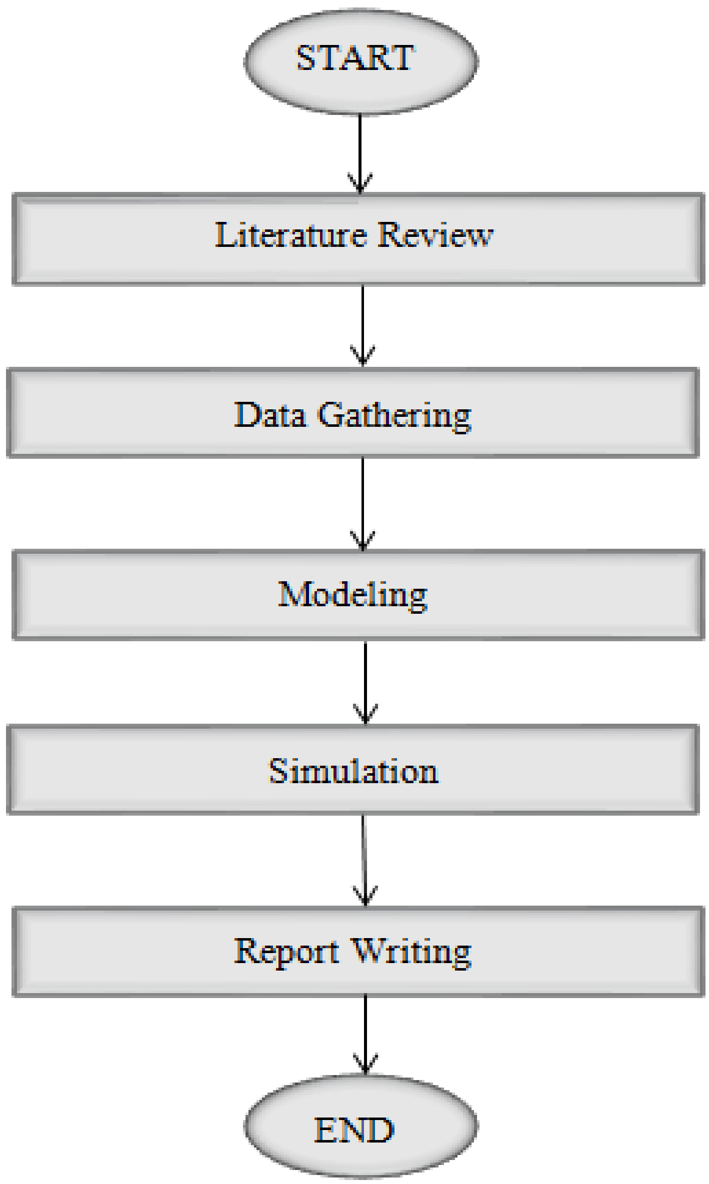

Figure 3.1: Project Methodology

For this project, it is essential that every single step should be taken properly. The first step is to do a literature review on past related researches. A background study on the proposed research is very important to be conducted. This is to ensure the research conducted will convey significant impact and contribution to a novel knowledge and understanding in this area. The second step is the wire rope modeling and simulation. Prior the modeling, the ideal configurations of the wire rope need to be determined. The selection of the best configuration of the wire rope is very crucial step as the performance of the whole system depends on it. The LSRS built should resemble the actual vehicle specification as close as possible in order to ensure the accuracy of the simulation results. The wire rope will undergo simulations with different types of configuration. ANSYS will be used for this purpose..

3.2 Experimental Setup

Since wire rope will be used to fabricate the LSRS, it is crucial to know the characteristics of the wire rope such as its strength and torsional rigidity. Among the important factor of the setup is the torsional balance. Special attention is to be given to the torque compatibility among different mooring components of wire. This is to prevent excessive twisting from unbalanced torque during handling, installation, operation and recovery.

There are two categories of torsional imbalance problem to be considered;

3.2.1 Twist introduced into components and transferred between them during installation, which may then cause operational problems; and

3.2.2 Incompatibility between installed components in operation.

3.3 Gantt Chart and Milestone

Table 1 and Table 2 below show the project Gantt chart for both semesters in conducting the project.

