UNIVERSITY OF EDUCATION, WINNEBA

EXPERIMENTAL STUDY ON A REDESIGN COIL SPRING COMPRESSOR FOR LIGHT COMMERCIAL VEHICLES

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A Thesis Submitted to the Department of MECHANICAL ENGINEERING TECHNOLOGY, Faculty of TECHNICAL EDUCATION, School of Graduate Studies, University of Education, Winneba in Partial Fulfillment of the Requirements for the award of Master of Philosophy in (Mechanical Engineering Technology) Degree

JUNE, 2021

DECLARATION

STUDENT'S DECLARATION

I, **ACHEAMPONG KWABENA ISAAC**, declare that this Thesis with the exception of quotation and references contained in the published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: ………………………………….

DATE: …………………………………………..

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this Thesis was supervised in accordance with the guidelines established on the supervision of Thesis by the University of Education, Winneba.

NAME: **DR. S. K. AMEDORME**

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DATE: ………………………………………………….

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I own much appreciation and gratitude to the Almighty God who has guided and kept me safe and from the reach of mine adventurers. I also thank Him for the wisdom, knowledge and guidance to successfully complete this programme.

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My appreciation goes to Ing. Dr. Samuel Wiafe, dean faculty of Engineering Sunyani Technical University, Mr. Bernard Aboagye, former HOD, and finally, I am thankful to all authors whose works I have cited.

DEDICATION

Dedicated to my dear wife Mercy Owusu Acheampong and my lovely kids, Nana Akua Asaah, Abena Pinamang and Yaw Owoahene.

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ABSTRACT

This study examined various types of coil spring compressors in the automobile industries. A coil spring compressor for compressing a coil spring during the assembly of subassemblies of automotive suspension systems, having a head jaw positioned above a base and movable with respect to the base. The coil spring compressor is provided with a pair of guide bars suspended from the head plate and on which a slidable carriage is mounted. The carriage carries a pair of compressing assemblies facing each other in the vertical positions and positioned at both the upper and lower parts of the coil spring. Each assembly comprises a pair of compressor arms interconnected with each other. Each compressor arm is provided with a jaw mount to which a compressing hook is adjustably attached. The jaws are introduced between some few successive turns of the coil spring by operating handles provided on the compressor arms. The purpose of this design is to be use on various types of suspension disassembly and assembly of vehicles, the tool includes the upper and the lower jaw which by the smooth turning of the screw lowers to compress the coil spring or turns to release the compressed coil spring. The new design was made from mild steel and tools used for the construction are Electric arc welding machine, power and hand hacksaws, the bench vice, assorted hammers, vice, etc. The findings indicated that the new design is more efficient than the existing one. It was also recommended that car owners who visit the workshop should insist on the use of the right compression tool in the disassemble and assemble of their suspension systems.

CHAPTER ONE

1.1 Introduction

Coil springs, are widely used in motor vehicle industry as one of the primary elastic members of the vehicle suspension system. They are used as a connection between the wheel and the body of the vehicle; they tone down the shocks that would otherwise be transmitted from uneven surface of the road to the body of the vehicle. Nowadays, coil springs are subjected to significantly larger stresses compared to ones used in previous generations of vehicles, and they due to fail which may need replacement or repair hence the analysis of the coil compressor remover. A Coil spring is an integral part of an automobile suspension systems, it is used for the purposes of storing energy and subsequently releasing it when needed (Kong, Abdullah, Schramm, Omar, & Haris, 2018). A coil spring is used in vehicles to absorb shocks and maintain the force between two contacting surfaces, it also maintains the weight of the vehicle together with a shock absorber usually called strut. (Dixon, 2008). Owing to their benefits in weight, durability, space and easiness of manufacture, majority of car manufacturers chooses coil spring other than balloons. Steel alloys are the most commonly used materials for springs but other metals like beryllium copper alloy, phosphor bronze, and titanium rubber urethane may be used for cylindrical non-coil spring(Chen, 2011). Due to the high compressive force required to compress coil springs, a lot of components and devices have been designed in the past to serve the purpose (Rao, Srinivasa, & Reddy, 2015). Almost all the existing coil spring compressors or the existing ones have failed to be reliable, due to the following, uneasiness to be operated by one person, unstableness on the workshop floor, at times trap the fingers of the user, and in some cases in the cause of operation can fly to face of the user there by causing accident to the user as well others. Coil springs usually fail due to many factors which include unprofessional installation and violation of the use of the system. The failed system will have to be installed to normalcy and without the use of one form of spring coil compressor or the other there is no way the system will be installed correctly. Apart from the belt spring coil compressor, the others consist of two jaws, one of which is fixed and the other movable. They must be capable of resisting large forces in particular, axial forces such as those that the coils of an automobile vehicle suspension spring are capable of exerting. Examples of some of the existing coil spring compressors are The Branick 7600 professional coil spring compressor which is used for the heaviest coil over shocks on light cars and SUV's without the need for additional adapters, as it also handles extra torque. Its multi-position upper spring hooks are adjustable up to 4 inches. It was made out of Branick's manufacturing facility in Fargo. This compressor is at times dangerous especially when it is not properly mounted on the walls and per it's design it cannot be mounted free to the workshop floor and this type of compressor is so designed that they can be mobile and can be use everywhere. Another type of a coil compressor is the hydraulic coil spring compressor which is a foot operated coil spring compressor designed for car and van suspension system strut (Tomeze & Hasheesh, 2017). It has adjustable spring retainers and is used on spring diameter of up to 507mm and 550mm, it has a maximum compression of 1000 kg/1 tone. The weight of this device is usually 31.5kg, and this equipment is made to be safe to the user by allowing for safe removal of the spring from the system, though quick and easy but putting them up again to put the top mounting plate on most of the time prove difficult and also takes a lot of the users time and energy.

Furthermore Shankly coil spring compressor is used for compressing strut and other coil spring for passenger and light vehicles providing the user a versatile compressor solution. It has an operating capacity of 300mm and overall length of 300mm. the problem with this type of compressor is that the thread inside of the compressor can strip out to cause the spring violently decompress which can cause an injury to the operator or the environment. An important is this The belt coil spring compressor which is an improvised tool made from a cargo belt (CLB) and an adjuster. It is not an internationally recognized tool for the removal or compressing of spring coils but very popular in Ghana, it is almost used in all workshops in Ghana and by the mechanics and the Technician of the various workshops. Though it is in use, this tool or method of coil spring removal is one of the dangerous method ever existed, per the energy built up in springs when compressed the adjuster does fail or at times when the pressure build up exceed that which the built can contain the belt fail without any given signal. The most common and versatile is the Owatana tools company an (OTC) coil spring compressor which is convenient and affordable, and it fits a wide range of struts and requires no special adapter shoe. Safety locking pins holds the compressor jaws in place. This tool compresses springs of 4 to 9 inches with wire diameter of 7/16 to 11/16 inches built to use with an impact wrench. This tool cannot be operated by one technician, it need two or more persons to be able to operate smoothly and safely. The dangers associated with a coil spring compressor cannot be overstated and therefore there is the need to conduct research on them and design a safe compressor.

1.2 Statement of the Problem

It has been found out from almost all coil spring compressor users that, the operation of the entire coil spring compressor has some problems and they are at times very difficult to operate. That is, it is not easily to be operated and cannot be easily operated by one person. It causes a lot of inconvenience and sometimes causes injuries to the operator(s), it also requires a lot of time to operate. The reason for the inconvenience in operation is attributed to the design and construction of these tools, and this particular belt type of coil spring compressor used mostly in Ghana has the same demerits as the other compressors. It sometimes traps the user or one's finger when the release mechanism is delayed. In some cases, the coil spring flies to the face of the operator when the mechanism fails. This situation poses a lot of danger not to the operator only but also people around the scene. It is therefore important to improve the design of the existing Owanatana coil spring compressor to provide easy and safety operation of the removal of coil springs.

1.3 Aims and Objectives

The aim of this study is to redesign and construct the Owatana coil spring compressor device that will be easily accessible and very cheap in the market compare to the high cost of the existing one on the Ghanaian market and for the local workshops and Mechanics in order to ensure their safety and that of those who visit their workshops. This objective will be achieved through the following specific objectives

1. To redesign the Owatana tool compressor
2. To construct the new design of the compressor
3. To conduct experiment on both the new and the old designs to determine the forces (that is the loads) and the rate of deflection on them.
4. To undertake comparative study on the new spring coil compressor to determined its efficiency and safety.

1.4 Significance of the Study

The study will go a long way to eliminate the problems that are most of the time associated with use of some of the existing coil spring compressors especially the Owatana tool company compressor in use in most of the mechanical workshops and also to eliminate almost all the accidents related to the use of other compressors most especially the OTC 6494 coil spring compressor and the improvised coil spring belt compressor system which is mostly recognized and used in Ghana and most of the time becomes a trap to it users especially when the release mechanism delays. To also make accessible a tool for the Ghanaian mechanical Technician which will be safe and at the same time operated with ease and also improve the time rate of work at the workshop.

1.5 Scope of the Study

There are a lot of coil spring compressors in use in most of the Mechanical or in the Automobile industry, but the research could not cover all of them. However, the study was limited to the redesign and construction of the Owatana tools company (OTC) coil spring compressor due to the limitation of time and resource.

1.6 Organization of the Thesis

This thesis is five chapter research which comprises of chapter one, chapter two, chapter three, chapter four, and chapter five. Chapter one consists of the background to the study, statement of the problem, objective of the study, significance of the study, scope and limitations of the study, and organization of the thesis. Chapter two focuses on the literature review of the various practical works done by others. Chapter three also includes the methodology used in the research. Chapter four covers results and discuss the outcome of the research, while chapter five also gives the conclusion of the research and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

As introduced in the first chapter, that there are a lot of spring coil compressors in use, simple structure, low cost, effectiveness and compact design have led the Owatana Tool Company compressor to become one of the popular compressor type in use. The main disadvantage of this is that it does not have a supporting stand hence difficult to be operated by one person. In order to have full understanding of this work, a practical review on the various works and types of coil spring compressors in use shall be considered. This chapter discussed thoroughly a number of coil spring compressors in use in the field of the Automobile industry and one will clearly see that a lot of work has been done to improve upon the design and operation of the various coil spring compressors over time. The research done by other persons which are related with this research were discussed. The facts from their research were used to guide this research in correct way. The source came from the journals wrote by the previous researchers. Their theory and results help this research as they can be a comparison between this research and theirs.

2.1 Suspension System

A car suspension system is the mechanism that physically separates the car body from the wheels of the car (Sam, Y M 2007). Basically, this system consists of two main parts. They are the suspension spring and the shock absorber. A suspension must be able to minimize the vertical force exerted to the passengers in the car. Sam, Y M (2007) also said that to achieve minimum vertical force, the vertical car body acceleration must be minimized. The suspension system can be categorized into passive, semi-active and active suspension system according to external power input to the system and/or a control bandwidth (Appleyard & Wellstead, 1995*)*. From the figure below, these three systems can be differentiated. Figure 2.1 shows a passive suspension system which is a conventional suspension system that consists of a non-controlled spring and shock-absorbing damper. For the semi-active suspension, it has the same elements as the passive suspension system but the damper has two or more selectable damping rate. The system is illustrated in Figure 2.2. For the third type, the active suspension is one in which the passive components are augmented by actuators that supply additional force. Figure 2.3 shows the mechanism of the active suspension system.

2.1.1 Passive Suspension System

Passive suspension system is used widely by commercial vehicles nowadays to control the dynamics of a vehicle's vertical motion as well as pitch and roll. The word passive is used to explain that the suspension elements cannot supply energy to the suspension system. This system controls the motion of the body and wheel by limiting their relative velocities to a rate that gives the desired characteristics. Some type of damping element need to be used and be placed between the body and the wheels of the vehicle. The damping element can be like a hydraulic shock absorber. An early design for automobile suspension system focused on unconstrained optimizations for passive suspension system which indicate the desirability of low suspension stiffness, reduced unsprung mass, and an optimum damping ratio for the best controllability (Thompson, 1971). Thus the passive suspension systems, which approach optimal characteristics, had offered an attractive choice for a vehicle suspension system and had been widely used for car. However, as mentioned before, the suspension spring and damper do not provide energy to the suspension system and control only the motion of the car body and wheel by limiting the suspension velocity according to the rate determined by the designer. This gives a meaning that the performance of a passive suspension system is variable subject to the road profiles.

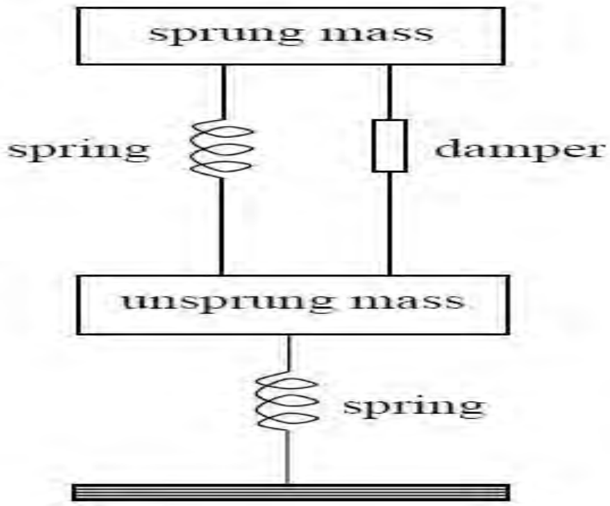


Figure 2.1: The Passive suspension system

Source: Yahaya (2006)

2.1.2 Semi-active Suspension System

Based on the Figure illustrated in Figure 2.1, the semi-active suspension system is just look like passive suspension system. Sam, Y M (2007) mentioned that in early semi-active suspension system, the regulating of the damping force can be achieved by utilizing the controlled dampers under closed loop control, and such is only capable of dissipating energy. As shown in the Figure 2.2, this system uses two types of dampers which are named as the two state dampers and the continuous variable dampers. A major problem was detected from this system. Sam (2006*)* again said that while this system controls the body frequencies effectively, the raped switching, particularly when there are high velocities across the dampers, generate high-frequency harmonics which makes the suspension feel harsh, and leads to the generation of unacceptable noise.

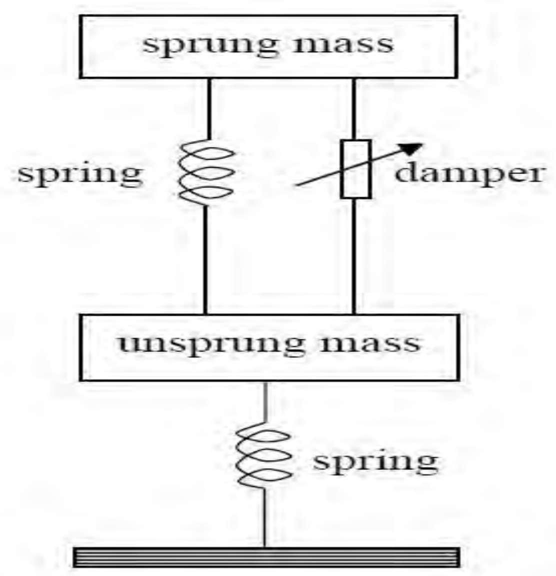


Figure 2.2: Semi-active suspension system

Source: Yahaya (2006)

2.1.3 Active Suspension System

Sam and Yahaya (2007) mentioned that the active suspensions have been divided into two categories, the low-bandwidth or soft active suspension and the high-bandwidth or stiff active suspension. The major difference between these two categories is the position of the actuator. From the figure below (Figure 2.3), the actuator for low bandwidth or soft active suspensions is located in series with a damper and spring. This figure explains that the wheel hop motion is controlled passively by the damper so that the active function of the suspension can be restricted to body motion. This type of system is good for improving the ride comfort. For the other categories, the high bandwidth of stiff active suspension, the actuator is positioned to be in parallel with the damper and spring. It is shown in Figure 2.4. The actuator connects the unsprung mass to the body, thus it can control both the wheel hop motion and also the body motion. The advantage of this system is it can improve both the ride comfort and ride handling simultaneously. When compared to a low bandwidth suspension system, it only improves the ride comfort. This explains why a high bandwidth type is being studied more than a low bandwidth type.

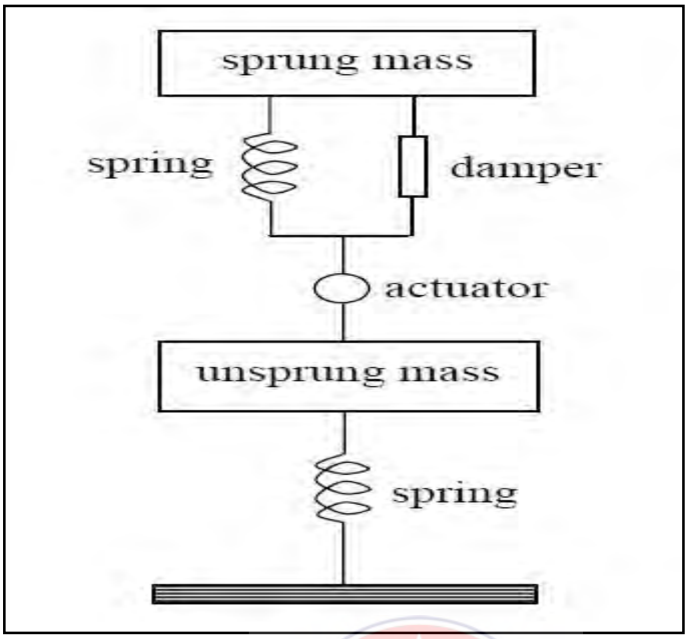


Figure 2.3: A low bandwidth of soft active suspension system

Source: Yahaya (2006)

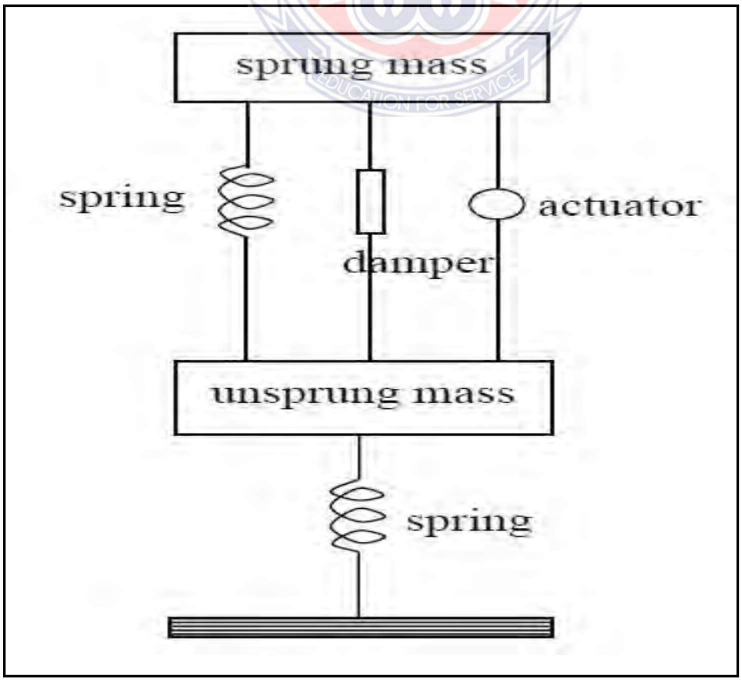


Figure 2.4: A high bandwidth of stiff active suspension system

Source: Yahaya (2006)

In automotive industry nowadays, the type of suspension system used is the active suspension system with a high bandwidth. This is justified by Sam (2006) as he mentioned that this type of suspension system is used in this country because it can give both good stability and also the riding handling and comfort. He also said that this type of suspension system is widely developed by engineers because it still can be improved. In our country, the main automotive industry is PROTON. Following the latest technology, the PROTON used this type of suspension system to be installed in their vehicles. This can be justified from PROTON website regarding their research and development department.

