THE DEVELOPMENT OF A SUSPENSION SPRING IN TERM OF DIMENSION

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ABSTRACT

This thesis involved with the development on the dimension of suspension spring. The parameter focused on was the wire diameter, (*d*). Suspension spring is very important for automotive industry as its functions are t give riding comfort, good stability and good control of the car. The objective of this thesis is to develop a new optimum dimension for wire diameter of a suspension spring. The technique used for developing the diameter was finite element analysis. The spring will be modeled using Solidworks and undergo static loading and cyclic loading which then will give the fatigue value. The wire diameter was changed within a range which is slightly different from the dimension of spring available in automotive market in Malaysia nowadays. An experiment was conducted which related with fatigue test. Specimens with the same material used for suspension spring was used. The fatigue test gives the data for S-N curves. From the cyclic loading, three methods were used, Morrow, Coffin-Manson, and Smith-Watson Topper method. The differences from the value obtained from these methods were compared. The load acting on the spring was exerted form the action of contact between the tire and the road. The results show the static failure, displacement, stress and the strain produced on the spring. The spring was analyzed until it is damaged which indicate the static failure value. Based on the analysis, the 12.5 mm wire diameter gives the optimum value which can have a longer fatigue life. The spring available in market was 13 mm and the value obtained from this thesis was slightly different from the market. The percentage of deviation was 3.8 %.

ABSTRAK

Tesis ini melibatkan pembangunan dari segi dimensi spring suspensi. Parameter yang digunakan memfokuskan pada diameter wayar, (*d*). Spring suspensi sangat penting kepada industri automotif kerana fungsinya adalah untuk memberi keselesaan semasa pemanduan, kestabilan yang bagus, dan pengawalan kereta yang baik. Objektif tesis ini adalah untuk membangunkan satu dimensi optimum untuk spring suspensi. Teknik yang digunakan adalah analisis unsur terhingga. Spring tersebut akan dimodelkan di dalam perisian Solidworks dan akan menjalani daya statik dan juga daya berulang yang akan memberikan nilai lesu. Diameter wayar telah ditukar berdasarkan julat yang sedikit berbeza daripada dimensi spring yang berada di pasaran automotif di Malaysia hari ini. Sebuah eksperimen telah dijalankan melibatkan ujian lesu. Contoh yang mempunyai bahan yang sama dengan spring suspensi telah digunakan. Ujian lesu memberikan data untuk lengkungan S-N. Daripada daya berulang, tiga cara digunakan, Morrow, Coffin-Manson, dan Smith-Watson Topper. Perbezaan nilai yang didapati daripada cara-cara tersebut dibandingkan. Daya yang dikenakan ke atas spring adalah hasil daripada sentuhan antara tayar dan jalan. Keputusan menunjukkan nilai kegagalan statik, anjakan, tekanan, dan tarikan dihasilkan ke atas spring. Spring tersebut dikaji hingga mencapai kerosakan yang akan menghasilkan nilai kegagalan statik. Berdasarkan analisis, diameter wayar 12.5 mm memberikan nilai yang optimum yang akan memberikan jangka lesu yang lebih lama. Spring yang berada di pasaran adalah 13 mm dan nilai yang didapati daripada tesis ini berbeza sedikit daripada pasaran. Peratus sisihan adalah 3.8 %.

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LIST OF SYMBOLS

ε	Strain value
σ	Stress value
S	Fatigue value
%	Percentage

LIST OF ABBREVIATIONS

d	Wire diameter
D	Loop diameter
FEA	Finite element analysis
mm	Millimeter
MPa	Mega pascal
N	Newton
P	Pitch
SAE	Society of Automotive Engineers
S-N	Stress versus number of cycle curve
SWT	Smith-Watson Topper

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In this chapter, it will give an overview about the title of this research, history of the research done before, the problem statements, the objective of this study and the scopes of study for this research. The overview will only be general information and the details for this research are discussed in other chapter. Basically, spring is an element which had the ability to compress and extent when a force is applied. After the force is removed, the spring will return to its original condition. For this research, a mechanical spring will be used. A mechanical spring can be defined as an elastic body that has the primary function to deflect or distort under load, and to return to its original shape when the load is removed (Prawoto, 2008). When the load is applied to a spring, the spring will experienced deformation and some of the available properties that can be analyzed from this deformation are the stress, strain and displacement. For this research also, the load will be exerted at the bottom of the wheel and not from the car body mass. The reason is because the car body mass is fixed mass acting on the spring while the bottom of the spring is the place where it will be attached to the wheel. The effect of movement of the wheel will provide loading from the wheel to the spring.