Table 1: Project Gantt Chart for FYP 1.

Project activities	Duration (Weeks)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Preliminary research work • Background studies														
Familiarization with wire rope configuration														
Propose suitable experiment setup														
Submission of Interim report														

Table 2: Project Gantt Chart for FYP 2.

Project activities	Duration (Weeks)													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Data gathering • Wire rope configuration	■	■	■											
Modeling and Simulation				■	■	■	■	■	■					
Performance checking										■	■	■	■	
Submission of final report														■

■ Planned work

Table 3: Project Milestone.

Project activities	Weeks	Completion (%)
Preliminary research work	3-6	10
Study of wire rope configuration	7-9	20
Propose suitable experiment setup	10-13	50
Data gathering	15-17	60
Modeling and simulation	18-24	80
Performance checking	24-27	100

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Modeling of the Wire Rope

In order to correlate between the simulation and the experimental results, wire rope of 1 + 6 strand, which has 7 strands in total, 1 center core surrounded by 6 wires in the outer layer has been chosen. The wire rope selected is made of galvanized steel and was manufactured by Titian Maju Enterprise. Because of its simple construction it is easier to simulate the model. Table below shows the parameter of the wire rope.

Table 4.1 Parameters of 1+6 wire rope

Parameters	**Value (mm)**
Outer wire diameter	1.18
Center wire diameter	1.2
Strand diameter	3.56
Lay length of the strand	53.6

The wire rope is modeled using CATIA™ V5R18. The solid model will later be imported to ANSYS™ for the simulation purposes. A few configuration of the wire rope will be simulated to find which are best to be used as LSRS. The data gained by the simulation will be needed to further validate via experimental works. Figure 4.1 shows the solid model of the wire rope.

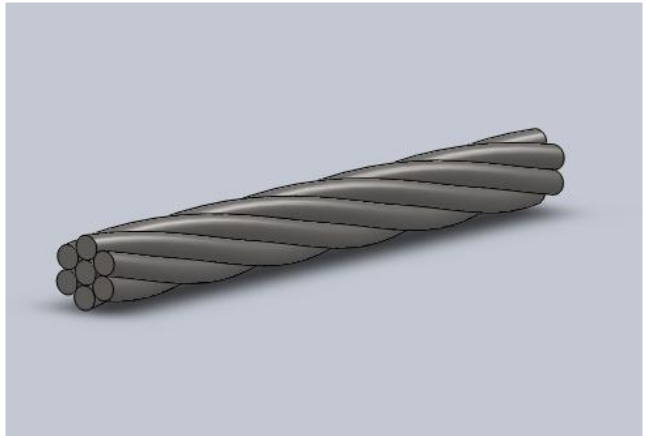

Figure 4.1 Solid model of 1+6 wire rope

4.2 Simulation of the wire rope

Simulation of the wire rope is done using ANSYS™ software. The model from CATIA™ software is first save in .IGF file before it can be imported to ANSYS™. Before running the simulation, there are few settings need to be done on the Static Structural option in the Mechanical Workbench. First, simulation on the single wire rope (as shown in figure 4.1) is done to see how it will behave. The contacts of the model need to be set, in this case, the contacts between all those wires would be frictional and since it is a galvanized steel wire, the frictional coefficient is set to 0.115. After that, the modeled need to be meshed. The mesh sizing is set to as low as 0.0007m, with zero relevance. Lower size of the mesh will result in longer time it took to run the simulation whereas larger size of the mesh could result in error in the simulation. One end of the wire rope is set as fixed support and at the other end, a moment with a magnitude of 0.1Nm is applied. Targeted solution is Total Deformation, Equivalent Stress, Maximum Principal Stress, Equivalent Elastic Strain, and Total angle deflection. Figure 4.2 until Figure 4.5 shows the solutions of the simulation and Table 4.2 shows the summarize result of the single wire simulation.

