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STUDY OF SPRING DESIGN PARAMETERS AND THEIR OPTIMIZATION TO ENHANCE SPRING ENERGY STORAGE CAPACITY UNDER THE ACTION OF STATIC LOAD

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Abstract

Spring is the mechanical device which used in energy storage whose magnitude will vary with respect to every alternate cycle. Thus it can be says that, spring elements are subjected to magnitude of fluctuating load during their entire service life. Energy storage capacity is the function of maximum possible deformation spring can undergoes for applied magnitude of loading. The spring will be a good source of energy reservoir, if designed and manufactured with optimized parameter range maintained throughout the process. The various characteristics affected on spring performance will chalk out at the end of research paper writing ad that will be a great lead for manufacturing engineer to manufacture such idle spring structure. The value of various parameters like for example wire diameter (d), maintained up to one particular limit will add positive response in operation, but slight increase or decrease in said value will immediately start to take performance level down, so along with optimization, defining idle range for such parameters existence is also an important task supposed to address through this paper. Effective design will not only address, issues like strength, reliability but it ultimately effecting on cost of structure which need to maintain within affordable range. Case study under consideration, though dealing spring design for gradually applied load, real time picture is quite different, where spring structure will continuously impacting by variable stress magnitude during every alternate cycle, so design required high consideration for FOS (Factor of Safety) to accommodate dynamic loading effects too. This paper describe an approach of design fellow who investigate his attention in spring design, its performance measure, parameter alteration and hence design optimization to address the basic product design development issues like product cost and quality and launching time.

Key words: Spring, deformation, load, stress etc**.**

1. Introduction

Spring is mechanical device used to store the energy with respect to every cycle of variable load acting. Energy stored per unit of spring volume is the function of material properties and various design aspects maintained plus shaped out precisely. For example, minimum adjacent gap maintained between various turns of spring will enables the spring structure to deform to maximum possible extent and thus exhibits maximum capacity of energy storage. But spring structure design to maintained maximum adjacent gap, if acted upon by loading which deform it beyond permissible limit, thus with exceeding limit of maximum possible deflection, entire structure will put forth to failure.

Patented and cold drawn steel wire has reduced ultimate tensile strength, as residual stresses as a impact of cold drawing operation will not allow structure to take quiet more load as alloyed spring wire finished with mild heat treatment and slow cooling can. So the wire has got less endurance strength which broadens its use when uncertainty in the magnitude of load acting will be risen spontaneously.

The alloyed steel, high carbon steel, spring steel wires are few of the popular steel categories recommended in the operation at vast.

Spring elements are designed for fixed magnitude of load (Three to four times more than highest load intensity of fluctuating load acting), testing is also done for same magnitude of load acting (As pattern of load intensity varying is difficult to predict and tends to vary cycle to cycle always). Fatigue failure of mechanical component is not only the function of intensity of varying load, but it also strongly affected by component surface finish, component size, environmental conditions etc. Consideration of all such factors together will reduces spring material strength with making process of analysis complicated further.

As per helical spring structure is concern, it always subjected to torsional shear stress under impact of axial loading. In addition to stresses induced due external loading, material intermolecular discontinuities, type of heat treatment and cooling methodology recommended also affects strongly in the stress inducement. Leaf spring structure, which acts suspension support to automobile assembly subjected to magnitude of bending stress. The door supporting spring i.e. helical torsion sprigs are added with impact for bending in combination with shear stress. Apart to this all, type of curvature affect spring has imposed during manufacturing, type of geometry which causes factor stress concentration to become more stronger are few of the reasons can be enlisted behind stress inducement and hence structure weaken.

Spring structure can impart with more safety if made with provision for more deformation to occur. Degree of spring deformation and hence energy storage will be the function of number of active turns in coil, adjacent gap maintained between various turns of coil, spring material, modulus of elasticity, modulus of rigidity and type of heat treatment and thus cooling operation structure was recommended for.

Spring wire diameter, spring mean coil diameter and spring index also add positive impact on capacity of spring energy storage if maintained for one precise value or range. Spring wire diameter, will not only defines spring strength during entire operation but responsible for its precise manufacturing with good control taken over its cost and hence affordability. The correct value maintained for spring index will stabilize the structure with enhancing its capacity to sustain the load in axial direction or any as such loading structure will subjected further, but selection for wrong value and design process execution done so will lead the structure to buckle under applied load which though not put forth structure under failure, it not makes structure liable to withstand for applied loading conditions which are getting serious more and more with respect to time.