An easy way to understand is when the wheel move over a bump, the wheel will move upward in a sudden moment and exert a compression force to the suspension spring. After it move pass the bump, the spring will return to its original condition. However, in real phenomenon, the cycle happens very fast as the wheel rotates and moves over bumps, straight road or moves over holes. Thus, the spring will compress and extend simultaneously. Until the vehicles come to a stop, the spring will experience continuous force or what is known as cyclic loading. The action done by the spring while the vehicles are moving is very important as the spring will absorb the impact created by the wheel on the vehicles. If the spring fails to absorb the forces, this will cause the car body mass to receive a greater force which then will give a poor stability to the vehicles. It also can put the passengers in uncomfortable situation as they will experience the force exerted from the wheel.

A vehicle will require a good suspension spring to operate on the road without harming the passengers and in the meantime, give a comfort ride to them. This situation needs to be solved by introducing a good quality suspension spring which can provide a higher stability, safer condition and comfortable ride to the passengers. This research will study the factors to improve the suspension spring quality and properties.

1.2 BACKGROUND

The reason why the suspension spring nowadays needs to be developed is because the function of the suspension spring itself needs to be improved. The function of the suspension spring for an automobile is to keep the good control stability for the vehicles. Other than that, suspension spring also functioning in providing a riding comfort to the passengers. The purpose of keeping the good control stability of the vehicles is to ensure that the vehicles are safe to be used. Many of researchers worked hard to design a new suspension spring so that the suspension spring will be able to give good control stability.

In designing a suspension spring, there are many factors need to be considered. The major factor is the dimensions of suspension spring. The design parameters of a coil spring are the rod diameter, spring diameter and the number of coiled in the form of a helix (Das, 2006).

Based on history, the suspension spring was developed by adjusting the dimensions of the spring. After that, the material of the suspension spring was developed. Thus, the other factor need to be considered in this research is the material used to produce suspension spring. Other than these two factors, there are many more factors that can influence the performance of the suspension spring such as the shape of the suspension spring, the method of making the spring, the surface finish, human factor which involves with how the user operate the vehicles whether in suitable way or not, the road surface and many more. From this research, the new suspension spring that will be develop will focused more on the dimensions of the suspension spring. The new develop suspension spring must be able to have a longer life time and can withstand a cyclic loading without failure longer than the existing suspension spring.

1.3 PROBLEM STATEMENT

Suspension spring is one of the main parts that must be installed in an automotive vehicle. It helps to reduce the force taken by car's body. The force which exerted from the movement of the wheel along the road can give the passengers an uncomfortable ride. Spring is the solution as it will absorb the vibration cause by the wheels. However, production of suspension spring required so many factors that need to be revised. This research will identify the problems that are faced in fabricating suspension spring. The problems will become the factors that can influence the ability of the spring to operate as shock absorber. The major problem that was identified a long time ago when the first car was invented is the spring dimensions. A spring need to have its optimum dimension so that it can give optimum result to the vehicles. As many people aware, spring had the ability to return to its initial state when the force exerted to it was removed. This ability will be utilised when the spring was manufacture with exact optimum dimensions. The dimensions that will be considered are the wire diameter of the spring, the diameter of the spring or coil diameter, the length of the spring and the distance between the loops of the spring.

Even though the dimension was determined perfectly, a spring will still be a mechanical device that experienced a cyclic loading or continuous loading. As the law clarify, a material that received a simultaneous load will reach to its limit or as also known as the fatigue life cycle. The spring material cannot withstand the cyclic loading forever. At one moment the spring will reach its failure point. This is also become the one of the problem faced in fabricating suspension spring.

1.4 OBJECTIVE

The objective of this research is to develop a new suspension spring in term of dimension and optimize the spring wire diameter, (*d*).

1.5 SCOPE OF STUDY

In order to achieve the objective of this study, the following were outlined as follows:

a. To study the factors that will be considered into the new design.
b. Computer modelling using software such as SOLIDWORKS.
c. Model analysis using PATRAN/NASTRAN for static loading.
d. Model analysis using software such as GLYPHWORKS and DESIGN LIFE for cyclic loading.
e. Analyze the data obtained and select the data that have optimum results.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, 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.

2.2 SUSPENSION SYSTEM

A car suspension system is the mechanism that physically separates the car body from the wheels of the car (Sam, 2006). 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 (2006) 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 and 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.