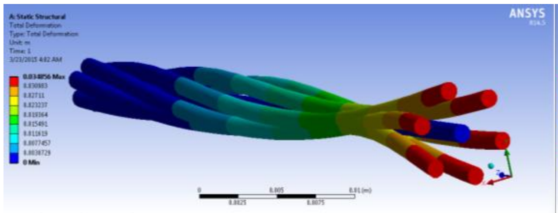

Figure 4.2 Single Wire Total Deformation Solutions

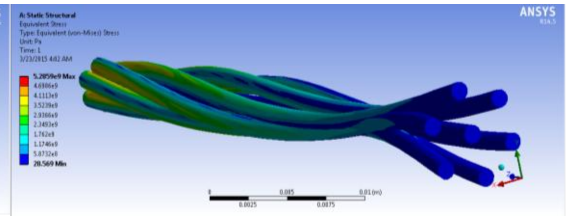

Figure 4.3 Single Wire Equivalent Stress Solutions

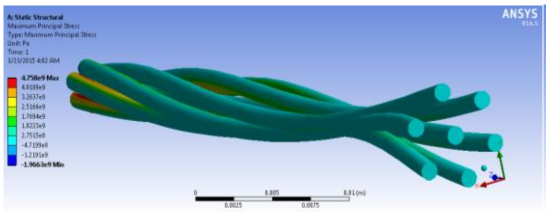

Figure 4.4 Single Wire Maximum Principal Stress Solution

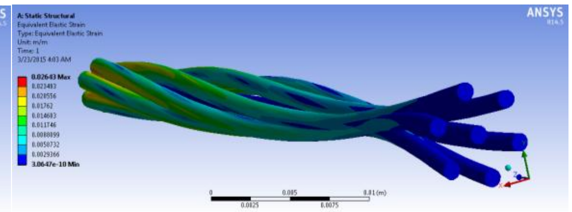

Figure 4.5 Single Wire Equivalent Elastic Strain Solutions

Table 4.2 Results of single wire simulation

Results	**Maximum Value**
Total Deformation	0.0348m
Equivalent Stress	5.2859E9 Pa
Maximum Principal Stress	4.78E9 Pa
Equivalent Elastic Strain	0.0264 m/m
Total Angle Deflection	3.4324°

The simulation is then further proceed with a different configuration of the wire ropes. Combinations of four wire ropes are chosen where it is arranged in two of the wire ropes are in a right hand lay and the other two in a left hand lay. The arrangement is proposed so that the first two of the left hand lay can counteract the other two of the right hand lay. This is because when applied in steering shaft, LSRS will be rotated in both directions to steer the vehicle to turn left or right. Figure 4.7 shows the illustration of the mentioned wire rope configuration and its drawing.

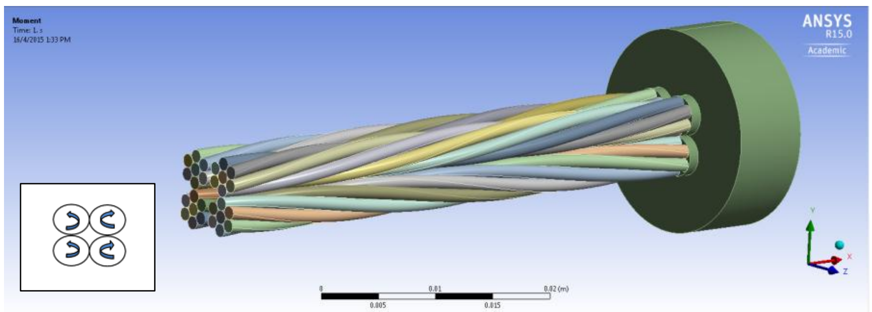

Figure 4.6 Four strand wire ropes

To simulate the 4 strand wire ropes, author attached a cylinder shape holder at both end of the wire rope. It functions to act as one surface body to attach all those wires, which will make the setting to run the simulation much more when selecting one end as fixed support, and applying a moment on another end. This is because it will be easier to click on one body instead of selecting the wire ropes one by one which is a total of 28 (7x4) surface body. On the contact section, any contact involving the cylinder shape holder will be set as “bonded” whereas between the wire ropes will be “frictional” with a coefficient of 0.115 just like on the single wire simulation. The mesh sizing is set to 0.001m, with zero relevance. The targeted solution is same with single wire simulations which are Total Deformation, Equivalent Stress, Maximum Principal Stress, Equivalent Elastic Strain, and Total angle deflection. Figure 4.7 until Figure 4.10 shows the solutions of the simulation and Table 4.3 shows the summarize result of the 4 strand simulation.