Spring and strut

Generally, a mechanical spring is defined as an elastic body whose mechanical function is to store energy when deflected by a force and to return the equivalent amount of energy on being released. This spring need to have the mechanical properties which are required by a suspension spring. Springs are crucial suspension elements in cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities (Shokrieh, Mahmood & Davood 2003). The function of the suspension spring is to maintain good control stability and to improve riding comfort (Watanabe, 2001). Types of springs are Tension/extension spring, compression spring, torsion spring, constant spring, variable spring, and variable stiffness spring. Springs are storage devices for mechanical energy, think of them as analogous to batteries (Alami, and Abdul, 2020). The earliest spring driven clocks appeared in the 1400s, fast forward some 600 years one still have to charge the watch every day and it's not nearly as fast as winding a clock. The main function of a spring is to store energy and release it when necessary and function under the right load (Myong, et al, 2007). The most common types of springs are coil springs. These are made of round wire and include compression, extension, and torsion springs. Spring wire forms are spring wires formed in a bracket-like manner. They can assist in storing energy and release it due to their shape. These are not coiled nor have a cylindrical shape, rather they are curved and/or have concave shapes that allow them to be attached to a load and absorb energy or force (Rebek & Julius, 2009). Spring leafs are one type of wire form that has been around for ages. Spring leaves where made out of flat wire that was curved to form an arc and was used in a suspension like manner for carriages and other heavy loads.

A strut is a structural component commonly found in engineering, aeronautics, architecture and anatomy. Struts generally work by resisting longitudinal compression, but they may also serve in tension (An & Draughn, 1999). The strut is a common damper type used on many of today's independent suspension, front wheel drive vehicles as well as some rear wheel drive vehicles.

A strut is a major structural part of a suspension. It takes the place of the upper control arm and upper ball joint used in conventional suspensions. Because of its design, a strut is lighter and takes up less space than the shock absorbers in conventional suspension systems. Struts perform two main jobs. First, struts perform a damping function like shock absorbers (Song, 2004). Internally, a strut is similar to a shock absorber. A piston is attached to the end of the piston rod and works against hydraulic fluid to control spring and suspension movement. Figure 2.5. Just like shock absorbers, the valving generates resistance to forces created by the up and down motion of the suspension. Also like shock absorbers, a strut is velocity sensitive, meaning that it is valves so that the amount of resistance can increase or decrease depending on how fast the suspension moves (Dixon, 2008). Struts also perform a second job. Unlike shock absorbers, struts provide structural support for the vehicle suspension, support the spring, and hold the tire in an aligned position. Additionally, they bear much of the side load placed on the vehicle's suspension. As a result, struts affect riding comfort and handling as well as vehicle control, braking, steering, wheel alignment and wear on other suspension.

Figure 2.5: Types of coil springs (a) Coil spring (b) Strut (c) Pre-assembled unit

2.2 Spring Dimension

In producing spring, there are 3 main dimensions that need to be focused on. These dimensions are the parameters that affect the behavior of spring (Bakhshesh, et al., 2012). Usually, for each country, it will set the standard dimension for the spring that will be installed in the vehicle produced inside the country. The 3 dimensions are the wire diameter (*d*), loop diameter (*D*) and the distance between two consecutive loops or known as pitch (*P*). For better understanding, the dimension is illustrated as in the Figure 2.6.

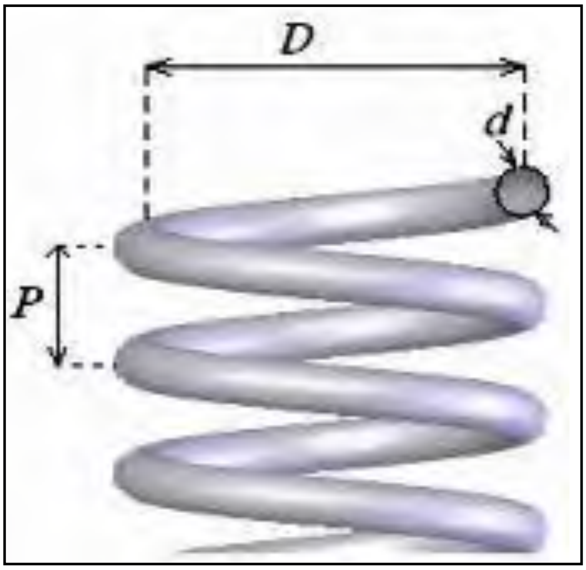


Figure 2.6: Parameter of helical spring

Bakhshesh, et al (2012) used the dimension listed in Table 2.1 for his research which he claimed as the standardize dimension. The wire diameter for suspension spring is 13 mm and it is proved by Bakhshesh statement and also from the dimension of the suspension spring measured in the laboratory. The sample used was a suspension spring from PROTON car.

Table 2.1: Spring specifications

Parameter	Value
Wire diameter (d)	13 mm
Mid diameter (D)	145 mm
Spring height	440 mm
Maximum force	3000 N

Table 2.2: PROTON car spring specifications

Parameter	Value
Wire diameter (d)	13 mm
Mid diameter (D)	145 mm
Spring height	400 mm

From the above tables, the wire diameter (*d*) and coil diameter (*D*) are the same. It shows that these dimensions are already used in automotive industry in our century. The dimensions above can be classified as the optimum dimensions because they are used in manufacturing the suspension springs. The dimensions in Table 2.1 and Table 2.2 were then compared with Tawfik, et al (2009) proposed dimension. Tawfik, et al (2009) also chose the dimension as close as Baksheih, et al (2012). The coil diameter (D) that he used was 150 mm while the wire diameter was varied from 13 to 20 mm. The other dimension for wire diameter chosen was 12 mm which was chose by Tse (1994). Das (2006) uses 10 mm of wire diameter in his study of steel spring. Another research done before chose the wire diameter to be 11 mm was used by Michakczyk (2009). Gopinath (2012) select the wire diameter to be 10 mm. From the research done by Stoicescu (2009), the optimum wire diameter that he obtained was 14.81 mm. Other than that, Mallick (1987) chose 4 inches or equal to 10.16 mm as the wire diameter. 14.62 mm wire diameter was selected by Yong (1998). In the laboratory, the suspension spring provided was from PROTON car. The suspension spring was examined and measured. The wire diameter of the spring was 13 mm. Thus, for this research, the wire diameter (d) will be manipulated.

In this research, the dimension parameters will be the main factor that will be discussed. From the literature by previous researchers, many of them manipulate the dimension of the wire diameter (*d*). This is because the coil diameter cannot be adjusted without changing the socket at the wheel and the car body. Basically, the suspension spring is located between the wheel and car body. If the diameter of the coil being manipulated, it can cause the suspension spring not to be installed into the vehicle. Every vehicle that used suspension spring will have a socket at the wheel where the suspension spring will be attached. The socket will be in constant size so the diameter cannot be easily changed without considering the size of the socket at the wheel and also of the body of the car. Das (2006) mentioned that the design parameters of a coil spring are the rod diameter, spring diameter and the number of coiled in the form of helix.

2.3 Spring Material

From history, the gasoline-powered automobile can be traced back to 1870, when the first car was made in Austria; the mass production of cars did not start until the early 1900s both in Germany and in the United States. The first automotive coil spring was installed on the Model-T Ford in 1910, where the suspension combined the leaf spring and the coil spring. The earliest coil spring material had approximately a 500 MPa design stress level (Prawoto et al., 2008). Nowadays, it is common to have a coil spring with a design stress of around 1200 MPa.

Talib (2009) said that, in making the suspension part, fiber-reinforced polymers have been vigorously developed for many applications, mainly because of the potential for weight savings. Fiber-reinforced polymers have many advantages compared to steel such as (a) the possibility of reducing noise, vibrations and ride harshness due to their damping factors; (b) the absence of corrosion problems, which means lower maintenance costs; and (c) lower tooling costs, which has favorable impact on the manufacturing costs. If a steel part is replaced with a composite-based part, it will yield a significant weight savings (Talib, 2009). However, the manufacturing of composite material is complicated and yet to be achieved in successful result. This is why many engineers take the opportunity attempting to design a composite spring or suspension.

2.4 Coil Spring Compressors

The Owatana tools company in 2018, also came about with this coil spring compressor that is convenient and affordable; it fits a wide range of struts and requires no special adapter shoe safety locking pins which holds the compressor jaws in place (Bujok, Klempa, Yakubchik, Ryba, & Porzer, 2018). This tool compresses springs of 4 to 9 inches with wire diameter of 7/16 to 11/16 inches built to use with an impact wrench. Figure 2.7. Though is convenient and affordable, its stability on the workshop floor is a big setback of this tool and it cannot be operated by one person and this make the use of this tool uncomfortable.

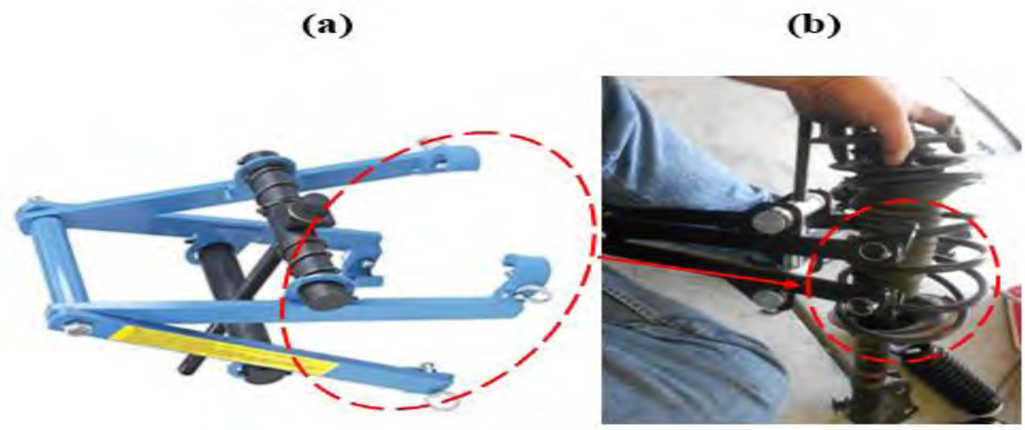


Figure 2.7: (a) OTC Coil spring. (b) Fitted with a coil spring

Stanley M. Pace invented a tool for coil spring compression in 1962 (Pace, 1962). His invention came as a result of the realization of the need to get a tool for the purpose of coil spring compression. This invention comprised of a cage which had corner angle irons secured together at the upper end by peripheral frame members and connection frame members cast as an integral unit. The compressor arm slides for adjustment, employing a locking pin for rapid, easy operation (Shah, 2018). This tool was mainly used to compress heavy duty coil spring and the problem was that it could not be used on lighter vehicle coil springs. Figure 2.8.

A B

Figure 2.8: Stanley M Pace coil spring

Tsuyoshi Matsuura did a research to produce a compressor which had its fingers independently device having relatively few parts whereby a coil spring of the type conventionally used in connection with shock absorbers or the like for motor vehicles may be readily and conveniently compressed for its removal, insertion or replacement (Matsuura, 1985). The vertical positions of the push-down fingers were independently and readily adjusted relative to the coil spring to be assembled. It was later proposed that a head plate should be mounted on top of a vertically slidable drive shaft which was to be driven by a motor through a clutch (Princi, 2019). His prime objective was to provide a very practical, efficient and economical compressor coil spring compressor. On a coil spring compressor which utilized a vehicle gear drive assembly (Figure 2.9).

In his work, patented in May 1985 (Lala, Lehnerer, Hanson, & Stevens, 1987) the spring compressor included a pair of elongated parallel threaded guide shafts having an upper spring engaging shoe secured to the upper end thereof and a lower support link secured at their lower ends. The gear drive assembly was mounted on the guide shafts intermediate the upper spring engaging shoe and the lower support link and was utilized to support a lower spring engaging shoe in spaced apart, facing relationship with the upper spring engaging shoe{Bujok, 2018 #44}. In his findings, he stated that a helical drive arrangement was provided for simultaneously relating the two sleeves to cause the helical gear assembly to move along the guide shafts. Figure 2.10.

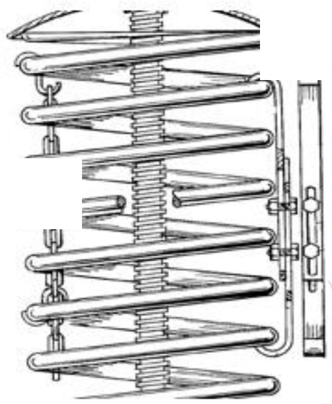


Figure 2.9: Tsuyoshi Matsuura coil spring

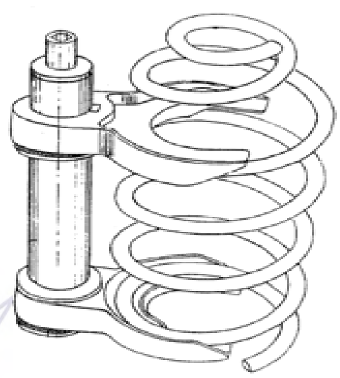


Figure 2.10: Gear drive coil spring.

In 1985 Yuji Ito Filed to construct a coil spring compressor in which the vertical position of clamping fingers was readily adjusted (Ito, 1985). That could have included a head plate which was positioned above a base and movable with respect to the base. It was explained that each clamping assembly comprises a pair of clamping arms interconnecting with each other so that the clamping fingers provided at the inner free ends of each arms extend toward the coil spring to be introduced between two successive turns of the coil spring. The findings indicated that one of the clamping arms of each pair has an operation handle which served to the vertical adjustment of the clamping finger position as well as to the opening and closing movement of the clamping arms (Zou, 2016 #51). Shown in figure 2.11. In 1953 Perkins conducted a research into axially compression of helical springs (Perkins, 1953). His work centered on a compressor which was used to axially compress springs. His work proved that a more efficient compressor is one which provides a very practical, efficient and economical device having few parts. His findings showed that, such a device could be used to compress coil springs in any position in order that a mechanic can remove any component of the knee action assembly without the pressure of the spring interfering with the work being performed on the knee action assembly (Toxiri et al., 2019). See figure 2.10. In 1923 Michael Dossier**,** the researcher presented a work on a compressor which was simple and cheap so that even low income earners can afford (Harold, 1923). He seek to produce a compressor which include two Jaws, one of which is fixed at one end of a guide tube, while the other jaw is slidably mounted on a tube and connected to a slide provided with a radial finger member in the shape of a wedge extending through a slot in the tube. His findings were that, each of its jaws should comprise a body from which extend two arms and constituting claws or clamps having a shape and dimension which corresponds to those one of the coils spring to be compressed (Thakur, 2019). Shown in Figure 2.11.

Figure 2.11: Yuji Ito Compressor tool

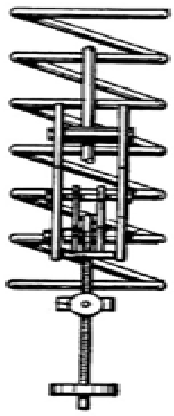


Figure 2.12: Hans coil spring

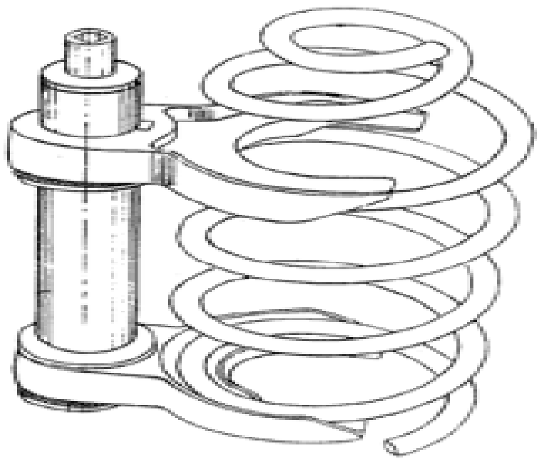


Figure 2.13: Slidable coil spring

In 2017 Young delve deeply into The Branick 7600 professional compressor, this type of coil spring compressor as shown in Figure 2.14 Branick 7600 professional compressor, used for the heaviest coil over shocks on light cars and SUV's without the need for additional adapters, as it also handles extra torque (Young, 2017). Its multi-position upper spring hooks are adjustable up to 4 inches. It was made out of Branick's manufacturing facility in Fargo, ND. The Branick 7600 professional compressor.

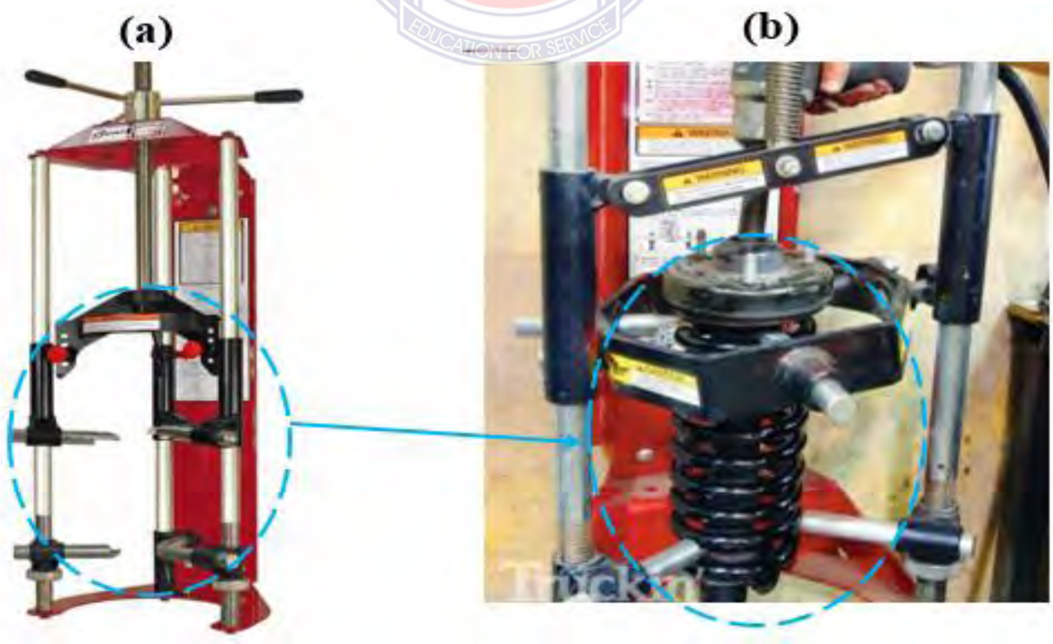


Figure 2.14: (a) Branick 7600 professional. (b) Compressor in operation.