2. Types of spring: The discussion held so far clears, spring is mechanical element used as energy reservoir. The material yield point will limits the capacity of this energy storage. To serve various needs, following spring types and structures are intended in to service.

- **Helical spring:** Helically wrapped spring coils about its central axis either subjected to compression or tension. During, every alternate cycle of load acting, spring structure will be subjected to torsional shear stress which expectedly should not goes beyond maximum stress value induced at material yield point. Such type of spring structures generally introduced at the place of bike suspensions, bike stand, bi-cycle stand etc. During compression or tension movement of spring, structure will always subjected to torsional shear stress.

  Torsional shear stress = τ = Primary shear stress due to twisting + Secondary shear stress/Direct shear stress

  $\tau = \frac{16M_t}{\pi d^3} + \frac{P}{\frac{\pi}{4}d^2}$………(2.1)

- **Leaf spring:** Spring structure is used as automobile suspension, where magnitude of impact load acting will sustained due to sequence of small leaf, gradually varying in length will hold together under nut-bolt and clipping fasteners. Leafs are bent for different radius of curvature about their same point of origin. The leaf, bent for small radius of curvature will gain superior strength of deformation and thus load sustaining over leaf spring bent for lower radius of curvature. Each leaf thus entire leaf structure will subjected under magnitude of bending stress whose magnitude tends to fluctuate with respect to every alternate load cycle.

  Bending stress = σ_b = $\frac{M_b y}{I}$………(2.2)

- **Helical torsion spring:** Spring type will support door structure to retain its slow motion when released from load. Under the impact of movement, spring structure will subject to magnitude of bending and torsional shear stress. The effect of curvature and spring geometry also adds various stresses magnitude in addition the magnitude of stress induced due to external loading.

  Resultant stress acting on spring structure = $\tau + \sigma_b = \frac{16M_t}{\pi d^3} + \frac{M_b y}{I}$……..(2.3)

3. Spring design methodology and relevant mathematical model: Spring design is the process which compiling of various sub process arranged for definite sequence and that includes material selection to final product testing. Exercise will keep moving continue for every fresh product launching with bit changes made in the earlier one.

Various assumptions need to consider while addressing issues of spring design. Every design parameter cannot be derived up to the accurate possible extent so some mathematical relationships require their manual defining. The attempt of assumptions considered or few design parameters if seem on the verge of delivering faulty results, the alteration made in basic mathematical model will probably pulled out the desired one. Spring design intends following sequence of various tasks execution,

Material selection: Following material choices are available to address the process of spring design further,

a. Patented and cold drawn steel
b. Alloyed steel
c. Spring steel wire
d. Oil hardened steel

The material selection will mainly centric about values chosen for (E-Modulus of Elasticity) and (C- Modulus of Rigidity). The consideration given out for material factor of safety (FOS) also matters a lot in the view of effective product manufacturing requires less expenditure over various operations.

Spring geometry: Helical geometry will be chosen in spring design, also in addressing all relevant issues arise later. The degree of curvature and geometry type will results additional stresses acting, impact for which need to summarize with stress induced due to external loading. The more stress magnitude considered over actual induced one, will accommodate the effect of additional stresses acting on structure. The factor (K) introduced in design mathematics will intensify loading magnitude twice or thrice over the actual one.

The factor (K) is called as Wahl's factor and is value can be considered between (1 to 2.5) in an approximation.

Styles of ends: The inactive turns of coil are generally placed to extreme end of spring structure, they not participates in deformation but support the structure throughout operation. General spring structure will consist two such inactive turns located at extreme ends of spring. They are already flat in position and so, cannot put under deformation further but support the structure throughout operation. The idle spring structure would recommend for minimum number of such turns so with more number of active turns energy storage capacity will rise further.

Total number of turns (N) = Number of active turns (N_a) + Number of in active turns (N_i)……(3.1)

Spring Index: Value for material spring index should maintain between range (2 to 6). As excess or less consideration for these values will buckle the structure and not allows it to stabilize against higher axial load acting.

Calculation for wire diameter: The maximum shear stress sustaining capacity of material is the function of ultimate tensile strength, so the dimensions for spring wire can be predicted ultimately.

$\tau = 8\left(\frac{KPC}{\pi d^2}\right)$…………(3.2)

Where, expression for shear stress can written as, $\tau = 0.5\ S_{ut}$……(3.3)

Mean coil diameter prediction: Mean coil diameter (D), is the product of multiplication, spring index with wire diameter.