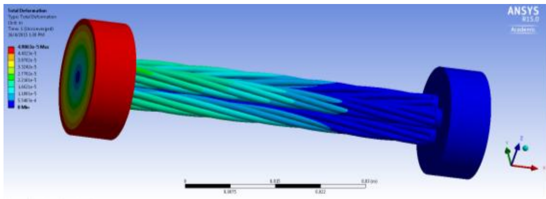

Figure 4.7 Four Strand Total Deformation Solutions

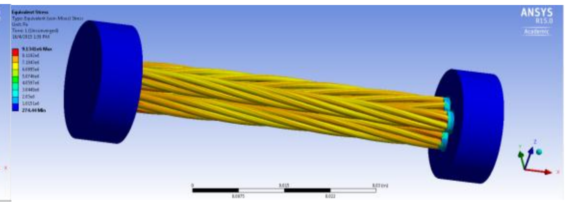

Figure 4.8 Four Equivalent Stress Solutions

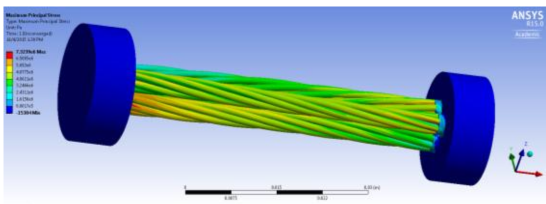

Figure 4.9 Four Strand Maximum Principal Stress Solutions

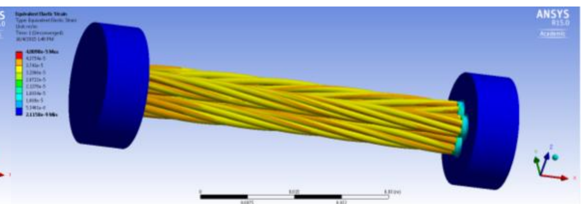

Figure 4.10 Four Strand Equivalent Elastic Strain Solutions

Table 4.3 Results of four strand simulation

Results	**Maximum Value**
Total Deformation	0.0000498m
Equivalent Stress	9.1341E6 Pa
Maximum Principal Stress	7.3239E6 Pa
Equivalent Elastic Strain	0.0000481m/m
Total Angle Deflection	0.4618°

4.3 Validation Experimental Test Setup

Once the pattern or arrangement of the wire rope has been finalized, experiments will be performed on the simulations done earlier to verify its results. Before author come out with an experimental setup, author first study the characteristics of a common torsion test machine such as what specifications, equipment and principals are involve in such testing machine. These machines are quite hard to reach in Malaysia where most type of rope testing machine is tension test machine instead of torsional test machine. Author even contacted Standards and Industrial Research Institute of Malaysia (SIRIM) and they claim that they have no working torsional test machine in their possession. Author then continue to find a test set up to find torsional rigidity of small wires from research papers. Figure 4.11 shows the proposed tension-torsion test for the LSRS.