The hydraulic coil spring compressor this tool is a foot operated coil spring compressor designed for car and van suspension system strut (Tomeze & Hasheesh, 2017). It has adjustable spring retainers and is used on spring diameter of up to 507mm and 550mm, it has a maximum compression of 1000kg/1 tone. The weight of this device is usually 31.5kg. Images of the hydraulic coil spring compressor both without and with a coil spring are shown in Figure 2.15 (a) and (b) respectively.

Figure 2.15: (a) Hydraulic coil spring. (b) Tool in operation

Shankly spring coil compressor, this is used for compressing strut and other coil spring for passenger and light vehicles providing the user a versatile compressor solution. It has an operating capacity of 12 inch and overall length of 12 inch (Edsall, 2017). They are used individually and when not set correctly it makes its uses very difficult, at times it needs an expect or a skilled technician to be able to operate it, and at times the compressed coil in the tool can fly and that makes it unsafe to the environment and the user, as shown in Figure2.16.

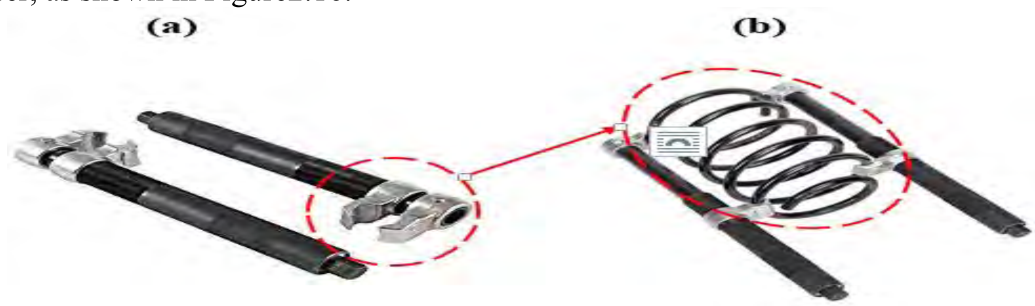


Figure 2.16: (a) Shankly spring. (b) Fitted with a coil spring.

The belt coil spring compressor, as shown in Figure 2.17 is an improvised tool made from a cargo belt (CLB) and an adjuster (Liu, 2020) It is very well recognized tool for the removal or compressing of spring coils in Ghana, it is almost used in all workshops in Ghana and by the mechanics and the Technicians in the various workshops.

Figure 2.17: (a) Belt coil spring. (b) Fitted with a coil spring

There are many patents on the various design of spring coil compressor of Owatana company tool compressor. However, details of the most of these patents which include the design studies are not accessible. Therefore the accessible information about these patents will be mentioned in this chapter. Between 1976 and 1977 a patent with the number US4009867A introduce an improved coil spring compressor for use in the assembly of automotive suspension systems, the said coil spring compressor being of the type in which a movable head plate is provided above a base for movement toward and away from said base to compress a coil spring mounted on a suspension strut which forms part of the suspension system to be assembled and which is secured to said the base, wherein the improvement comprises a pair of spaced guide bars connected to and pending from said movable head plate, a slidable carriage mounted on said guide bars for sliding movement and a pair of compressing assemblies mounted on said carriage opposite with one another at both sides of said coil spring, each of these compressing assemblies comprising a pair of compressor arms pivoted to the carriage and provided, respectively, with a finger mount at the inner free end thereof, compressing finger assemblies adjustably attached to the corresponding finger mounts, and means for independently adjusting relative positions of the finger assemblies to the associated finger mounts, one of this compressor arms being provided with an operating handle, and the compressor arms being interconnected with each other so that on actuating one arm by the handle the finger assemblies on both arms conjointly extend toward the coil spring to engage between any desired successive turns of the coil spring.

From 1977 to 1978 a U.S. patent with the number US4105188A invented a coil spring compressor which had a adjusting means of comprises adjusting bolts rotatably held in and by the associated finger mounts and screw-engaged in the finger assemblies and wherein the said finger assemblies are held movable along the longitudinal directions of the adjusting bolts without rotation together with the latter, so that the rotation of the adjusting bolts causes the finger assemblies to move in the longitudinal directions of the adjusting bolts.

The Japanese patent number JPS56109826A which came into being in the year 1980 to 1981 A coil spring compressor according to the invention has two finger assemblies, which comprises a hook-like finger which engage the coil spring to compress the same, and a shaft having a threaded hole in which the associated adjusting bolt is screwed.
In same year of 1980 to 1981 a U.S patent with the number US4295634A came out with a coil spring compressor where according to research, each of said finger assemblies comprises a threaded portion on which a fastening member can be screw-engaged.

According to patent number DE3021084A1 dated between 1980 and 1981 A coil spring compressor was invented which has two fingers mounts comprises an elongated hole through which the shaft of the associated finger assembly extends and which allows the movement of the associated finger assembly in the longitudinal axis direction of the elongated hole within a predetermined limit. Numerous spring coil compressors have been developed over the years with some having challenges, The objective of the present invention is to provide a coil spring compressor in which the vertical positions of the push-down fingers may be independently and readily adjusted relative to the coil spring to be assembled.

According to the present invention, there is provided a coil spring compressor of the kind described in the cop ending application mentioned above wherein the push-down fingers are adjustably connected to the corresponding compressor arms so as to allow independent adjustment of the relative positions of the push-down fingers to the corresponding compressor arms and thereby to allow all of the fingers to come into engagement with the associated portions of the coil spring.

With this arrangement, if any one (or two) of the fingers does not come into engagement with the coil spring despite that the remaining fingers being in engagement, it is possible to adjust the finger or fingers in question to enable all the fingers to come into contact with the coil spring.

Further properties of the invention will become apparent from the detailed description given in chapter three below. When literature is researched about this topic it is observed that coil spring forms which have the capability of being compressed by other forms of compressors. Other researchers have made contributions about the design of an independent arm compressor but none have thought of making the Owatana tool compressor and independent one that can be freely mounted on the floor for effective compression.

2.5 Previous Studies on Coil Springs

As introduced in the first chapter; simple structure, low cost, and compact design have led MacPherson strut suspension to become one of the most popular suspension types. Main disadvantage of the MacPherson suspension is the side force on the damper that increases friction between damper parts and resulting in degraded ride comfort. The traditional method of assembling and disassembling is the use of different types of compressors in existence, however the packaging size of inclined spring is limited and this solution restricts the elimination of lateral forces at the desired level. Therefore, a new spring type which is called side load spring was developed in the early 1990's. Side load springs are special type of springs which prevent the reduced ride comfort and increased wear of damper parts by generating anti side forces.

There are certain publications about the reduction of side load on the damper in MacPherson suspension and the design procedures about the load placed on spring coils. In this part, researchers who have contributed to the topic and their studies are examined.

In 1994, Muhr, ünscche, Biecker, and Schnaubelt introduced advantages of side load spring to reduce the lateral force in MacPherson strut suspension (ünsche, Muhr, Biecker, & Schnaubelt, 1994). Their research was based on physical models and results of experimental studies showed the improvement in body acceleration and damper stroke which proved the effect of the new spring in ride comfort performance. However, their research was about only an existing side load spring and objective of their research is to determine the performance character of this side load spring. Further they did not provide any information about how to design a side load spring with desired characteristics.

In 1996, Suzuki, Kamiya, and Imaizumi introduced the FEA model for the side load spring and investigated the effects of structural parameters like number of free coils and slenderness ratio to the spring characteristics (Suzuki, Kamiya, Imaizumi, & Sanada, 1996). They also discussed the methods of the arrangement of setting position of spring and the arrangement of tilting angle of spring seat for reducing side force. There were many FEA models and experiments to validate the analyses; however, the research was still limited within the analysis of performance characteristics.

In 2000, Gotoh and Imaizumi used mechanical dynamics and FEA software in common to perform the design procedure and analysis of friction of the damper in their study (Gotoh & Imaizumi, 2000). In their paper, a FEA model for the side load spring and spring seats were built to study the effects of spring end coil angles and seat angles on the reaction force line of the side load spring. Then a new design procedure combining mechanical dynamics with FEA software was introduced. Finally, they compared the reaction force axis and frictions of suspension of new design with conventional springs to show the advantage of side load spring. However, the design procedure was not represented fully, and some improvements still need to be discussed for the design procedure part of this paper, especially to design a side load spring for an existing MacPherson suspension.

In 2001, Hamano and Nakamura offered L-shaped coil spring to reduce the friction on the MacPherson strut suspension system (Hamano, Nakamura, Enomoto, Sato, Nishizawa, & Ikeda, 2001). They explained the calculation method to determine the load axis firstly and applied to L-shaped spring. Then, they tried to validate the calculations by experimentally and using FEA and to see the effects of L-shaped coil spring to reduce the friction. However, their study was about only L-shaped form of side load springs and was not including the other shape forms and design methods, besides the offered FEA model was primitive.

In 2002, Nishizawa, Ikeda, Logsdon, Enomoto, Sato, and Hamano investigated the effects of rubber seats on coil spring force line (Nishizawa, Ikeda, Logsdon, Enomoto, Sato, & Hamano, 2002).They used FEA models for comparing the metal and rubber seats. This paper was only about the spring seat effects on the load and can be accepted as a supportive study for the design and analysis of load on springs.

In 2006, Nishizawa, Ruiz, Sakai, and Ikeda introduced a parametric study which investigated the effect of spring force line on vehicle self-steer for a MacPherson strut suspension system (Nishizawa, Ruiz, Sakai & Ikeda, 2006). Their study was not directly related to loads in spring coils but reducing lateral forces but it was helpful for the controlling of the spring force line. They developed a mathematical model of suspension system to obtain ideal force action line which minimizes self-steer of vehicle. Their study did not cover any aspects of designing loads on coil spring; on the other hand, their mathematical model and calculations may be useful while developing the mathematical model for load on coil springs springs.

In 2010, Ryu, Kang, Heo, Yim, and Jeon developed analytical processes for the design of a coil spring to reduce side load in MacPherson strut type suspension (Ryu, Kang, Heo, Yim, & Jeon, 2010).They constructed a kinematic model of the suspension to calculate and optimize spring force line to minimize the side load. At last, some experiments were carried out to validate the analysis results for spring force line and some other parameters like stiffness, stress and fatigue life. In their study, they investigated an S-shaped coil spring and focused on fatigue life of side load spring; however no mathematical model was offered for the centerline curvature of S-shaped coil spring.

In 2010, Choi, An, and Won introduced a study that included the design of pigtail coil springs (Choi, An, & Won, 2010). This study was not directly about acting load on coil springs; however design of pigtail may be combined with loads on springs. In 2012, Joshi and Chhabra developed a mathematical model *to* find piercing points and design the profile of side load springs (Joshi, & Singh2012). Their model was very useful particularly for the determination of upper and bottom piercing points. On the other hand, mathematical model to design the center curve of the side load spring was just an extension of the study of Liu (Liu, Zhuang, Yu, & Lou, 2008). There are many patents on coil spring designs and related to reduction of side loads on the damper of the MacPherson suspension. However, details of the most of these patents which include the design studies are considered here. Therefore, the accessible information about these patents will be mentioned in this section. In 1989, the U.S. patent with the number of 4883288 is one of the oldest studies about side force problem on suspension strut and aims to eliminate bending moments caused by side forces on the suspension strut rod; however, the method in this invention is the usage of bracket as a lateral support and side load spring phenomena was not an option in those years yet (Finn, Bottene, Fader, Steven, Doyle, Williams, Saieg, Lasic & King, 2004).

The U.S. patent with the number 4903985, whose invention year is 1990, is possibly the first study which offers to use spring with a curved or "S-shaped" spring centerline as a solution of lateral forces on the MacPherson strut. Inventors explain the situation very clearly and this invention can be assumed the oldest guiding study for side load spring works (Muhr & Schnaubelt, 1990). In 1992, the European patent with No 0225271 B1 is another study that addresses the problem of load on the MacPherson strut and it offers the solution of using air spring for reducing side effect of load. However, this invention is no more than a similar method of mounting coil spring with and offset or angle to the damper rod. This invention is the modified version of U.S. patent with the number of 4688774, and there are some extensions when compared to previous version (Armuth, 1992). And (Ivan & Armuth1987). In 1995, the U.S. patent with the number of 5467971 is another one of the studies about side load compensation in MacPherson strut suspensions. The inventors used the inclined spring seat to reduce not only the suspension strut friction and also steering friction caused by side loads on the suspension. The reduced steering friction is the main aspect of this invention. U.S. Patent with the number of 5454585 A was published just a few months ago from US 5467971 and proposes nearly the same design (Hurtubise, Perry, Kudla, & Armstrong, 1995), and (Dronen & Hellyer, 1995).

In 2001, the design of coil spring with curved centerline is offered in patent US 6328290 B1. In this invention, helical spring with a curved coil axis at a predetermined radius of curvature in unloaded state is proposed and various additional options are also added this curved coil spring like tilted end coils or pigtail end coils. This patent is one of the most inclusive studies that give information about side load spring and its design. Later, this invention is modified a little bit and published as US 6712346 B2 (Imaizumi, Aoyama, Kamila, Gotoh, & Irie, 2001), and (Imaizumi, 2004).

The U.S. patent with the number of 6375174 B2, which is offered as an invention in 2002, is another study that covers the design steps and options of a side load spring that enables to reduce side force on the damper rod. Side load spring is defined as C shaped coil spring in this study (Hasega & Imaizumi, 2002). In 2002, the U.S. patent with the number of 6481701 B2 offers a coil spring with varying coil diameter. In this study, inventors took the advantage of compactness of varying coil diameter when compressed and side load absorbing capability due its shape (Kessen & Fanson, 2002). In 2003, side load spring design is proposed in a U.S. patent No 6616131 B2 by using pigtail coil springs on the end coils and tilting these end coils to provide a centerline which has an offset to coil axis. Also, the effects of changing the tilting angles on the upper and lower end coils are investigated in this invention. This patent application was done by the one of the inventors of U.S. patent with No 6328290 B1 and invention is also very similar to that invention (Imaizumi, 2003), and (Imaizumi, Aoyama, Kamiya, Gotoh & Irie, 2001).

In 2004, the patent with publication number of US 2004/0169324 A1 proposes an invention that offers a strut assembly which minimizes the lateral load and undesired moment that causes sticking suspension. In this invention, inventors used the C shaped coil spring to eliminate lateral forces on the suspension. The patent with the publication number of US 2004/0169323 A1 patent is also taken by the same inventors and nearly the same invention is proposed in this study. In 2005, same inventors published another invention similar to previous study with the U.S. Patent No 6883790 B2 (Bottene, Fader, Steven, Doyle, Williams, Saieg, Lasic, & King, 2004), (Bottene, Fader, Steven, Doyle, Williams, Saieg, Lasic, & King, 2005). In 2004, in the patent with the number of US 20040178601 A1, a method that uses a second spring for absorbing lateral forces is invented. Inventors also mentioned curved helical coil spring as a solution for eliminating lateral loads, however difficulty of altering the shape of the spring and probability of insufficient results push them to solve this situation in a different way (Bottene, Fader, Doyle, Williams, Saieg, Lasic, & King, 2004). In 2013, in the patent number of CN 103310047 A, inventor proposes an optimization method for elimination of lateral force by establishing a multi rigid body simulation model which regulates the coordinates of hard points and determines the force action line of coil spring by changing the geometrical parameters of the spring seat to optimize lateral force on the strut rod (Bottene, Fader, Doyle, Williams, Saieg, Lasic, & King, 2004).

CHAPTER THREE

METHODS AND MATERIALS

3.1 Introduction

This chapter presents the methodology used in the design of coil spring of vehicles and modified coil spring compressors as well as material selection procedures.

3.2 Proposed Designs

This thesis will go through series of processes, that is the design, construction and testing stages, at the design stage two different designs was analyzed and one of the designs were chosen based on their strength, safety, durability, mobility and stability on the floor during operation. Below shows two different designs for the work.