$D = C*d$…..(3.4)

Restrict the value for maximum permissible spring deformation: The maximum permissible deformation is restricted to 30 mm for spring structure under study.

Calculate the spring stiffness: Spring stiffness is the ratio of load vs. deflection

$K_s = P/\delta$……(3.5)

Calculation for number of active and inactive turns: The number of active turns can predict from following equation,

$\delta = (\frac{8PD^3N}{Cd^4})$…..(3.6)

N- Total number of active turns (In the paper work, all turns are considered as active only)

Define precise value for spring coils adjacent gap: More spring can deform more the energy it can be stored and vice versa. The adjacent gap is maintained for (1 mm).

Finding various spring lengths: The degree of deformation supports the phenomenon of spring contraction and expansion which can be studied under various spring lengths as defined and discussed below,

a. [Solid length = Number of turns (N) * Spring wire diameter (d)
b. Total axial gap for spring under partial deformation = (N-1)* Gap between adjacent spring
c. Compression length = Total axial gap + Maximum permissible deformation (δ)
d. Free length = Solid length + Compression length]………(3.7)

Finding pitch of spring: It is distance between point on one turn of coil to concern point on next subsequent thread measures in axial direction.

Free length = Total number of turns in coil (N) * Pitch (p)……(3.8)

Energy storage capacity of spring:

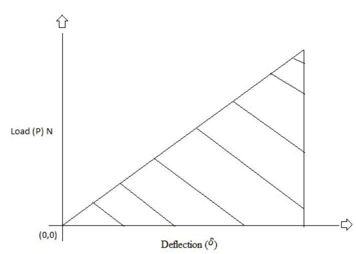


Fig (3.1): Work done during gradual loading apply on specimen

The work done, hence energy stored per unit specimen volume, can be expressed as follows,

Work done (W) = Energy stored (E) = $\frac{1}{2} * P * \delta$ (N.mm)……(3.9)

The region/area falls under gradually increased loading/straight line represents amount of work done and hence energy stored during that work done.
The above formulation can be altered in terms of various spring parameters to predict what exact quantity of energy it can be stored under the action of gradually applied loadings.

$E = \frac{1}{2K} (\frac{\pi\tau PD^2N}{Cd})$ (N.mm)……..(3.10)

4. Case study and Problem definition:

- **Case Study:** The spring of motor bike suspensions are expected to provide with enhanced capacity to absorb shocks and vibration. The compact spring construction will reduces space utilization and thus ultimate dimension reduction of all accessories introduced to hold spring structure at proper position during and even after purpose served, which shall also reduce the cost of product design development. The compact coil and hence spring construction will widen the area of its applicability too. Suggest an optimized parameters set in designing and manufacturing of spring structure which will fulfill entire engineering requirement at best affordable deal.

- **Problem definition:** Design a spring structure which can sustain the least magnitude of static load (1250 N), whose intensity must consider equals to fluctuating
- load during actual design exercise. Assume all appropriate data and shape out the process which results in spring structure design capable for maximum energy storage and load sustaining during its entire service life.

5. Assumptions and parameter values considered: The spring design to address, problem definition stated above has carried out in various steps as shown down,

Problem Definition in brief: Spring design to sustain Magnitude of load acting (1250 N)

Spring material selection: Patented and Cold Drawn Steel Wire

S_{ut}= 1090 N/mm^2

C = 81370 N/mm^2

Type of spring geometry selected in the process of design further: Helical spring

Number of inactive turns in spring = 2 (Each located at extreme end of spring)

Total number of turns (N_t) = Active turns (N_a) + Inactive turns (N_i)

Various assumptions and parameters considered:

Spring index = C = 6

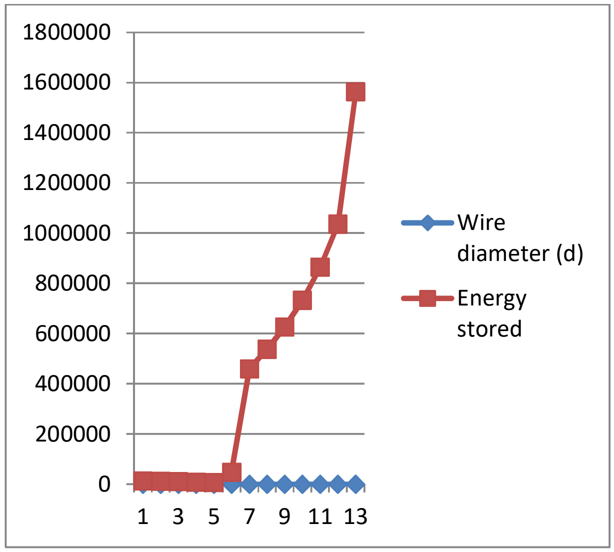
Maximum permissible spring deflection = δ = 30 mm

Adjacent gap between various turns of coil = 1 mm

By referring the set of various formulations right from (2.1) to (3.10), energy storage capacity of spring can be predicted under the set of applied loading conditions.