2.2.1 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.

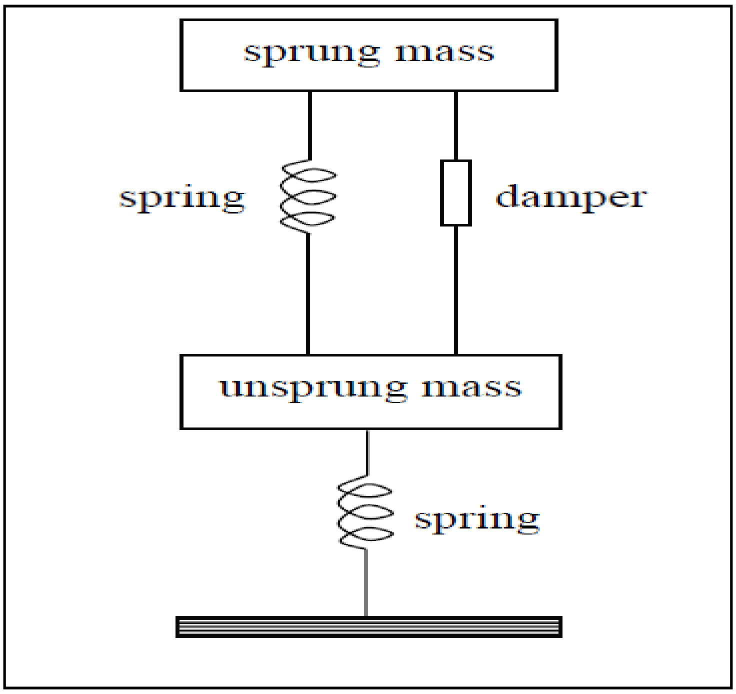

Figure 2.1 The passive suspension system

Source: Yahaya (2006)

2.2.2 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. Williams (1994) 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.

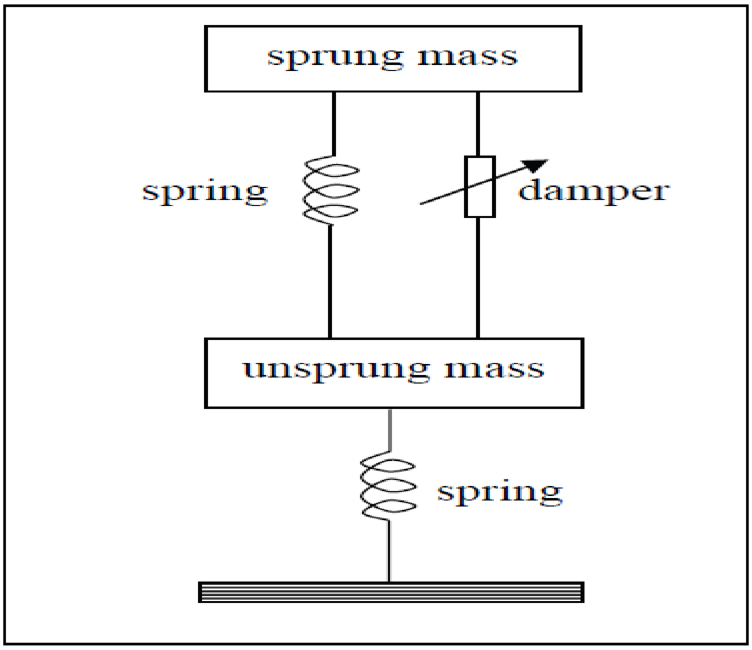

Figure 2.2 Semi active suspension system

Source: Yahaya (2006)

2.2.3 Active Suspension System

Crolla (1988) mentioned that he divided the active suspensions 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.