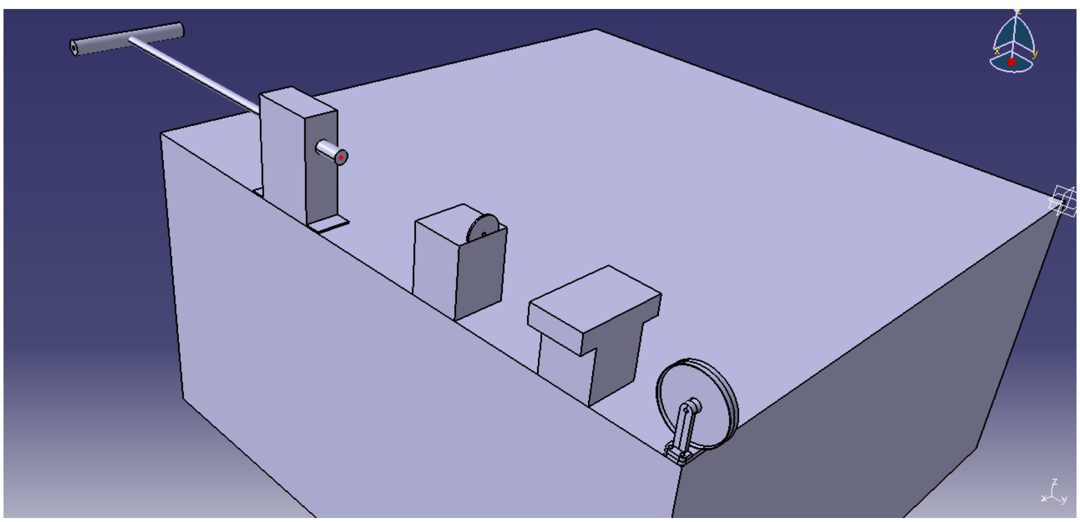

Figure 4.11 Torsion Experiment Setup

Figure 4.11 shows the basic layout of the experiment setup. Dead weight is applied on both ends where the one near the pulley functions to apply tension to the wire rope so that throughout the experiment, the wire rope will be in tension. The dead weight on the steel tube functions to apply torque to the cylinder mild steel which will give torsional force to the wire rope. After the torsional force is supplied to the wire rope, the angle of deflection of the wire rope can be determined using the protractor stand. A cable tie is tied to the wire rope just in front the protractor, and how much angle that it move, can be refer using the protractor. This setup is the most economical because most of the materials are easy to get especially from the hardware store. Despite its low cost compared to others, this setup is also able to provide the information which is in author's interest. This is why this setup is chosen to be fabricated.

4.3.1 The tools which author uses to fabricate this test setup are;

i. 40mm diameter cylinder mild steel
ii. 25.4mm diameter hollow steel tube
iii. Perspex
iv. Protractor
v. Protractor Stand
vi. Cable Tie
vii. Cable Clamp
viii. Pulley
ix. Rope/String
x. Dead Weight

4.3.2 Cylinder Mild Steel

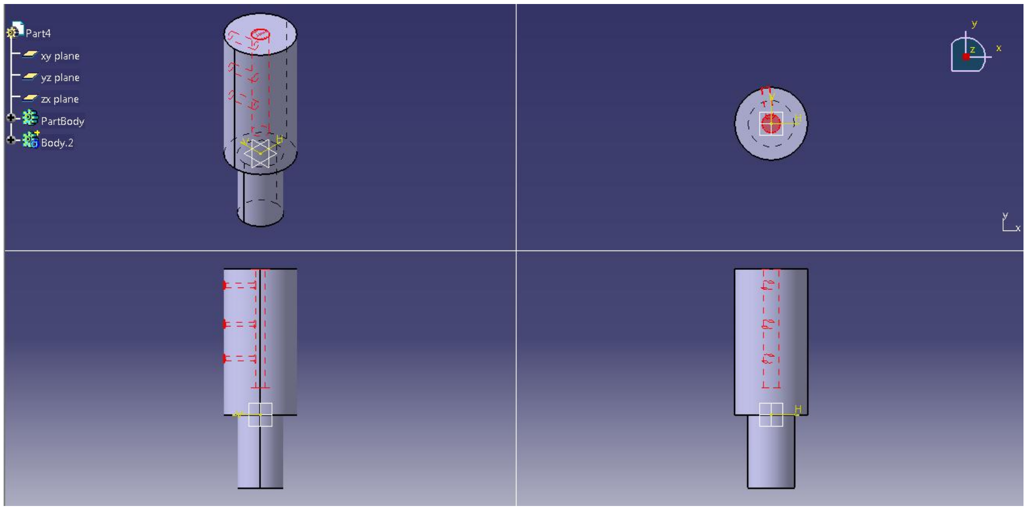

Figure 4.12 Cylinder Mild Steel Specifications

Figure 4.12 shows the specification of cylinder mild steel which will be used in the test setup. The 10mm diameter hole is where the 6mm diameter wire rope will be placed and another three whole is drilled with 2x tap M10x1.5 drill bit. Those three hole function as a space so that the wire rope can be screw so that it will remain in place when torsional force is applied. The cylinder mild steel is welded to the 25.4mm diameter steel tube.