6. Spring design and optimization methodology: The impact of various spring parameters in term, spring energy storage capacity is discussed below one by one. The various graphs posted below, studies, the spring energy storage capacity with respect to unique value of various spring parameters maintained.

6.1 Spring wire diameter (d) vs Energy storage (E): The wire diameter, imparts structure an ability to sustain with applied loading magnitude and ultimate stress induced because of.



Graph (6.1)- Wire diameter vs. Spring Energy storage Capacity

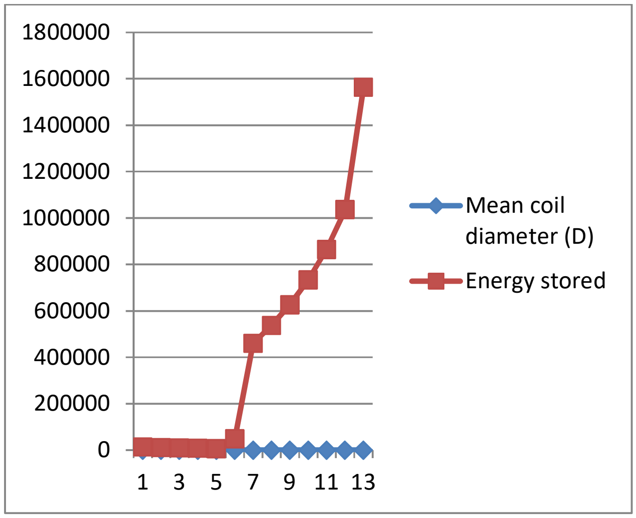
[**Note:** First few readings are plotted with respect to rise in wire diameter, and remaining half of the graph is function of wire diameter which reduced continuously in equal step interval]

From graph, it can conclude that, energy storage capacity of spring goes decreasing with increase in spring wire diameter.

For wire diameter, (9.77 mm), energy storage found (6789.43 N.mm), with further rise in wire diameter (12 mm), it found increased up to (48307.677 N.mm), and thus proportioned relationship between parameters in mind start guessing about further increased wire diameter should result in spring capacity enhancement but equation will start to violate when increased wire diameter beyond (13 mm) will takes this capacity down and will maintain result consistency every time the value found increased further. The maximum energy storage capacity registered at wire diameter (d =13mm) is (460380.27 N.mm). The deserving results are obtained when it has taken further down up to (5.5 mm), the highest energy storage capacity recorded to this point (1562582.478).

Thus increased wire diameter will bring good result in terms of energy storage capacity but same will start to fallen down when it will be taken up further. Decreased diameter, registered good results in terms the energy storage capacity but the level taken further down will leading to collapse entire structure as an immediate effect.

6.2 Mean coil diameter (D) vs Energy storage: Like previous parameter, wire diameter (d), the mean coil diameter (D) also affecting spring behavior in similar manner.

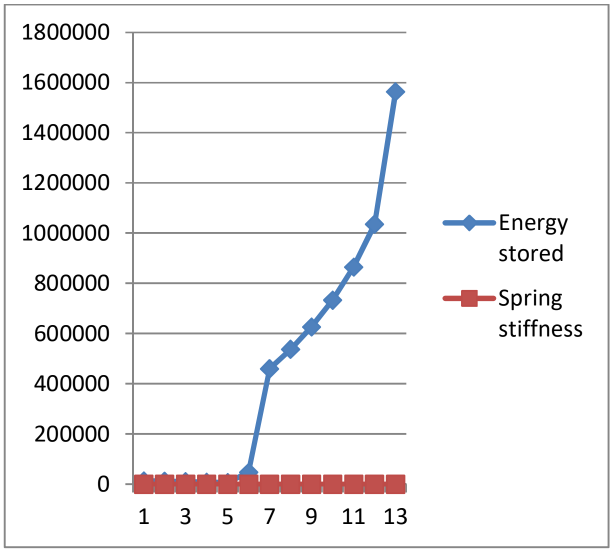


Graph (6.2)- Mean coil diameter vs. Spring Energy storage Capacity

Mean coil diameter (74.18 mm) records energy storage capacity cumulative manner, any further increase in value reduces this capacity and starting performance level take down. The highest energy storage capacity is registered at mean coil diameter (33.17) and equals to (1562582.478 N.mm).