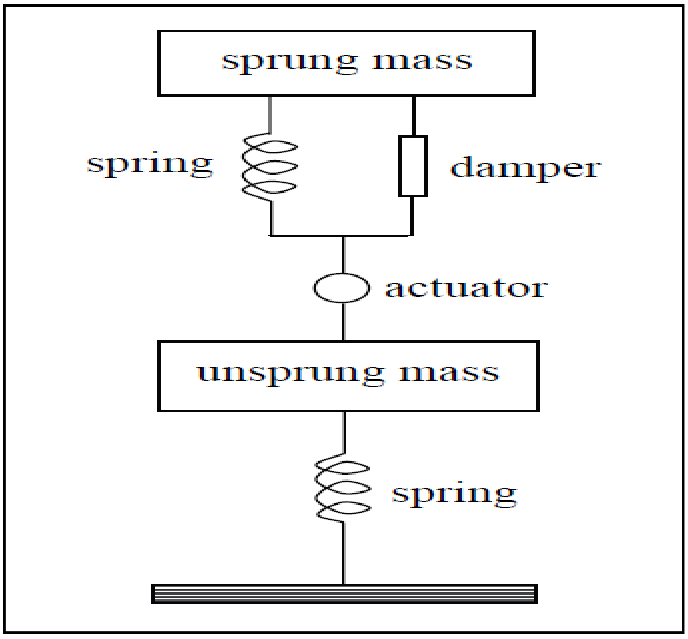

Figure 2.3 A low bandwidth of soft active suspension system

Source: Yahaya (2006)

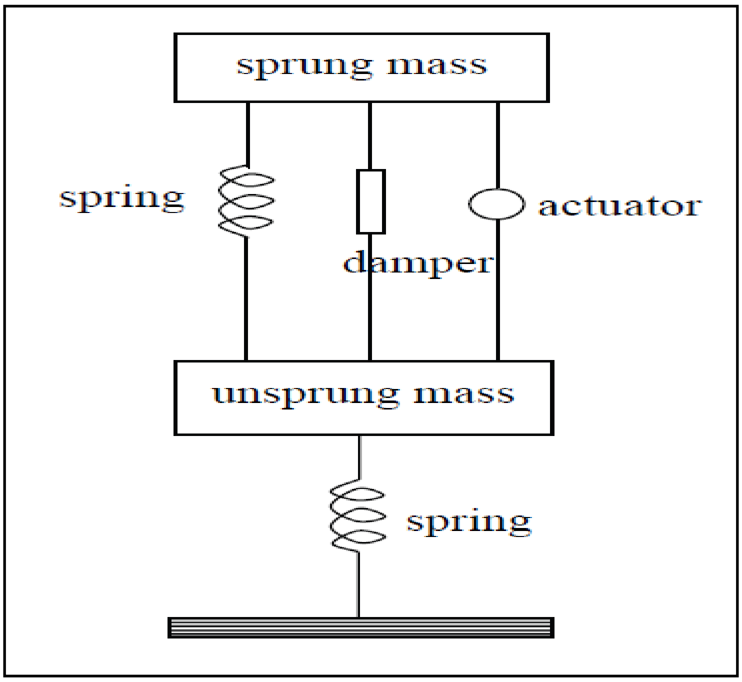

Figure 2.4 A high bandwidth of stiff active suspension system

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.

2.3 SPRING

For this research, it focused on the mechanical spring. 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, 2003). The function of the suspension spring is to maintain good control stability and to improve riding comfort (Watanabe, 2001).

2.4 SPRING DIMENSION

In producing spring, there are 3 main dimensions that need to be focused on. These dimensions are the parameters that affect the behaviour of spring (Bakhshesh, 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 2.5.

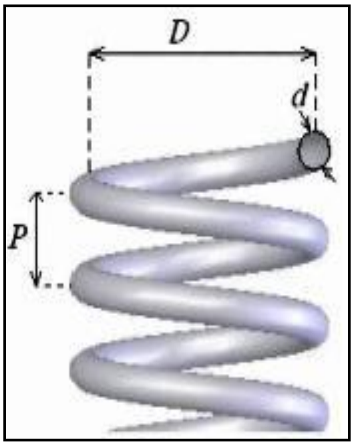

Figure 2.5 Parameter of helical spring

Bakhshesh (2012) used the dimension listed in Table 2.1 for his research which he claimed as the standardise 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 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 Talib (2009) proposed dimension. Talib (2009) also chose the dimension as close as Baksheih (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. The wire diameter will be selected in a chosen range which will be discussed in next chapter.

The range will be between the ranges mentioned by previous researcher. In order to get the optimum wire diameter, the values will be varied but still in constant order. The difference between each dimension will increase in well-ordered selected value. The selected dimensions are viewed also in next chapter. This research focused on the automotive industry in this country. Thus, the reference wire diameter will be 13 mm. It is because the wire diameter is widely use by manufacturer company in Malaysia.

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 located between the wheel and car body. If the diameter of the coil being manipulated, it can cause the suspension spring cannot be installed into the vehicles. 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 body 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.

2.5 SPRING MATERIAL

From the 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, 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. Fibre-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 favourable 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.