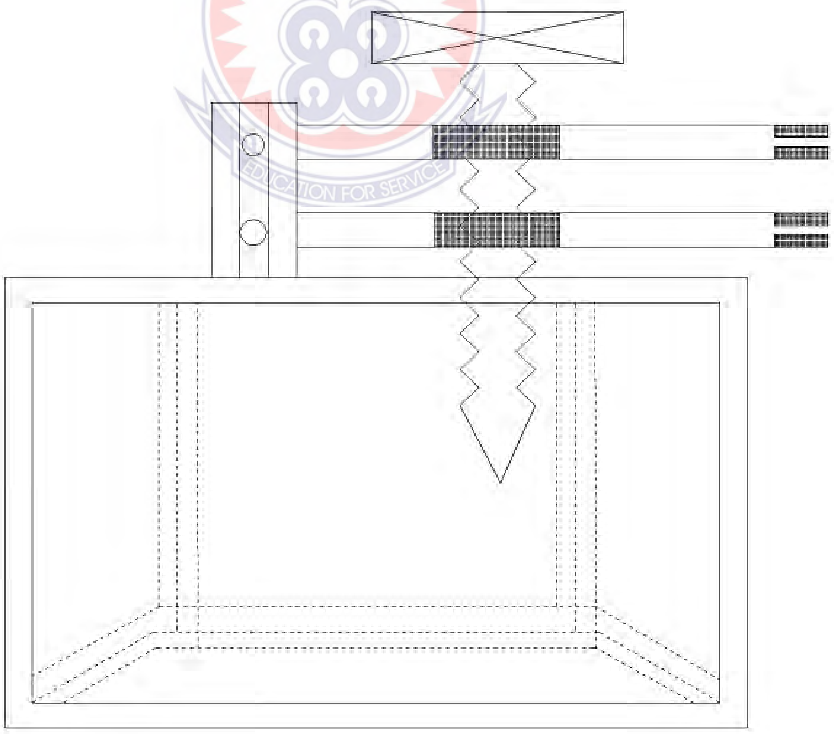
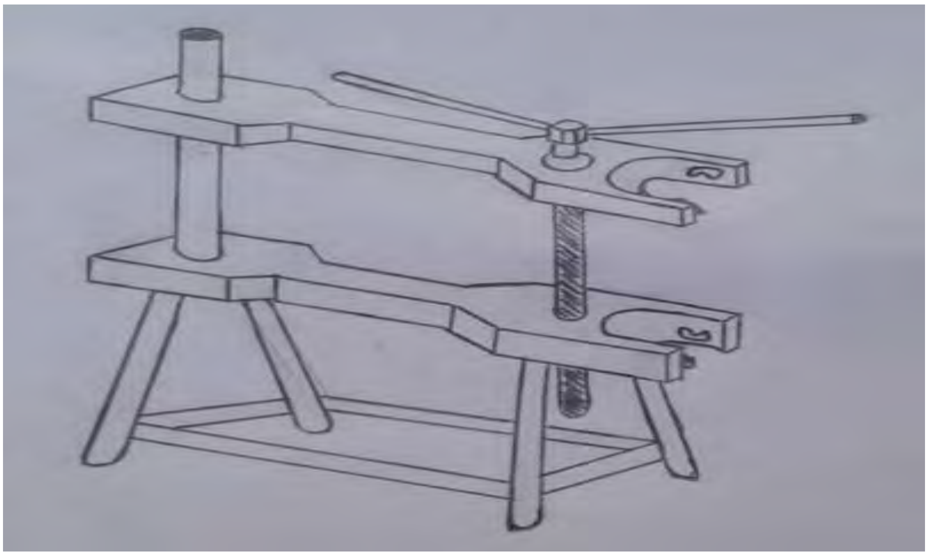


Figure 3.1: (a) TU coil spring compressor.



(b) TU coil spring compressor.

Table 3.1: Design matrix compilation of TU A and TU B

No.	Performance	TU A Rating (10%)	TU B Rating (10%)
1.	Stands	9	9
2.	Number of parts	8	10
3	Adjustments to accommodate various coils	10	6
4	Crabbing	9	7
5	Maintenance	10	8
6	Securing of coils in position	10	8
7	Easy operations	10	8
8	Cost effective	9	8
9	Mobility	9	9
10	Safety	10	8
Total		**94%**	**81%**

Design 3.1 a) (TU coil spring compressor) is selected over the second design based on the analysis from the above table, with the analysis performance of TU A compared to that of TU B and per the individual performance, TU A was chosen, with the stand both designs have strong and good stands that can accommodate all forces that may be

exerted on them, with the number of parts TU B have many member of parts compare to TU A. adjustments can be made on TU A both in the vertical and in the horizontal plain to accommodate various types of coil springs, unlike the TU B which does not have much space for adjustment and that cannot be used on many coil springs. Unlike the second design, the jaws of the first design are adjustable to conform to the size of any coil spring that need to be worked on whilst the jaws of the second design is fixed and hence can only be used on limited sizes of springs. Also the long shaft at the rear of the second design has to be lubricated at all times because the upper hook frame will always move towards and away from the lower hook frame during operation and it can't move smoothly if the friction between the hole on the upper long hook frame and the shaft is high, Meanwhile the first design is free from this problem. Lastly the first design has locking jaws which will hold the coil spring in a fixed position and prevent it from jumping out of the jaws during operation but the second one has no locking pins making the possibility of the load (spring) jumping out of the jaw when the screwing force is exerted on it high. In conclusion, the first design is easier to operate, cheaper cost of operation and most importantly safer than the second design.

The drawing in Figure 3.2 shows the details of the design labelling

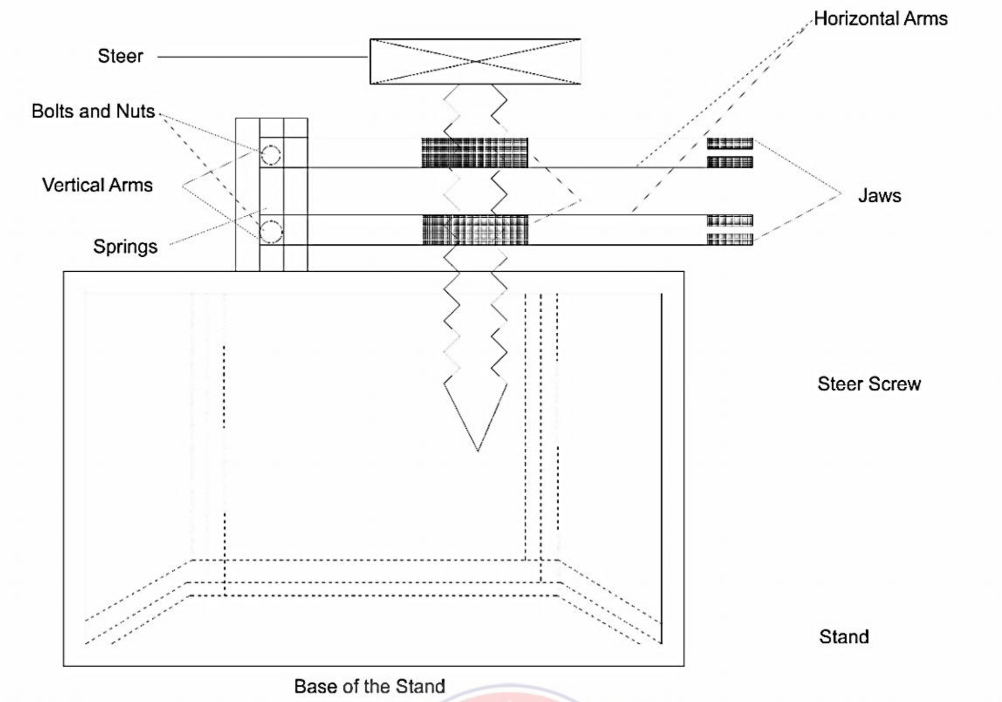


Figure 3.2: Detail drawing of the design

Table 3.2: Parts list and material of component

Parts	Number	Dimension	Materials
Jaw	4	90mm	Galvanized
Flat bars	4	600mm	Carbon steel
			Carbon steel
Flat bars (vertical arm)	2	270mm	Carbon steel
Stand	1	600 x 460mm	Carbon Steel
Plain Trunnion	3	70 x 50mm	Carbon Steel
Steering Screw	1	800mm	Carbon steel
Bolts and nuts	4	22mm	Carbon steel
Bolts and nuts	2	32mm	Carbon steel

Functions of the parts of the design

Stand: is a piece of rectangular shaped, which is also the base of the whole design use to support the equipment arrangements. The stand consists of a heavy angle iron base and joined in a vertical and horizontal direction to form the stand, which makes the design very firmed on the ground.

Steer screw: is a smooth fine screw long enough to hold both the upper and lower horizontal arms of the equipment and unlike other steering system of components, which has linkages, etc. which allows any vehicle, car, motorcycle, bicycle to follow the desired course, the steer screw allows the movement of the arms only in the up and down direction.

Jaw: The **jaws** are a pair of hinged or sliding components designed to grip a workpiece or the spring coil compressor in position so that compression can be done easily. The spring coil is mounted between the moveable upper jaw and the fixed lower jaw of the compressor.

Horizontal arm: with similar functions to a human arm, the arm help the equipment to be able to hold the spring coil, and compression and decompression is done on the arm. The links of such a manipulator are connected by joints allowing either upward or downward motion or translational (linear) displacement.

Trunnion: it is one part of a rotating joint where a shaft (the trunnion) is inserted into (and turns inside) a full or partial cylinder. Often used in opposing pairs, this joint allows tight tolerances and strength from a large surface contact area between the trunnion and the cylinder.

Bolts and nuts: A **bolt** is a form of threaded fastener with an external male thread requiring a matching pre-formed female thread such as a nut. This joints the horizontal arm to the vertical arm.

Springs: is an elastic object that stores mechanical energy and this is fitted between the horizontal and the vertical arms at one end to keep the distance between them constant.

3.3 Material Used

In constructing the device, the main material used is carbon steel. Table 3.2.2 shows the mechanical properties, knowing the properties of Carbon Steel content. It is used in the construction of the coil spring due to its high tensile strength and low cost, it is a major component used in building infrastructure, tools, ships, automobile, machines, appliances and weapons. Carbon steel is a steel that has some percentage of carbon in its base element, is has carbon content of between 0.05 to 0.25% by weight. Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum nickel, niobium, titanium, tungsten, vanadium or zirconium or any other element to add to obtain a designed alloying effect. The specified minimum for copper does not exceed 0.04%, or the maximum content specified for any of the following elements does not exceed the percentages needed; manganese 1.65, silicon 0.6, copper 0.60. As carbon percentage content rises, steel has the ability to become harder and stronger through heat treating, however it becomes less ductile. Examples of carbon steel is mild or low carbon steel and high tensile steel. Many considerations have to be addressed during this design, but it begins with material selection. Other things that were also considered were to be sure as much as possible about the device's intended operating environment and the space available for spring installation. Once the materials were selected, careful consider on how wire diameter and volume of coil springs can help determine the compressor spring's load handling capabilities, tolerances and manufacturability.

Table 3.3: Mechanical properties of carbon steel showed in metric

Mechanical Properties	Metric
Hardness	170
Tensile Strength, Ultimate	540 MPa
Tensile Strength, Yield	415 MPa
Elongation at Break	10%
Modulus of Elasticity	200 GPa
Bulk Modulus	140 GPa
Poisson's Ratio	0.29
Machinability	160%
Shear Modulus	80Pa

3.4 Operating Capacity of the Design

The new design of the Owatana tool compressor which may possess most the features of the original tool which are that, it is convenient and affordable; it fits a wide range of struts and requires no special adapter shoe. Safety locking pins holds the compressor jaws in place. This tool compresses springs of 100 to 230mm with wire diameter of 80/410 to 280/410 mm built to use with an impact wrench. The new design will possess all the qualities of the old design with little changes with respect to the following; it will be able to compress 260 to 710 mm long compressor with a diameter of 130 to 410 mm coil spring.

3.5 Tools and Equipment used for Constructing

An arc welding machine was used to join the various parts together; this arc welding machine (IGBT MMA inventor DC) has a capacity of 200 Amp and 220v potential difference with an EU plug. Parts were also cut using both a power hack saw and manual hacksaw and portable grinding machine. All surfaces were smoothening with the use of both pedestal and portable grinding machine with different grades of abrasives. A turner Lathe machine Rs 115000/piece was used for the cutting of all external threads and also drilling and boring of holes in the shafts. All work holdings were done with the used of the vice. Spanners of various sizes were used for the tightening of all nuts to the various bolts and threads etc. Files were used to smoothen certain corners and the removal of burrs. Pillar drills were also use to drill holes in irregular and flat bars all to accomplish the task at hand.

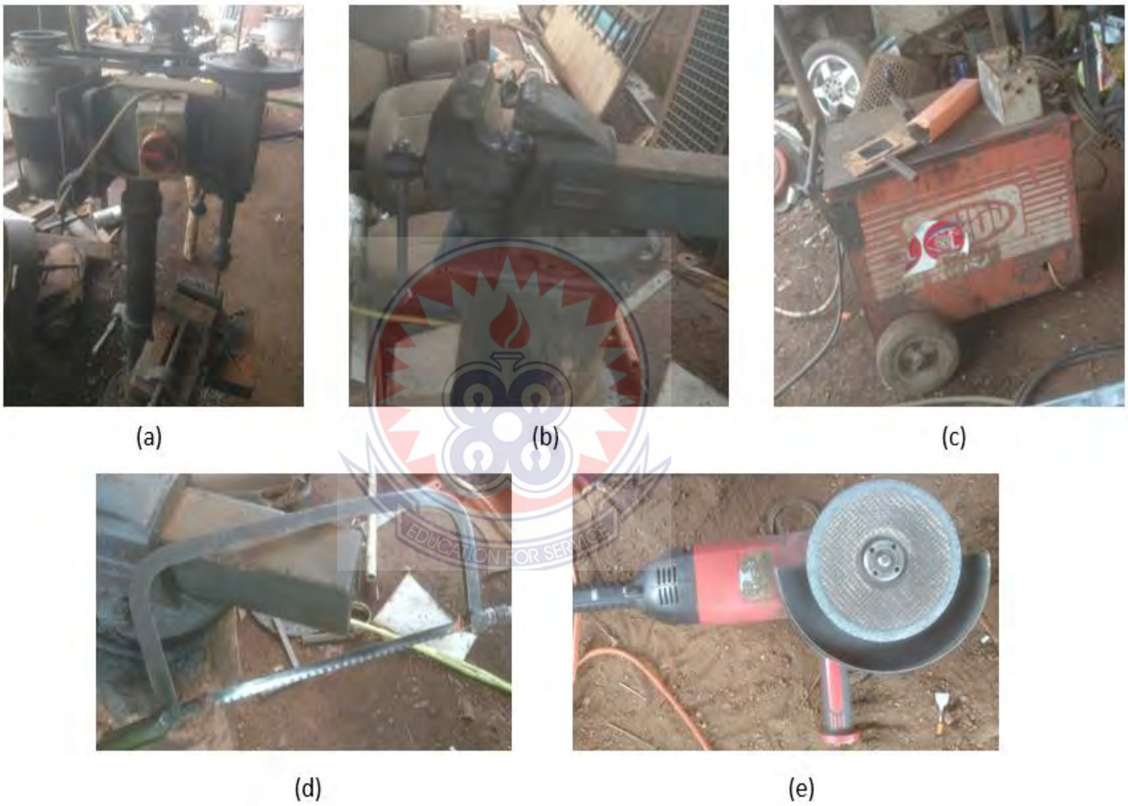


Figure 3.3: Tools and equipment used (a) Pillar drilling machine (b) Vice (c) Arc welding machine (d) Hacksaw (e) Grinding machine.

3.6 Helical Coil Springs Design Procedure

The helical coils springs are made up of a wire coiled in the form of a helix and are intended for compressive or tensile loads. The cross-section of the wire of the spring is generally circular and the two main types of helical coil springs are compression and tension helical springs. Only the compression springs will be of interest in this study because of coil spring compressor design and will help in measuring the characteristics when the compressor is used. A typical compression coil spring can be seen in Figure 3.4.

Figure 3.4: Compression Helical Coil Spring

3.6.1 Definitions of the Some Terms Used in Compression Coil Springs

Solid Length: That is the length when the spring is compressed until the coils come in contact with each other.

$$L_S = n'.d \qquad \textbf{(3.1)}$$

Where

Ls = solid length

n= is the number of active coils and

d= internal diameter of the coil

Free length: It is the length of the spring in the free or unloaded condition.

$$L_F = n'.d + \delta_{max} + 0.15\,\delta_{max} \qquad \textbf{(3.2)}$$

Where Lf = the free length of the coil

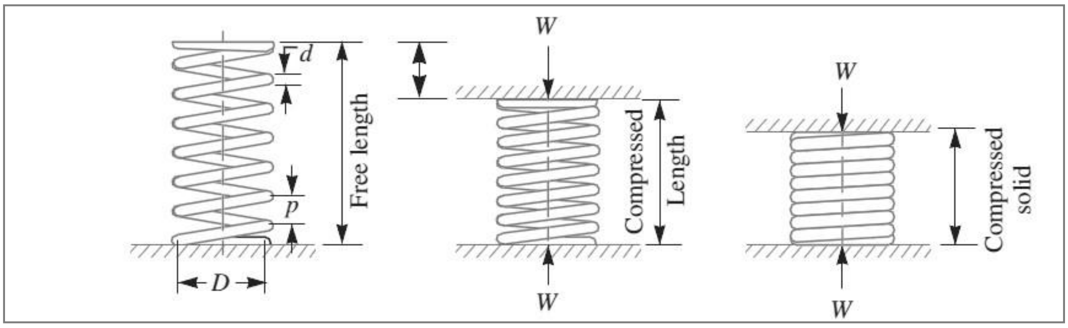


Figure 3.5: Free and Solid Length of the Helical Coil Spring

Spring index: The ratio of the mean diameter of the coil to the diameter of the wire.

$$C = \frac{D}{d} \qquad \textbf{(3.3)}$$

Spring rate (stiffness): The load required per unit deflection of the spring.

$$k = \frac{W}{\delta} \qquad \textbf{(3.4)}$$

Pitch: The axial distance between adjacent coils in uncompressed state.

$$p = \frac{Free\ length - Solid\ Lenth}{n' - 1} \quad or\ p = \frac{L_F - L_S}{n'} + d \qquad \textbf{(3.5)}$$

3.6.2 End connections for compression springs

The end connections are suitably formed to apply the load and common used forms are shown in Figure 3.6.