6.3 Material stiffness (k) vs Energy storage: More will be the stiffness, less will be the deformation and hence less energy can be stored, exercise of storing any extra energy amount will leading structure towards failure, as induced shear stress will already exceeded the permissible shear stress induced at material yield point during simple tension test.

In the following graph higher stiffness causes less energy storage. The stiffness (92 N.mm) is allow spring to store (8486.79 N.mm) magnitude of energy, where decrease in stiffness, in fact if it has taken to (1.99) will causes to stored (1562582.478 N.mm) and which is not practical true. Thus equation very clear is that, energy storage capacity shows inverse relationship with magnitude of material stiffness maintained by the time of spring structure manufacturing.



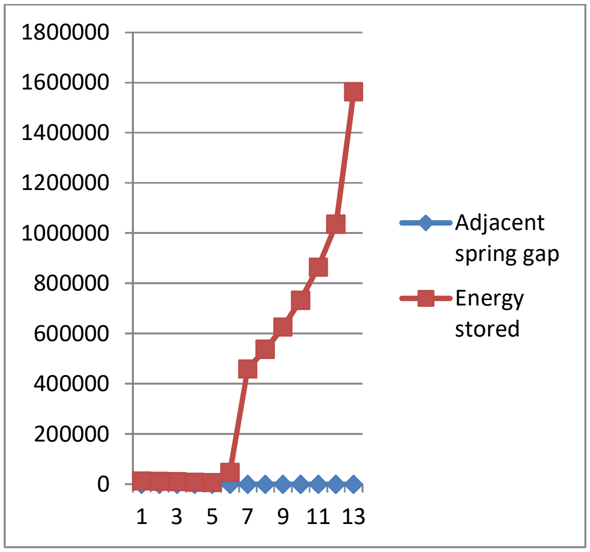
Graph (6.3)- Spring stiffness vs. Spring energy storage Capacity

6.4 Spring coils adjacent gap vs Energy storage: More will be the adjacent gap, less will be the deformation and hence less will be the capacity of energy storage per unit volume. In other hand, possibility with confirmation also can be discussed as, less will be the adjacent gap maintained more will be the spring capacity of deformation and resulting in highest energy storage ultimately.

Generally (0.5 to 1 mm) adjacent gap is maintained while designing the spring structure, based on that further, maximum permissible spring deformation will be restricted to some fixed value. To hold that deformation, number of active and inactive turns, spring structure supposed to introduce with, will think later. The styles of end and spring geometry are other secondary aspects need to deal immediate later the previous work investigation and things shaping has done.

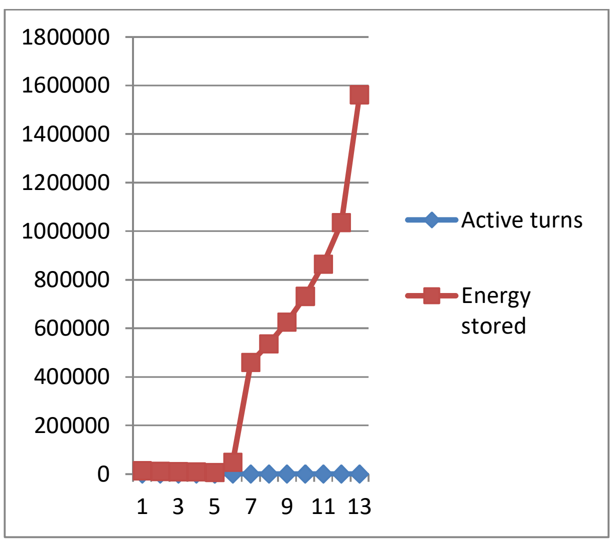
In the posted graph below, spring adjacent gap maintained for minimum possible value (0.1 mm) shows spring maximum energy storage capacity (1562582.478 N.mm), with slightly raised the value for adjacent gap up to (0.8 mm), the respective energy storage capacity will falls down to (48307.677 N.mm or Joule). When the question of some parameter feasibility existence will come occur it should always liable to satisfy the safety condition. For example, adjacent spring coil gap- 0.1 mm should store the energy amount per unit volume less than maximum energy storage capacity per unit volume at material yield point during tensile test, which not leading material failure at all. So parameter consideration about possibility of giving out its maximum should also confirm it is not leading system towards failure under same exercise.