4.3.3 Hollow Steel Tube

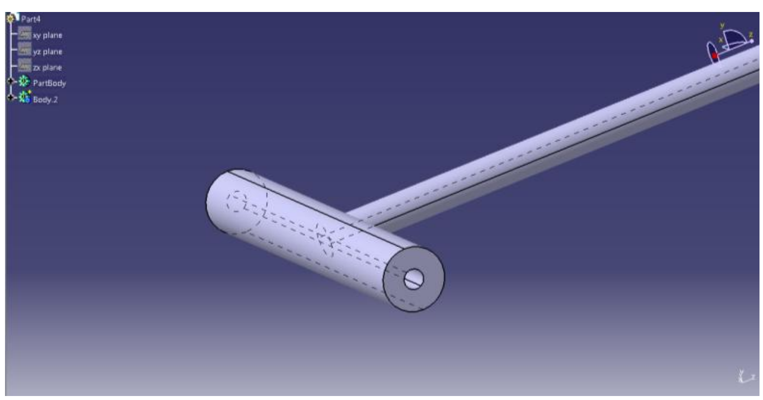

Figure 4.13 Hollow Steel Tube

Figure 4.13 shows hollow steel tube. The reason that it needs to be hollow is so that a string can be passed through it, and a dead weight can be hang at one end which will result in the steel tube to rotates thus act as a moment force applied.

4.3.4 Perspex Box

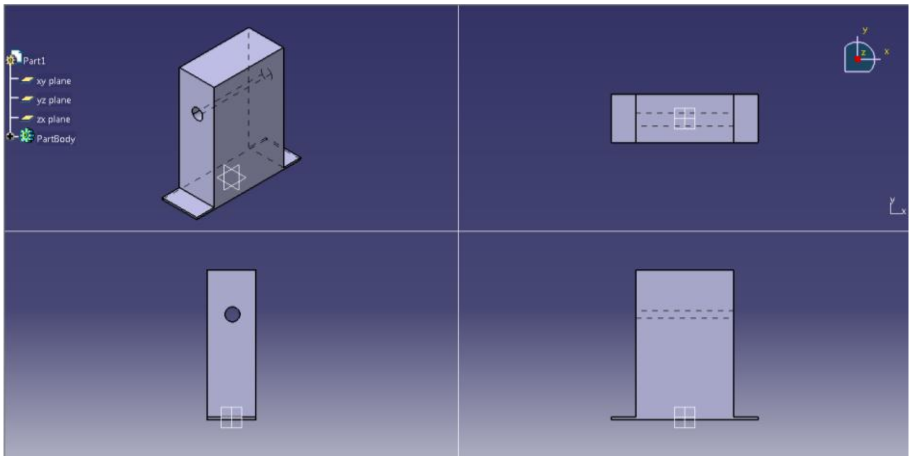

Figure 4.14 Perspex Box Specifications

Figure 4.15 shows the specification of the Perspex Box which is used in the test setup fabrication. The use of the Perspex box is mainly to hold the hollow steel tube where the steel tube will be placed through the two holes on the Perspex box. The extended base of the Perspex box is to make sure that it can be clamped to the table to ensure it will remain static during the experimentation.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Wire ropes are modeled and a configuration of wire rope use in LSRS is simulated in ANSYS™. The idle wire rope configuration that are to be used is LSRS are investigated from FEA simulation.

As compared to a single wire rope, the four strand wire rope gives higher torsional rigidity which are more suitable for LSRS but it is still yet to be confirmed with further experimental and validation. Other than the arrangement and the configuration of the wire rope, the torsional rigidity of the wire rope can also be modify by changing the wire rope parameters such as materials and its diameter.

5.2 Recommendation

It is acknowledged that, this project is fully being done under a working final year student along with guidance from the supervisor and master student assistance in order to achieve specified targets and objectives. To obtain more accurate results, the simulation results needs to be validated via experimental. As for the experiment, it is recommended to use the factory produced torsional machine. Among the options is either to perform the experiment using facilities in Standards and Industrial Research Institute of Malaysia (SIRIM) or to purchase the Torsional Test Machine for University use.

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