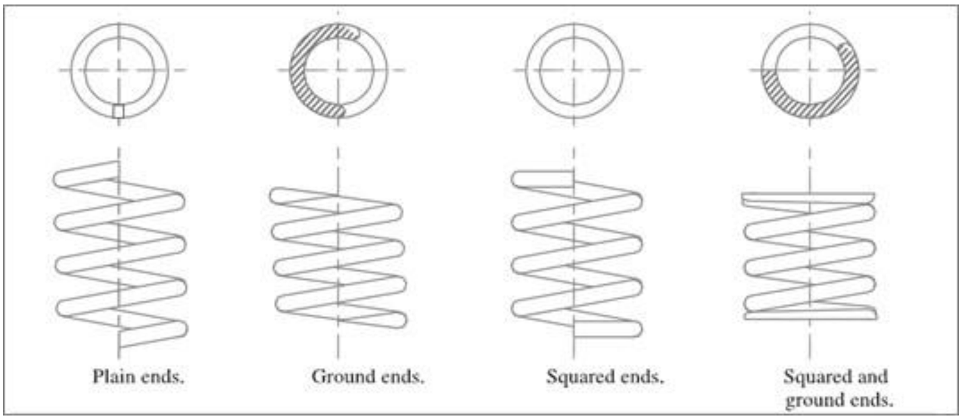


Figure 3.6: End Connection Types of Compression Springs

Table 3.4: Formulations for End Connection Types

Type of End	Total number of turns (n’)	Solid Length (L_s)	Free Length (L_f)
Plain Ends	n	(n+1).d	p.n+d
Ground ends	n+1	(n+1).d	p.(n+1)
Squared ends	n+2	(n+3).d	p.n+3d
Squared and ground ends	n+2	(n+2).d	p.n+2d

Stresses in Helical Springs of Coil Wire

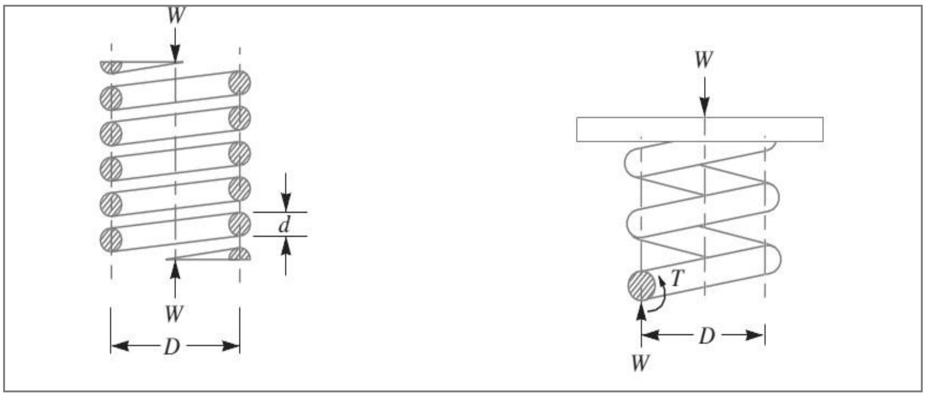


Figure 3.7: Axially Loaded Spring and Free Body Diagram

The spring is under the action of two forces; the axial force (W) and the twisting moment (T) which can be seen in Figure 3-4.

$$T = W \cdot \frac{D}{2} = \frac{\pi}{16} . \tau_1 . d^3 \quad \textbf{(3.6)}$$

The torsional shear stress;

$$\tau_1 = \frac{8W.D}{\pi . d^3} \quad \textbf{(3.7)}$$

The direct shear stress due to axial load W;

$$\tau_2 = \frac{4W}{\pi . d^2} \quad \textbf{(3.8)}$$

The resultant shear stress in the wire becomes;

$$\tau = \tau_1 \pm \tau_2 = \frac{8W.D}{\pi . d^3} \pm \frac{4W}{\pi . d^2} \quad \textbf{(3.9)}$$

Positive sign is for the inner edge and negative sign is for the outer edge of the wire.

As a result, the maximum shear stress;

$$\tau = \frac{8W.D}{\pi . d^3} + \frac{4W}{\pi . d^2} = \frac{8W.D}{\pi . d^3}\left(1 + \frac{d}{2D}\right) = \frac{8W.D}{\pi . d^3} \cdot K_S \quad \textbf{(3.10)}$$

$$K_S : Shear\ stress\ factor = 1 + \frac{1}{2C} \quad \textbf{(3.11)}$$

The shear stress diagrams according to Eq. (9);

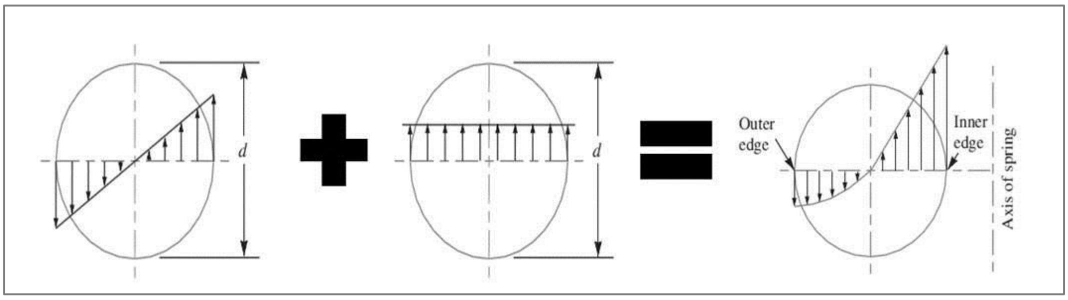


Figure 3.8: Torsional Shear, Direct Shear and Resultant Shear Stress Diagrams

In order to include the effect of the curvature of the w ire, Wahl's stress factor (K) can be used. Then, the maximum shear stress induced in the wire;

$$\tau = K \cdot \frac{8W.D}{\pi.d^3} = K \cdot \frac{8W.C}{\pi.d^2} \quad \textbf{(3.12)}$$

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \quad \textbf{(3.13)}$$

The maximum shear stress equation has importance, because, while doing the static analysis validation of the analysis model in ANSYS, the results will be checked according to maximum shear stress value and deformation according to applied load.

3.6.3 Deflection of Helical Springs of Circular Wire

The total active length of the coil spring;

$$l = Length\ of\ one\ coil \cdot number\ of\ active\ coils = \pi D \cdot n \quad \textbf{(3.14)}$$

The axial deflection of the spring;

$$\delta = \theta \cdot \frac{D}{2} \quad \textbf{(3.15)}$$

It is known that;

$$\theta = \frac{T.l}{J.G} \quad \textbf{(3.16)}$$

$$J = \frac{\pi}{32} \cdot d^4 \quad \textbf{(3.17)}$$

After substitutions, the deflection for an applied load becomes;

$$\delta = \frac{8W.D^3.n}{G.d^4} = \frac{8W.C^3.n}{G.d} \quad \textbf{(3.18)}$$

Then, the stiffness of the spring can be written as;

$$\frac{W}{\delta} = \frac{G.d^4}{8D^3.n} = \frac{G.d}{8C^3.n} = constant \rightarrow k \quad \textbf{(3.19)}$$

3.6.4 Buckling of Compression Coil Springs

Large deformations may cause buckling in compression coil springs. The condition for stability of steel springs can be investigated by checking the relation which is given in Eq. (20).

$$L_f < 2.63\frac{D}{\gamma} \quad \textbf{(3.20)}$$

Here γ is a constant related to end condition and γ values for usual end conditions can be seen in Table 3.5.

Table 3.5: End Condition Constants for Compression Coil Springs

End Condition	End Condition Constant, γ
Spring supported between flat parallel surfaces (fixed ends)	0.5
One end supported by flat surface perpendicular to spring axis (fixed); other end pivoted (hinged)	0.707
Both ends pivoted (hinged)	1
One end clamped; other end free	2

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter seeks to analyses the results and also discusses the redesign and construction of the OTC spring coil compressor, based on the operational principle of the original OTC currently in use in the automobile industry and comment by some key players in the use of coil spring compressor.

4.2 Experimental Results of the Modify Coil Spring Compressor

After the design and construction of the compressor, and in order to make sure the equipment meets standard it required to meet that is per the operation of the OTC compressor. A particular helical coil spring which have the below parameters was used in testing the equipment. The coil spring used for the testing have the following information as per its design. Free length of spring 345mm, Pitch 70mm, Mean diameter 150mm,Wire diameter 125mm, Number of active coils 6 Music diameter 13mm. Using scale hanged over the TU compressor and the experiment performed three different times the following results were obtain per the following, load, deflection, and angles, coil spring seat type, and the average results were picked. Below is the outcome of the results from the test.

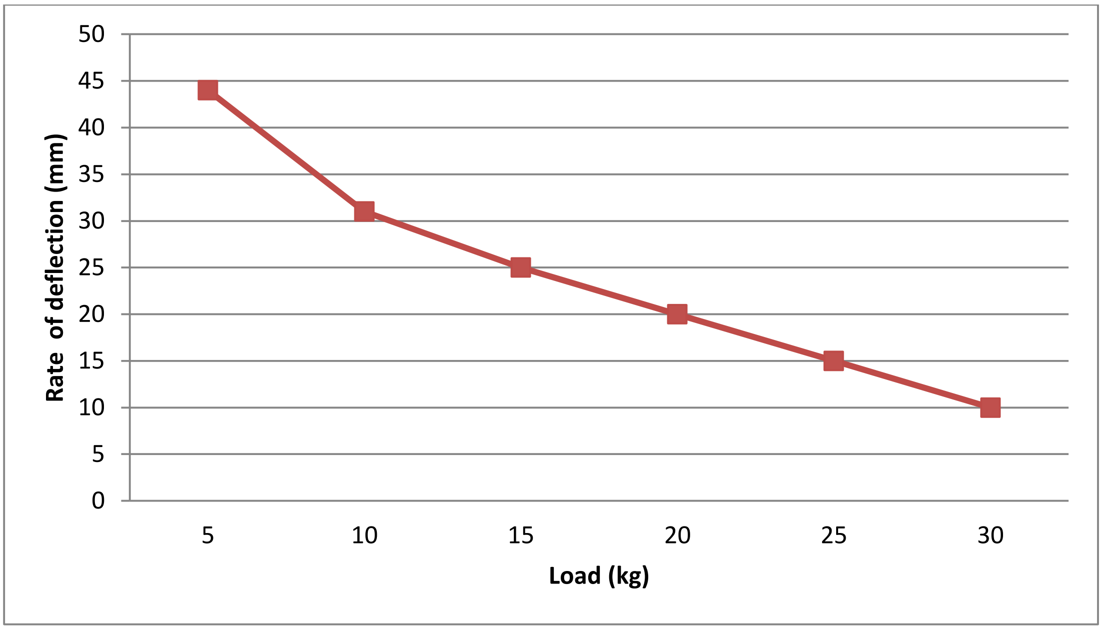


Figure 4.1: Rate of deflection in (mm) against load in (kg)

It is now clear from the graph that when the coil spring was not loaded (free length) the total length was 345mm when the compressor placed a load of 5kg on the spring at the initial stage the length was reduce from 345 to 301mm which means that at the load of 5kg the compressor was able to reduce the length by 44mm and that means that at that point there was no any resistance from the coil spring so from the graph at load 5kg deflection was 44mm. When the compressor placed a load 10kg deflection was from 301 to 270mm this time unlike the initial load of 5kg which gave a deflection of 44mm this time the deflection was 40mm which shows that resistance have started setting in, at 15kg of load from the compressor deflection was 25mm, and at 20kg deflection was 20mm, at 25kg deflection was 15mm and at 30kg deflection was 10mm this goes on to show that though there some form of resistance pursed by the coil still the new designed compressor was still able to place a load and some rate of deflection were achieved. This means that at load 15kg and deflection 100mm any loaded coil spring can unloaded and be loaded this new design, by this assessment one can say that new the design has performed its functions just like the original OTC spring coil compressor. The test that was conducted is on the angle, load, and deflection.

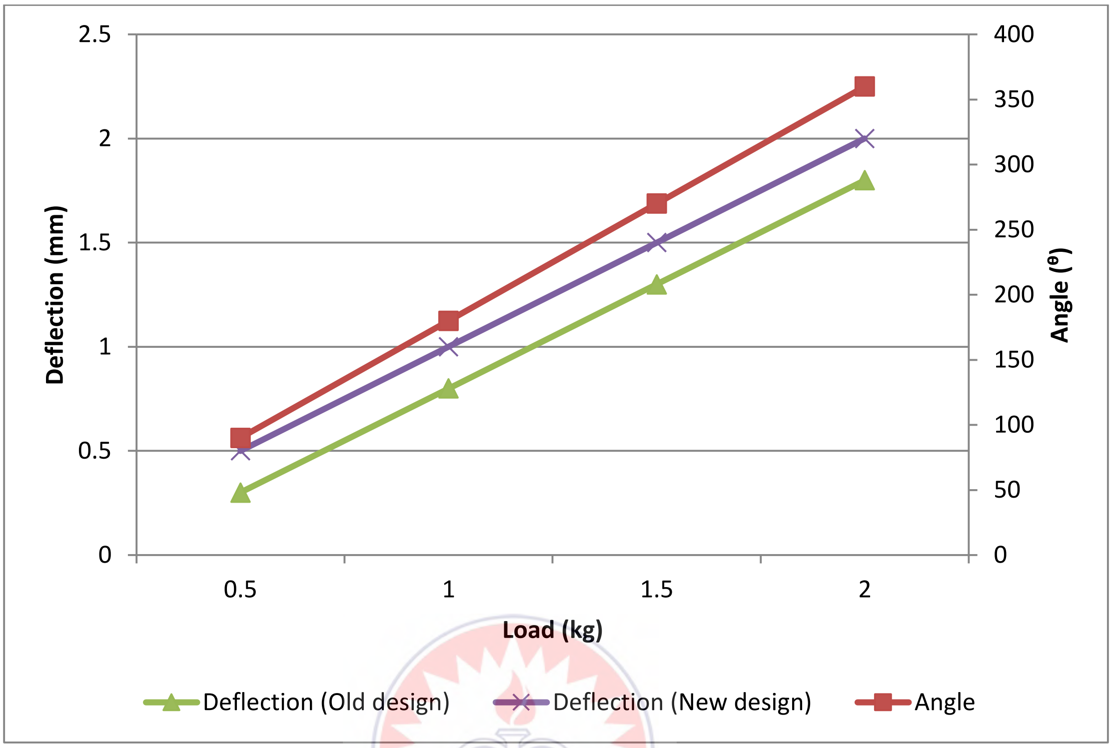


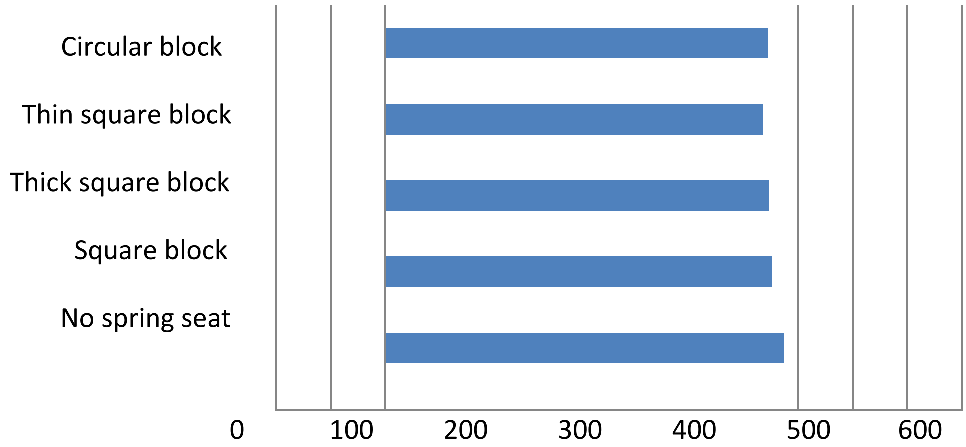
Figure 4.2: Rate of deflection in (mm) load in (kg), and angle in (degree) for both new and the existing design

From the above graph which was plot with rate of deflection in (mm), load in (kg) and angle in (^{0}) for both the new and the existing design, it is clear that at angle 90^0 and load of 0.5kg for the new design deflection was 0.5mm, at 180^0 and load of 1kg, deflection moved from 0.5mm to 1mm, at 270^0 load and deflection also move by 0.5 that is from 1kg and 1mm to 1.5kg and 1.5mm respectively and at 360 load and deflection gets 2 kg and 2 mm exactly so this shows that at any increase in the angle and load, deflection will change in respect to the angle. Comparing the modified design to the existing design from the above graph with the same applied load and angle the rate the following results were obtained, when the new design achieved 0.5mm at 90^0 the old design obtain 0.3mm, at 180^0 the deflection in the existing design was 0.8mm, at 270^0 the rate of deflection was 1.3mm and at 360^0 the rate of deflection was 1.8mm so from the above analysis deflection was lagging in the old design one could conclude that the modified or the new design is efficient than the old design.

4.3 Spring Seat Types and the Compressor

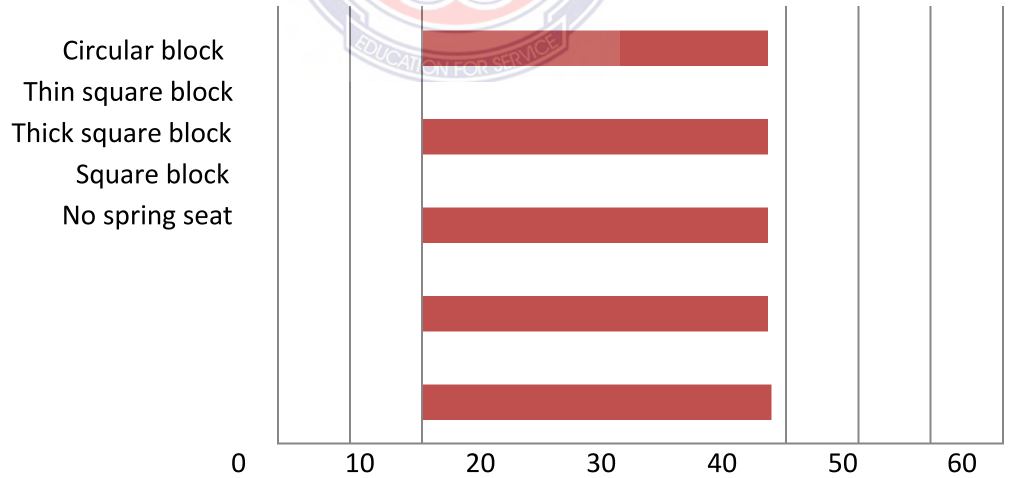
Spring seat design is very important to obtain the proper function of suspension system. In this part, tests are done with the spring that has no spring seats and it is investigated whether the spring seat affects the results or not. According to the results, there occurs some singular point on coil spring ends due to nonhomogeneous load applied to the center of the spring by the compressor. However, by varying loads in these regions accurate results can be obtained. Nevertheless, it is decided to use blocks as spring seat geometry to be able to apply load more realistic and comparable manner in the testing of this study. Sizes of the blocks are selected large enough and thick, thus the deformation of the blocks becomes negligible. In other words, blocks that are used as spring seat behave like rigid bodies. Also, the size of the blocks is limited due to increased size of blocks also increases the effort for the testing.

After testing the spring coils that do not have spring seat, a few types of spring with seats are tested to enable the applied load to the center of the spring and exam for these spring seat tests with the same examination features and compared the results. The results for springs with different spring seats can be seen. The comparisons of the results for different spring seat types are presented in Figure 4.3 and Figure 4.4.



	No spring seat	Square block	Thick square block	Thin square block	Circular block
Max. Shear Stress(Mpa)	536,67	526,68	523,3	517,93	522,54

Figure 4.3: Comparison of Maximum Shear Stress of Spring Seat Types



	No spring seat	Square block	Thick square block	Thin square block	Circular block
Max Deflection(mm)	47,762	47,484	47,482	47,492	47,487

Figure 4.4: comparison of Maximum Deflection of Spring Seat Types

4.4 Force Generation

Force generation change according to applied force and the deformation is given in Figure 4.5 and Figure 4.6, respectively.

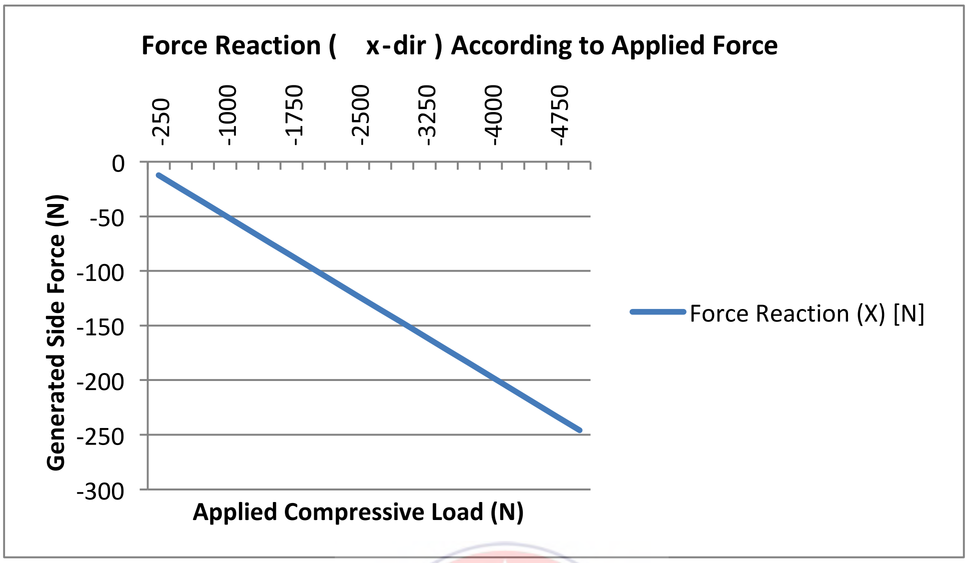


Figure 4.5: Generated Side Force According to Applied Load (c_u=2 mm and α=6°)

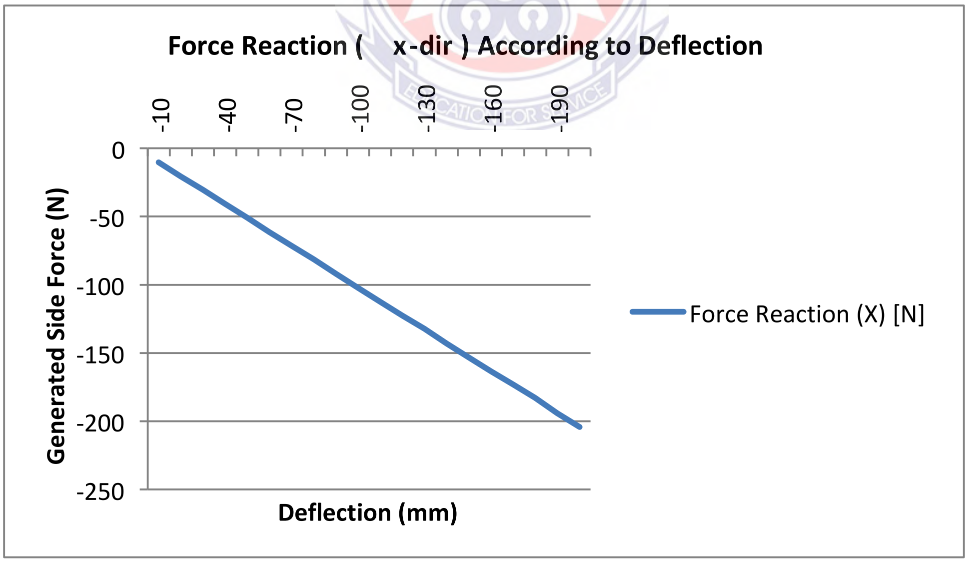


Figure 4.6: Generated Side Force According to Given Deflection (c_u=2 mm and α=6°)

As shown in Figure 4.5 and Figure 4.6 generated side force according to deflection or force shows a linear characteristic which seems unrealistic. It is thought that this is caused by analysis model and these results are investigated furthermore. These studies will be explained in the next section.

4.5 Effect of Spring Free Length Change

Effect of the free length change of the spring on the generated and reduced side force can be seen in Figure 4.7 and Figure 4.8 increased free length of the spring increases the generated side force and decreases the reduced side force inherently. However, it should be noted that since the free length change of the spring changes the stiffness of the spring, deformation of the spring according to applied force is also changed while maximum shear stress value does not change considerably, and related results can be seen in Figure 4.7.

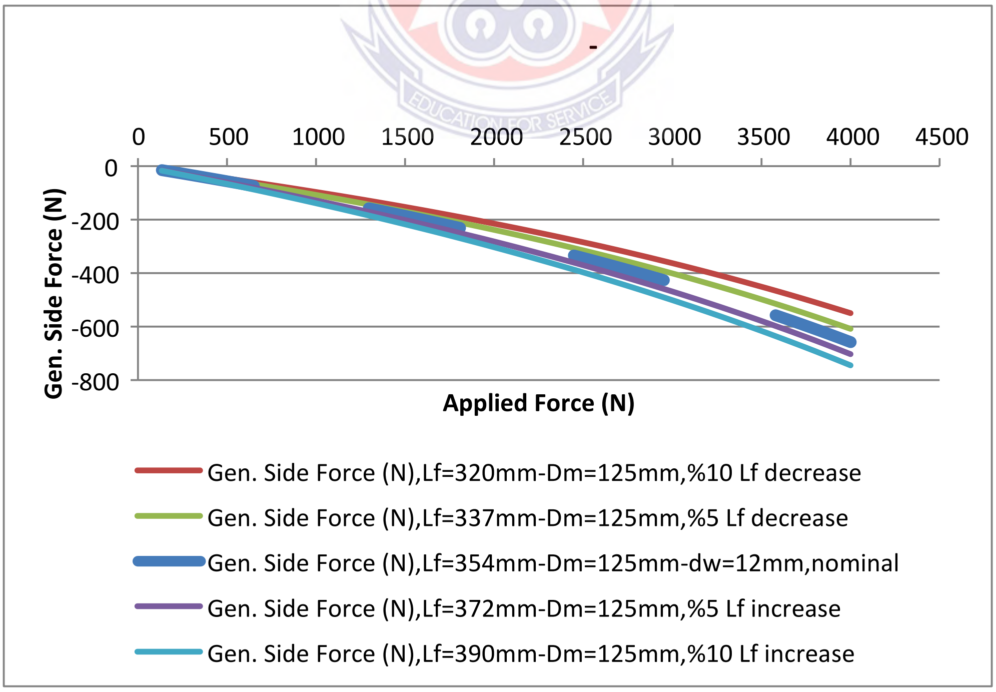


Figure 4.7: Generated Side Force Against-Effect of Spring Free Length Change

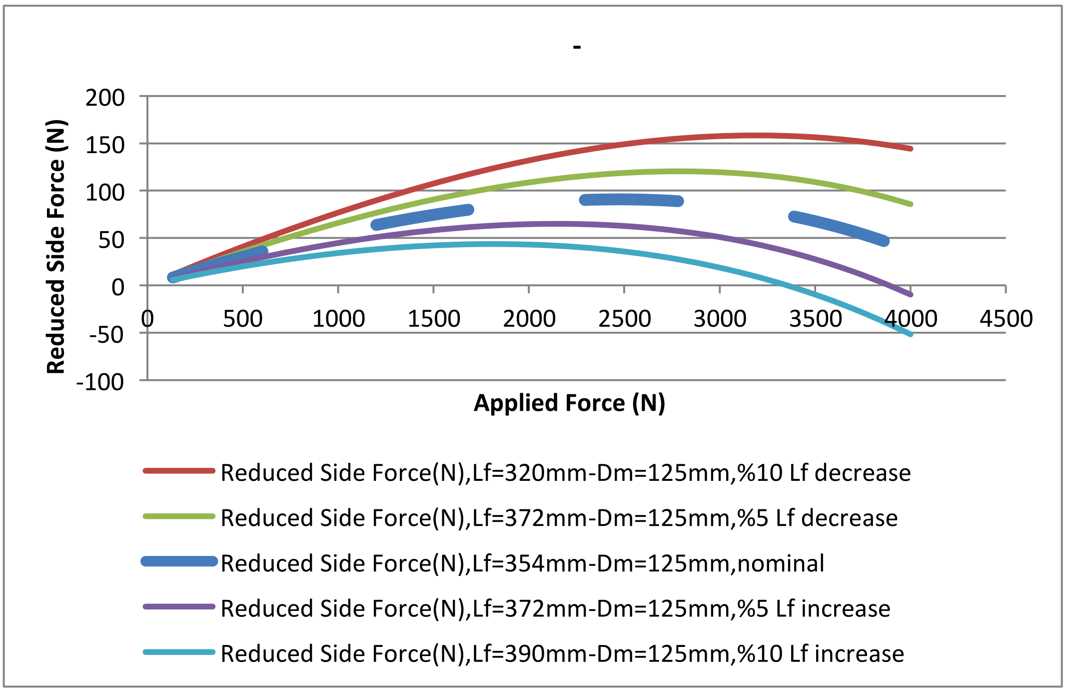


Figure 4.8: Reduced Side Force against Effect of Spring Free Length Change

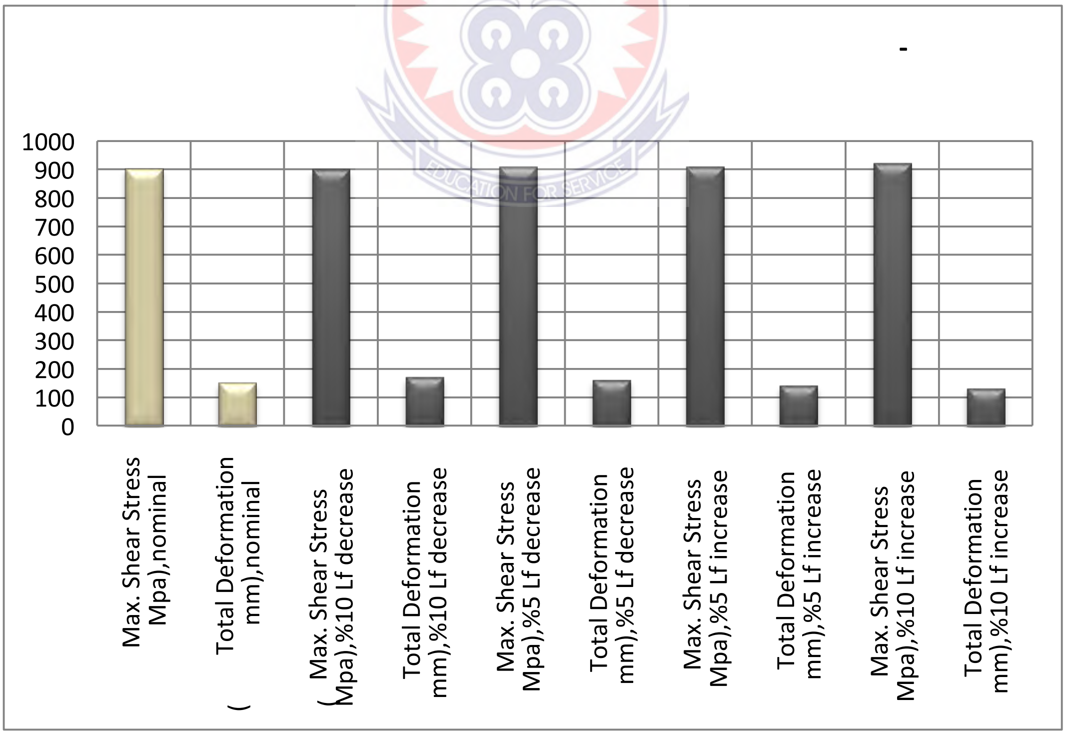


Figure 4.9: Comparison of Max. Shear Stress and Deformation Effect of Spring Free Length Change

4.6 Effect of the Coil Mean Diameter Change

The effects of the mean diameter change of the coil on the generated and reduced applied force is investigated and the results can be seen in Figure 4.10 and Figure 4.11 Increased mean diameter of the coil decreases as the applied force and increases the reduced side force accordingly. However, the mean diameter change of the coil changes the stiffness of the spring, deformation of the spring according to applied force is changed significantly while maximum shear stress value does not differ much, and related results can be seen in Figure 4.12.

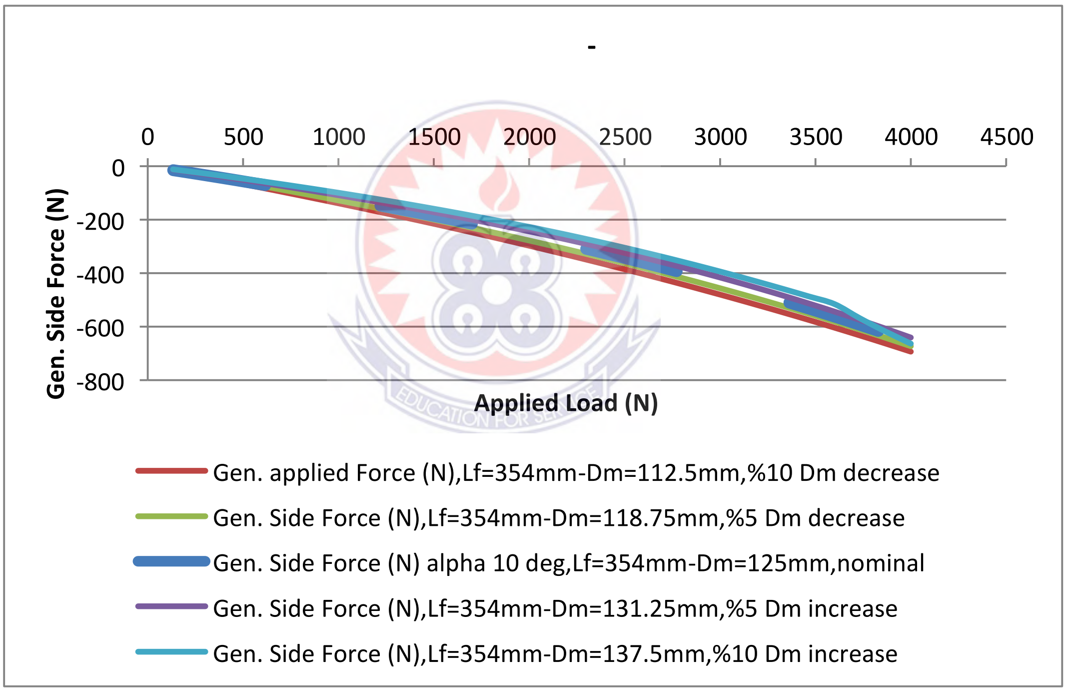


Figure 4.10: Generated Side Force Against applied Load.

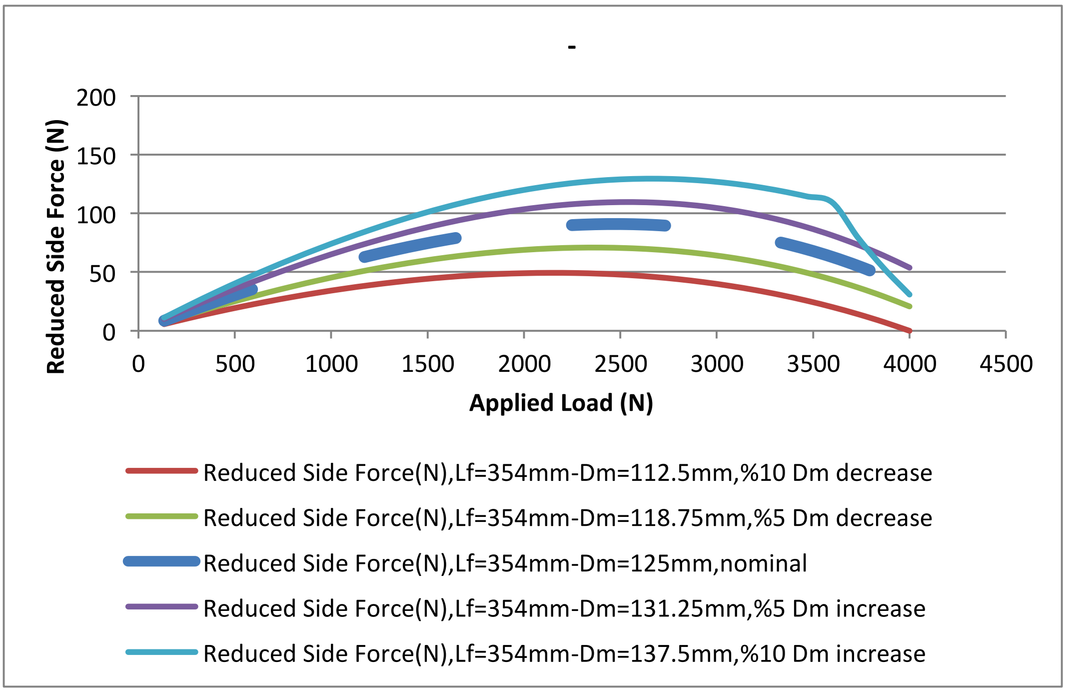


Figure 4.11: Reduced Side Force Against applied Load.

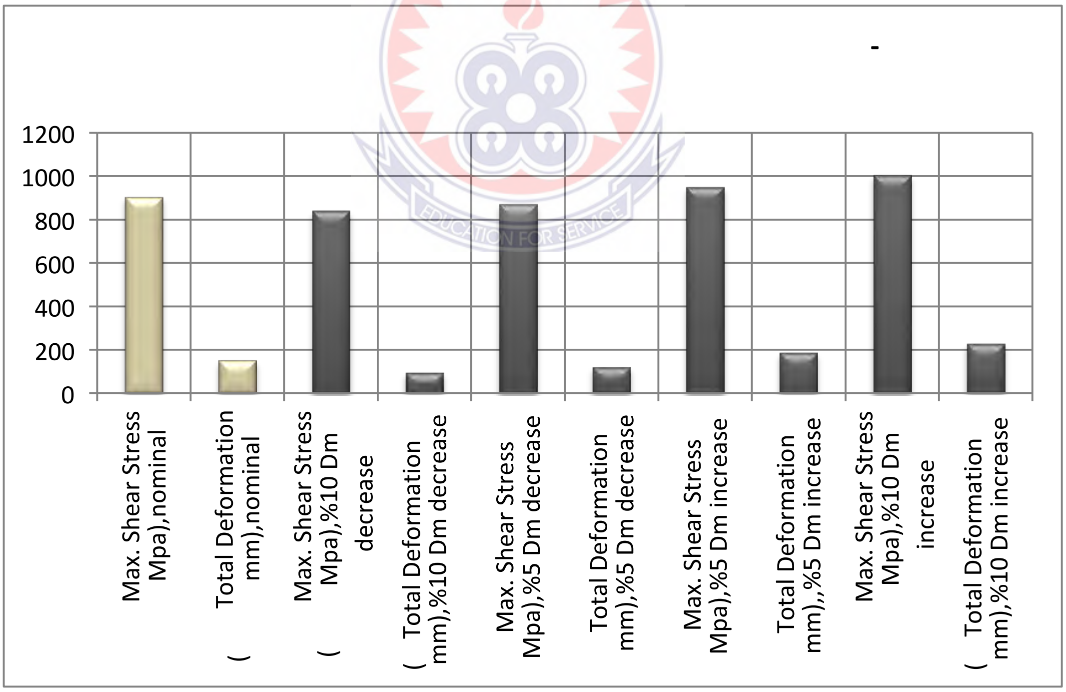


Figure 4.12: comparison of Max. Shear Stress and Deformation Effect of Coil Mean Diameter Change

4.6.1 Effect of the Wire Diameter Change

Effect of the wire diameter change on the generated and reduced side force is looked at and the results can be seen in Figure 4.13 and Figure 4.14. Reduced wire diameter increases the generated side force and decreases the reduced side force for specific region of the applied force. However, change of the wire diameter changes the stiffness of the spring, the maximum shear stress and the deformation of the spring according to applied force is changed significantly, and related results can be seen in Figure 4.15.

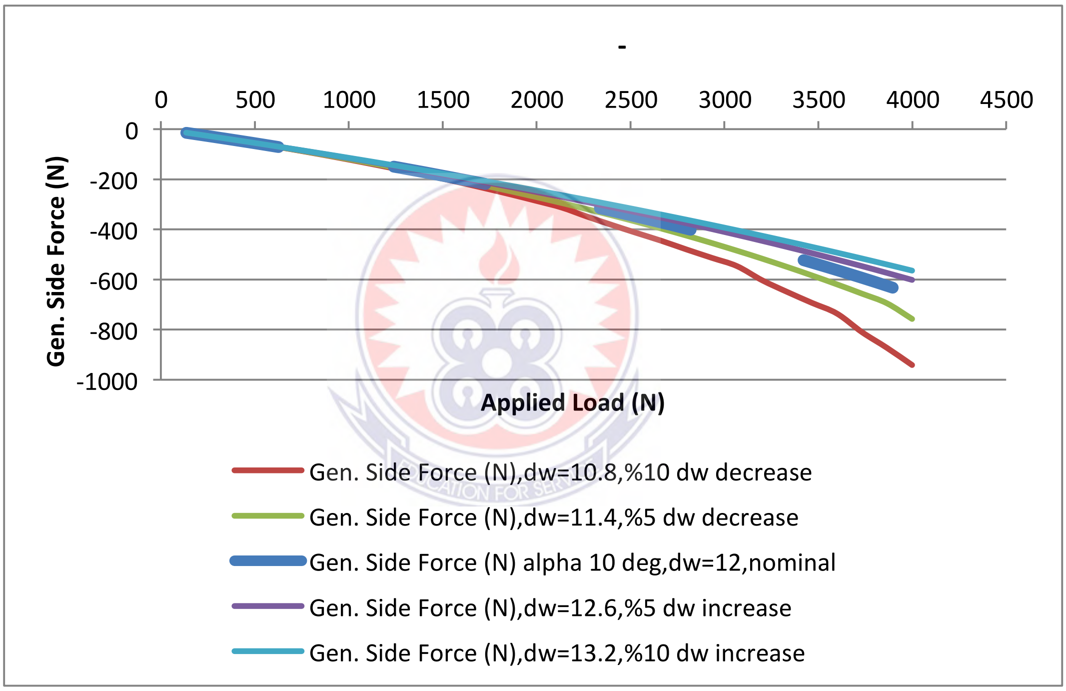


Figure 4.13: Generated Side Force Against applied load.

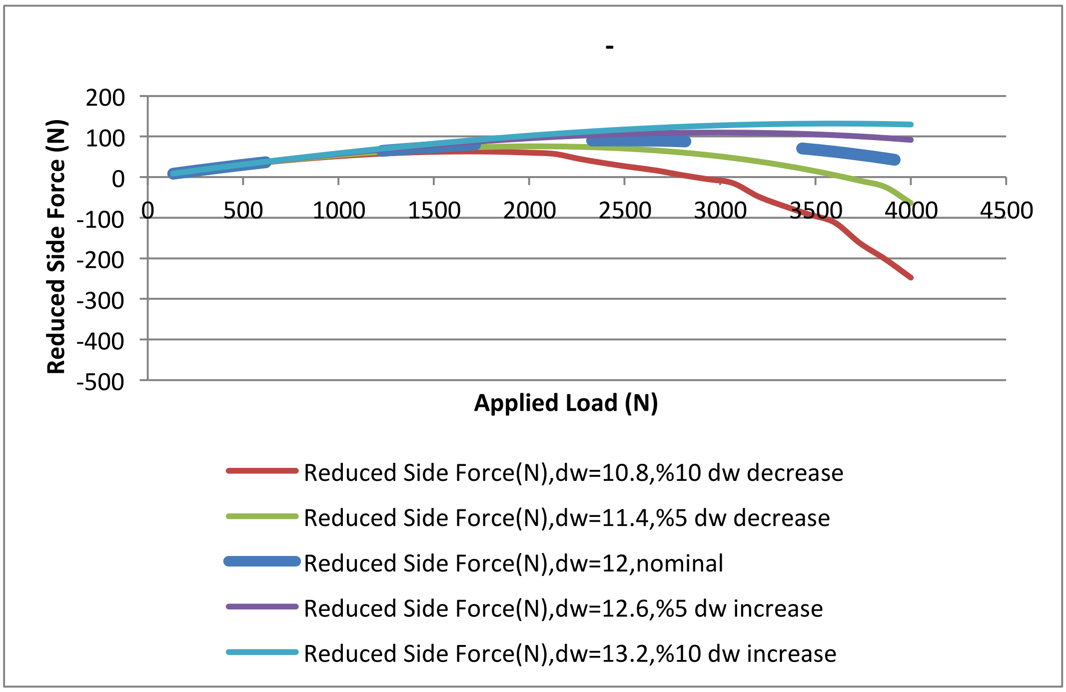


Figure 4.14: Reduced Side Force Against applied load.

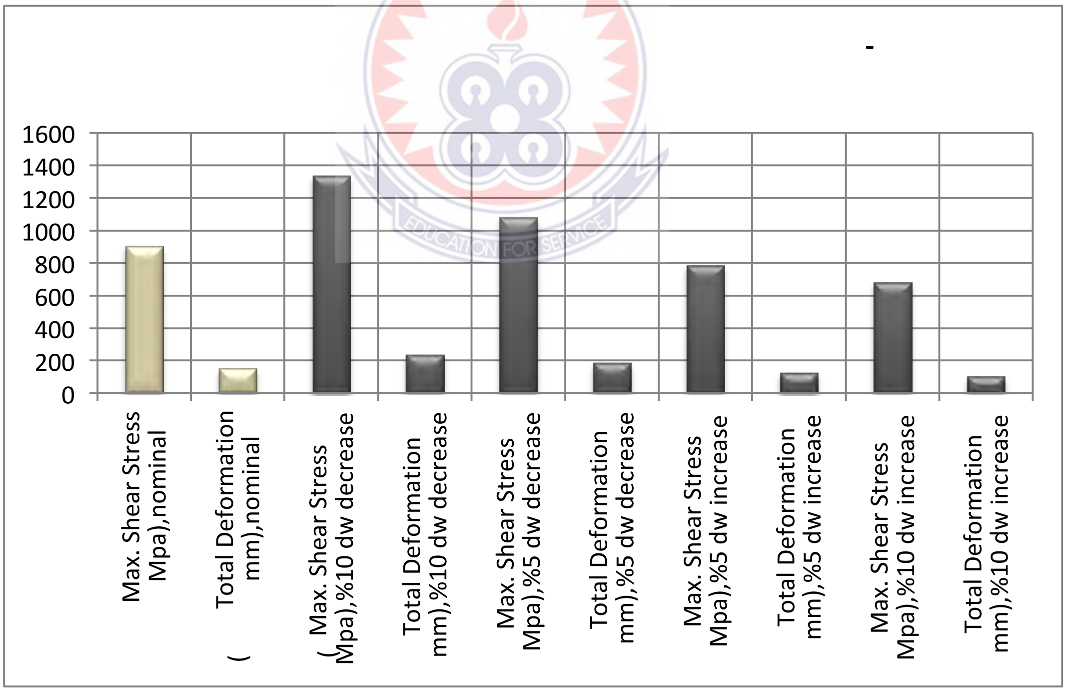


Figure 4.15: Comparison of Max. Shear Stress and Deformation Effect of Wire Diameter Change

4.6.2 Comparison of the Effect of the Parameters

Lastly, effect of the change of the all parameters is examined. Comparisons of the results can be seen from Figure 4.16 to Figure 4.17. As a result, order of importance of the effect of the parameters is; free length of the spring, mean diameter of the coil and wire diameter, respectively. However, it should be noted that this ranking is done according to the results of the generated side force. If the maximum shear stress and the deformation are examined, results will be different. Hence, this point should be taken into consideration while designing or changing the design of a loaded spring. Nevertheless, this sensitivity analysis should be further developed and combined effect of the parameters should be examined.

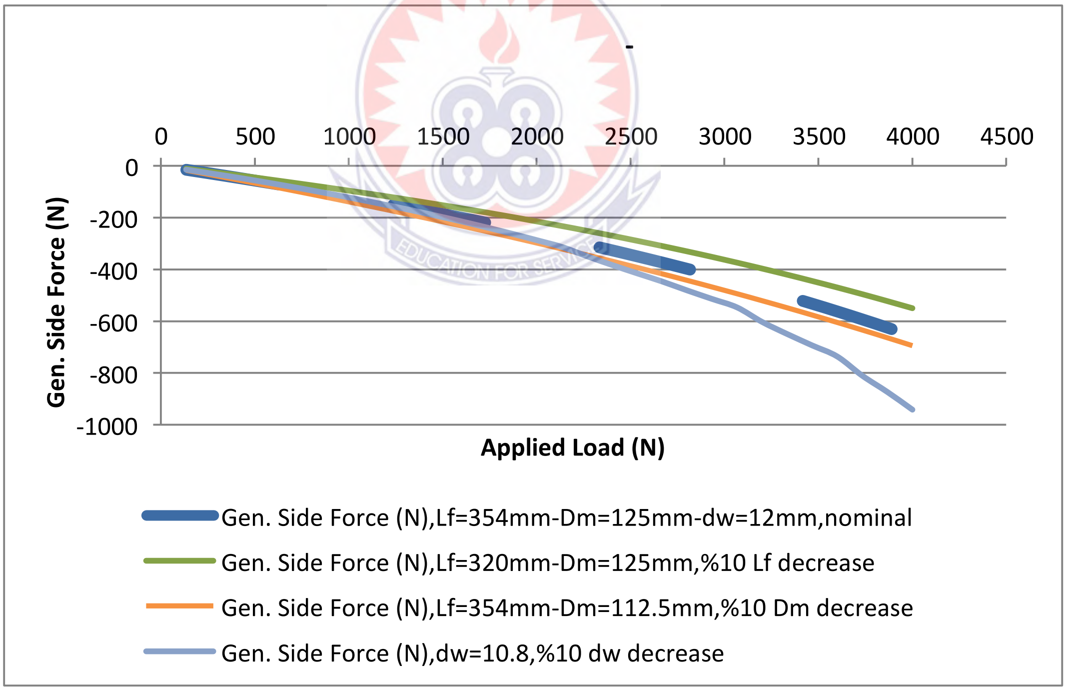


Figure 4.16: Generated Side Force Against Applied Load

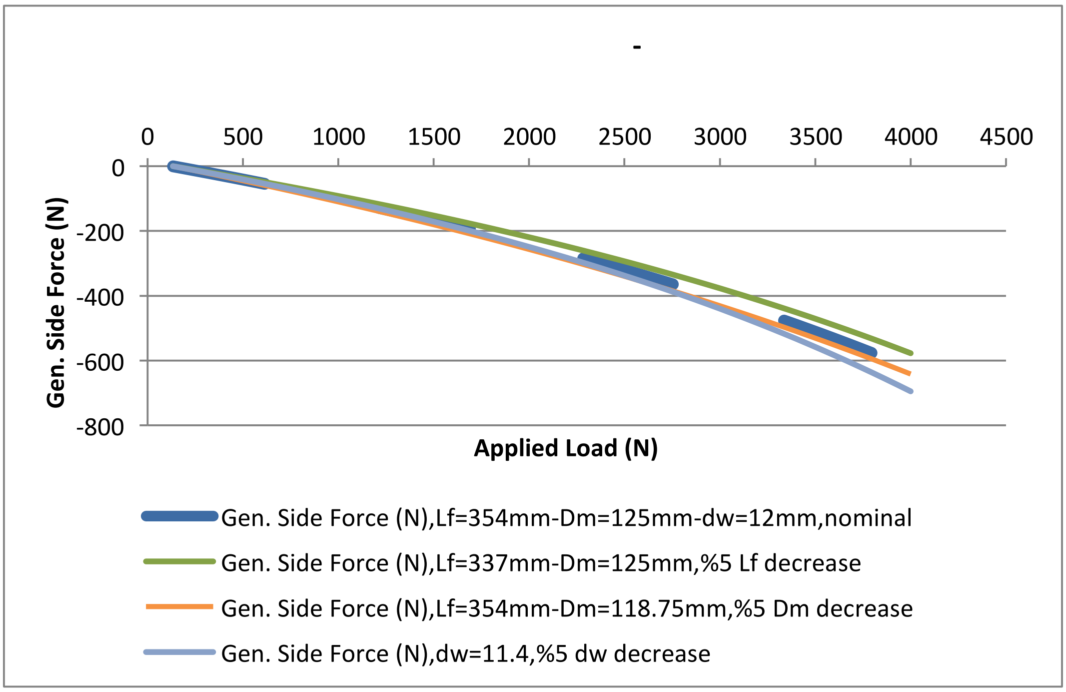


Figure 4.17: Generated Side Force against Applied Load in 5% Decrease

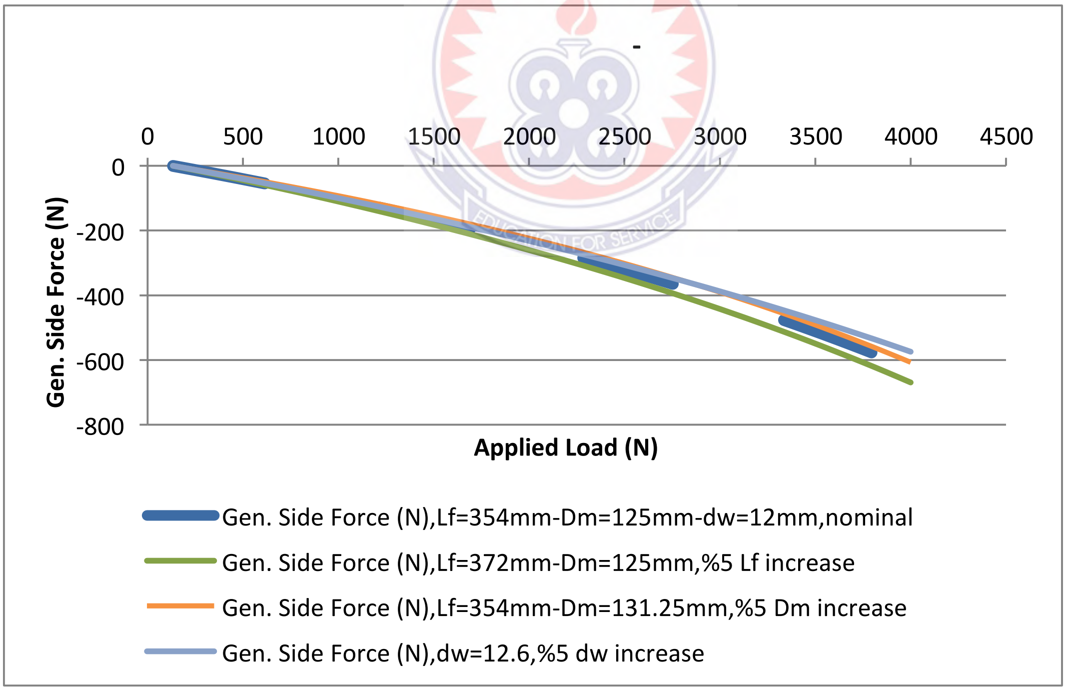


Figure 4.18: Generated Side Force Against applied Load 5% Increase

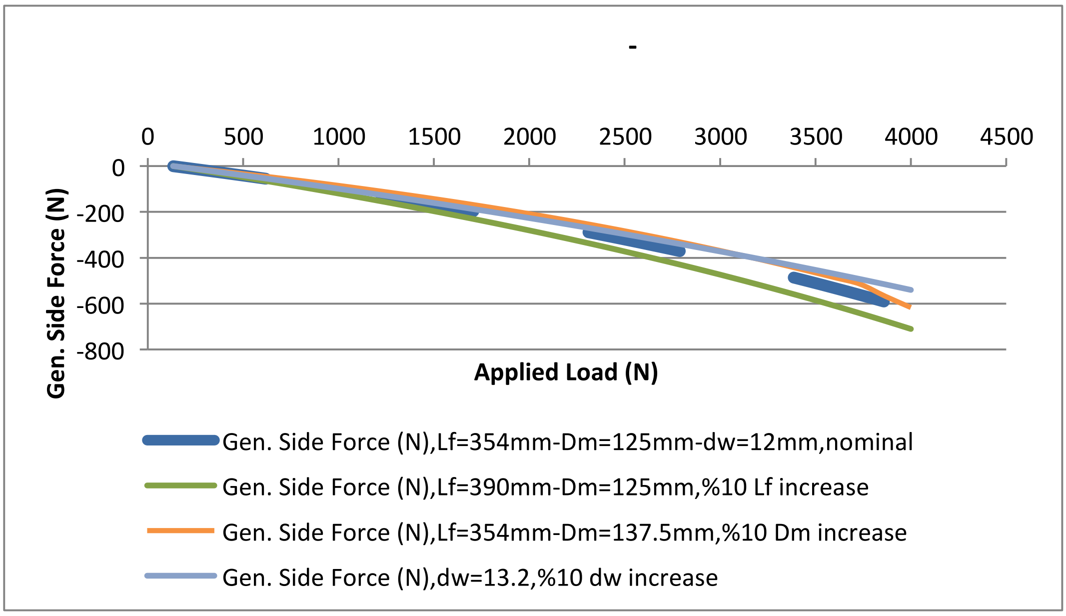


Figure 4.19: Generated Side Force verse Applied load 10% Increase.

4.7 Construction of the proposed design

The TU coil spring is constructed by modifying the OTC coil spring compressor. From figure 4.20 the compressor is made up of the (a) Jaw (b).Plain Trunnion (c).Steering Screw and (d). Long hook frame or flat bar both horizontal and vertical, spring, bolt and nuts. Figure 4.21 is also made up of the stand of the newly constructed Coil Spring Compressor. Figure 4.22 is the complete assembly of the new design.

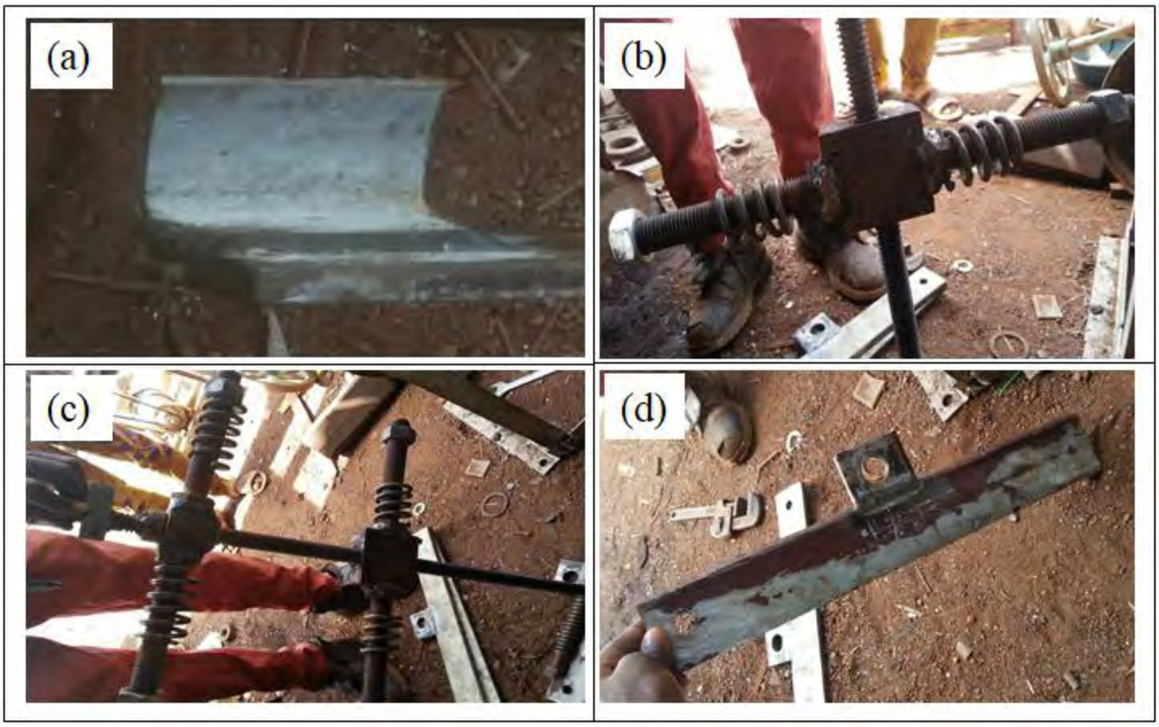


Figure 4.20: Components of the proposed Coil Spring Compressor
(a) Jaw (b) Plain Trunnion (c) Steering Screw and (d) Long Hook Frame.

The jaws hold the coil spring firmly to avoid it from sliding or striping off its hooks. It is being attached to the long hook frame, one jaw on each end of the long hook frame and made up of galvanized steel. The newly constructed coil spring compressor is made up of three trunnions, one on the lower frame, one on the upper frame and the third one is found at the end of the two frames. The two trunnions on the upper and the lower frame accommodates the steering screw and also connects the long hook frames to each other, it maintains the distance between the two long hook frame and avoid them from moving uncontrollably. It is made up of carbon steel and has a length of 300mm or (12 inches). The steering screw is a long rod which has three other smaller bars crossing its top most part, the small bars crossing the top most portions is used as a steer. When the component is being steered, it compresses the trunnion on the upper jaw towards and away from the lower trunnion end hence generate the force needed to compress and decompress the coil spring. It is a 78mm or (3 inches) round rod made of mild steel. Its length is 380mm or (15 inches) and has outside thread. The material used for its construction is carbon steel because the carbon content of the carbon steel is high and hence it is strong and hard enough to transmit the force from the steering screw to the load (coil spring) without breaking or distorting.

The stand is made up of four legs with four bars connecting one leg to the other. The purpose of the stand is to make sure that the device is stable to make working easier. A 40mm by 40mm or (1.5 by 1.5 inch) angle iron is used for the stand, in most cases the angle iron pieces are welded together to form a frame in which a fencing material is mounted. The length of the stand is 760mm or (30 inches) long so that the complete tool will be long enough to accommodate various lengths of coil springs and for it to be operated whilst the operator is in a standing position.

Figure 4.21: Base of the proposed newly Coil Spring Compressor design

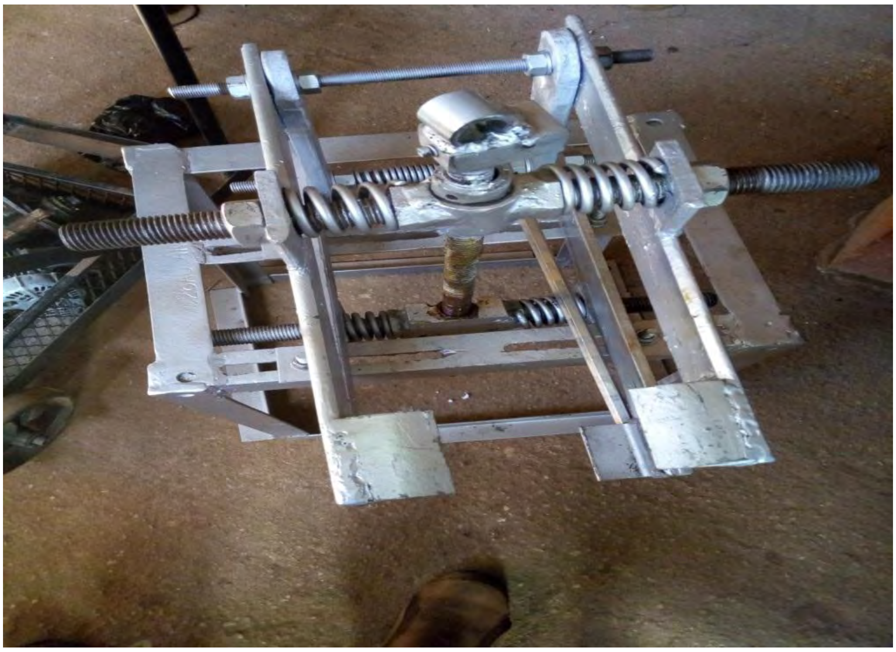


Figure 4.22: Assemble of the proposed T U spring coil compressor

4.8 Mode of Operation

This spring compressor allows the spring to be compressed with its upper spring arm against the lower spring arm with a very firm griping jaws so that the spring shape or the spring coils pitch are no longer an issue. The variable set arms spring compressing assembly, adjustable horizontal and vertical arms assembly and strut holding clamp with single hand operation widen the field of application this compressor to almost any strut or shock absorber while, at the same time satisfying the highest health and safety standard.

When the coil spring is inserted into the device, the lower part of the spring gets seated on the two jaws at the bottom whilst the two upper jaws hold the coil spring from the top part. The load (coil spring) is positioned properly so that there is minimal movement, The steering screw is then rotated clockwise to compress the upper trunnion and compel it to move the coil towards the lower trunnion, this action causes the upper long hook frame to also move towards the lower long hook frame. Since the jaws are fixed on the various hook frames, the movement of the hook frames will automatically cause the coil spring to be compressed. When the coil spring with the strut is at the compressed state or position, bolts on the absorber can then be removed with ease with a wrench and the strut be pulled out easily from the bottom. Same procedure can be followed to fix a new strut into the complete absorber.

4.9 Specific Improvement of the TU Coil Spring Compressor

The newly constructed coil spring compressor has been enforced with an additional trunnion to give it a square shape, its square shape allows the coil spring to be compressed axially and hence eliminate the possibility of the spring being pushed away as it is peculiar with OTC coil spring compressor. This new design has made the used of safety pins on OTC unnecessary yet safer to use. With the introduction of the stand, this tool can be set to a fixed position and yet be able to accommodate a wide range of coil springs without being dismantled, adjustment may be necessary only when there is the need. The introduction of the steering screw has eliminated the need to use a spanner for turning the screw to compress the spring as in the case of the OTC coil spring; this feature has reduced the operation time and has made the use of the OTC more enjoyable, safer to both operators and the environment.

4.9.1 Performance

No additional accessories are needed, the T U design of the spring compressing assembly, respectively the jaws, as well as of the radial and driving bar enables all designed spring coils suspensions and damper strut designs to be compressed and repaired, no additional jaws needed as shown in the complete assembly of the compressor. The jaws are able to withstand the forces exerted by the load (coil spring), the steering screw does not require so much force to be turned during operation. Also the steering screw is able to hold the spring in the compressed position without returning on its own.

The jaws in collaboration with the locking pins are able to hold the load (coil spring) in a stable position to stop it from moving freely. The plain trunnions are not fixed to any part of the body and that they have the ability to move slightly towards the direction of the jaws when in operation. Mobility of the compressor, though it can be fixed on the workshop floor permanently, it as well can be made mobile by moving it with the workshop trolley. The workshop trolley is ideal for use in garages and workshops allowing the user to carry out repairs conveniently next to the vehicle.

4.10 Safety

Allows for one-person operation unlike other compressors discussed in the literature as well as the O T C original design when one will need the support of the other in order to be able to operate the O T C, the T U design has the procedure that can be carried out by just one person, the strut holding clamp is equipped with a quick clamping and comfortable seating seat for the strut and a hand operation device to allow for ease of use. No damage to the strut, the special tube holding clamp can quickly be adjusted to the corresponding strut diameter and the height of the spring coils and the clamping jaws feature protect most plastic coatings.

With the redesigning of the OTC it is safe to operate compared to the original design, but remember any piece of equipment can be dangerous if not operated properly. The operator is always responsible for the safe operation of this equipment. The operator must be well vest in the operation of this equipment before putting it into use.

A compressed coil spring is very dangerous, be extremely careful, never stick fingers, hands, or other body parts anywhere that they may be pinched or smashed. This tool has and creates multiple pinch points. It may come lose with extreme force. There is a chance of parts being shot at high speeds, this could cause serious injury or death to the operator or by standers, keep hands, feet and all other body parts clear at all times. Never operate equipment of any kind if tired or under the influence of alcohol, drugs, medication or any substances that could affect your ability or judgment.

Using this tool requires dissemble of some components of the suspension, if the operator is not confident that the work could be completed safely, then have work performed by a certified technician or person who is familiar with the front suspension of the vehicle. Failure to reassemble the suspension properly can lead to serious injury or death.

CHAPTER FIVE

SUMMARY OF FINDING CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this study of the redesign, construction, and testing of the Owatana coil spring company tool were examined and important aspects of the tool was analyzed. This chapter mainly talks about the summary of findings, discussion, conclusion, recommendations, and possible suggestion for further research into the topic under study.

5.2 Summary of Findings

The work has been carried out successfully as expected, even though it came with some challenges. Getting access to tools and equipment to work with was a big challenge. Most of the tools and equipment that was used were obtained from certain individual workshops; some of the tools and equipment were available but not functional whilst others were completely unavailable. Working in workshops owned by individuals outside the school workshop caused so much inconvenience and more expensive, but despite all these difficulties and challenges, the aims of the design have been achieved.

- The TU coil spring is constructed by modifying the OTC coil spring compressor which has been in existence for some time now but because of the difficulty in operation of this tool many users did not enjoy its use hence many technicians opting for the belt type of coil spring compressors.

- This new design is made up of a stand, which has made the tool very simple and very convenient to be used by one person without the support of others and without also the use of pins as the new design is self-griping tool.
- The jaws are able to withstand the forces exerted by the load (coil spring), the steering screw does not require so much force to be turned during operation. Also the steering screw is able to hold the spring in the compressed position without returning on its own.
- The jaws in collaboration with the locking pins are able to hold the load (coil spring) in a stable position to stop it from moving freely. During visits to some of the workshops to find out what they know about spring coil compressors, it was clear from all indications that, all that the local workshops knew about compressors was the belt type compressors and nothing else. When asked if they know the danger it pose to them as operators and the environment, all that they could mention was the pinching and trapping of the fingers when in use, but they know not of other dangers. Resourcing of local automobile workshop is a major problem per discussion with the various shop owners. Tooling and equipping of the shops is a major factor in a lot of parked cars because in most cases the shops do not have what it takes to take up a task, that is where the right tool is used for the wrong job there by creating other problems for the car owners who go to the shops to have their cars maintained. Technology is advancing each passing day and automobile shops should also advance in that direction. Using the new design coil spring compressor would have been the safer means of removing and replacing of a suspension system of a car but the workshop technicians prefer going for cheap tooling and equipping devices rather than

going for right one which in most the times create problems for car owners instead of solving their problems.

There were a lot of expenses associated with this design, as the materials used in the design needed to attain certain qualities and in order for the equipment to withstand the test of time and durability. Almost all the materials were bought in the open market hence the high cost of it. That does not in any way suggest that the tool is expensive than the dangers associated with the use of some the improvise tools used at those shops. In the course of carrying out this design work, it was realized that the original design was not going to be of better performance, some elements needed to be inculcated into the design to improve it. The specific realization was that using one trunnion would be problematic, hence the additional trunnions to avoid the problem. This project has been very helpful in the sense that, it has broadened the knowledge of both the designer and the local automobile players who did not know much about the existence other compressor tools about from the belt type of compressor. This design has revealed some realities about tools production, and good working practices. The difficulty encountered has given so much experience which will help in other future designs.

The aim of the design analysis of the OTC compressor is to redesign and construct a coil spring compressor device that will be easily accessible to the local workshops and Mechanics in order to ensure their safety and that of those who visit their workshops, and also that will be easy and simple to operate per the number of persons who operate some of the existing compressors.

That will be safe to operate, per the new design, which will enable one person to operate. Reduce time spent in compressing a coil spring, because the old design requires that more than one person can operate the system and the safety of that tool was also in question. All the parameters set to achieve this design was attained except the time frame which was not met because of the difficulties in obtaining some of the materials and tools for the construction of this design.

5.3 Conclusion

On a visit to most of the Automobile workshop in the Sunyani Municipality it was found out that though they are into the removal of coils from car suspension but almost all of them use the belt system, so none of them knows about any accepted methods of removing this element. Some of them used the above mentioned methods because of the following reasons;

Some do not know that there is a standard ways of removing it;

Others also think that the tools are difficult to operate, most especially with the OTC design.

Whiles others are of the view that the tool is expensive to buy hence the use of the old methods which is not safe, difficult to be operated by one person, and difficult to have access to.

5.4 Recommendations

Based on the findings of this study from visits to some automobile workshops and the prevailing situations in these workshops, the researcher would therefore like to recommend the following for consideration. All car owners who visit the local workshops to have their suspension either replace or maintained should insist that technicians uses the appropriate method of removing the coil spring. Hired technicians should insist that the shop owners acquire the right tool for the right operation in the shop mostly when it has to do with the assembling and disassembling of spring coil compressors. Local Automobile workshop operators are not under any safety regulatory body and that certain measures are difficult to achieve with them but customers who service their cars at their shops should make them obtain some levels of training in this advancing era of technology and innovations.

5.5 Suggestion for Further Research

The researcher would advocate a compressive assessment of the automobile workshops in the Region and the country as a whole to ensure that the Technicians hired in the various workshops do know what tool to use at what point in time to minimized avoidable accidents in those workshops to ensure the safety of both personnel and the environment.

Further studies can also be carried out on the safety measures taken by the various workshop managers to ensure the safety of both technicians and the equipment at the workshop.

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APPENDIX I

Results obtained from the testing

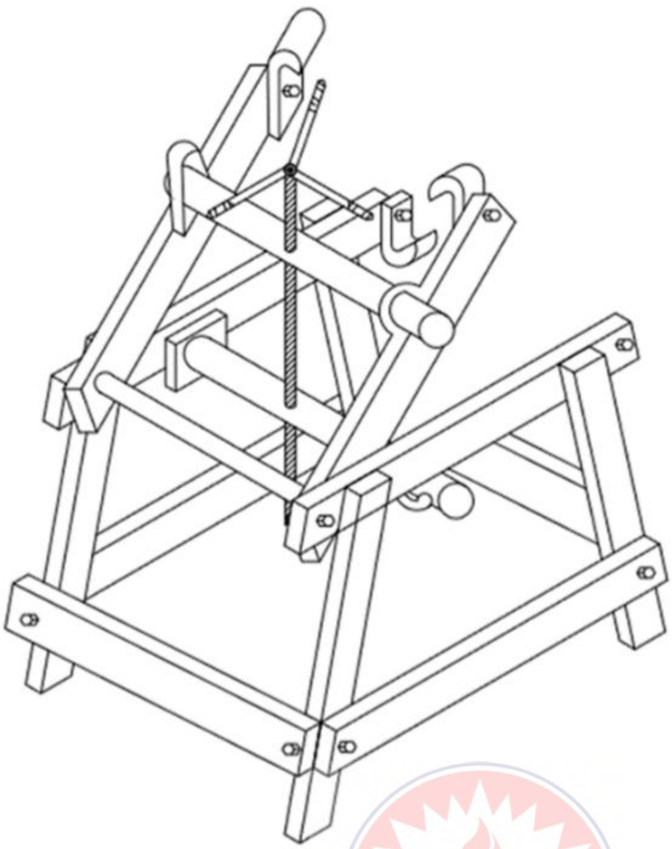
No.	Load (Kg)	Deflection
1	0	345
2	5	301
3	10	270
4	15	245
5	20	225
6	25	210
7	30	200

(a) Measured angle in (degrees), load in (kg) and deflection in (mm) for new design

No.	Angle(degree)	Load (KG)	deflection
1	0	0	345
2	90	0.5	.05
3	180	1	1
4	270	1.5	1.5
5	360	2	2

(b) Measured angle in (degrees), load in (kg) and deflection in (mm) for old design

No.	Angle(degree)	Load (KG)	deflection
1	0	0	345
2	90	0.5	0.3
3	180	1	0.8
4	270	1.5	1.3
5	360	2	1.8



TU coil spring compressor