Adjacent gap of (0.1 mm) maintained should not exceeds spring energy storage capacity beyond its permissible energy storage limit defined at yield point. Every such parameter responsible in highest output given should co link between amount of energy stored and corresponding margin of safety.



Graph (6.4)- Adjacent gap vs. Spring energy storage Capacity

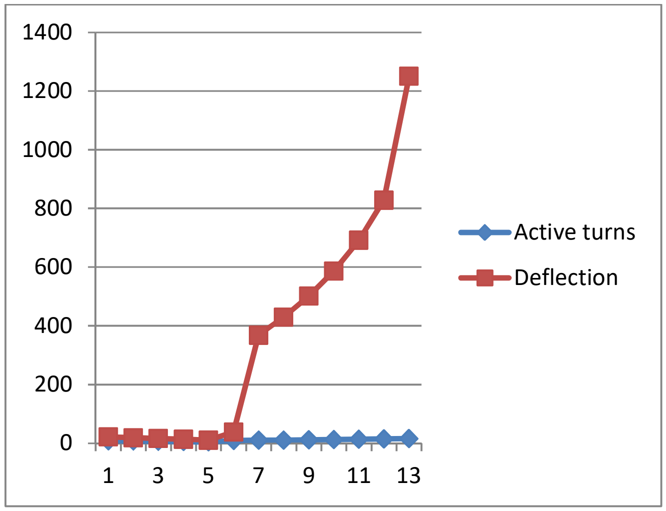
6.5 Number of active turn's vs Energy storage capacity: More will be the active turns a spring will have more will be the capacity of energy storage and given out the same once load applied will be taken out. The graph posted below verify this talk,



Graph (6.5)- Number of active turns vs. Spring energy storage Capacity

With highest number of turns (16), spring capacity of energy storage has found (1562582.478 N.mm). The number taken down further, i.e. (8), transform spring capacity simply unable to tackle with magnitude of load and hence expected energy storage tends to occur because of.

6.6 Number of active turn's vs Spring deflection under load applied: More number of active turns allows coil undergoes more deformation leading in storage higher energy magnitude. As discussed earlier, magnitude of deflection occurred should not goes beyond, highest possible deformation at material yield point under gradual loading.



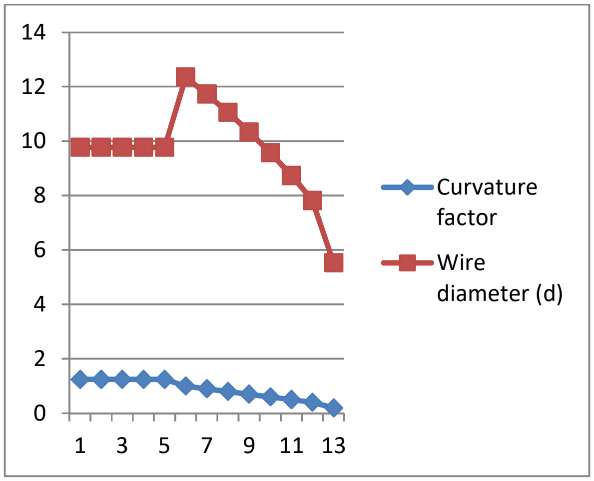
Graph (6.6)- Number of active turns vs. Deflection and hence energy storage capacity

The spring deflection goes increasing with increased number of active turns introduced in structure. Space limitations imposed structure to introduce in service will restricts the number of active and inactive turns to consider. The structure safety with highest energy storage capacity has registered for number of turns (16) is (1250.06 N.mm).

6.7 Curvature factor vs Wire diameter: Curvature factor is the consideration given about enhanced stress value induced because kind of curvature spring geometry has assigned for. This increased stress magnitude can be counted twice or thrice the stress magnitude induced under set of gradual loadings applied over structure. The curvature factor directives for more spring wire diameter to sustain any as such Sevier load magnitude spring will be subjected to. More will be the value considered for curvature factor, more will be the requirement for spring wire diameter but beyond one specific limit, enhanced spring wire diameter will leading structure to impart negative and adverse effect, which enabling structure to retain under set of loads apply

Thus relation, (S_{ut} α d) will no longer valid as soon as it exceeds one specific limit, respective wire diameter cannot sustain even for magnitude of load it has applied initially. The optimized wire diameter is required to maintain to establish the balance between strength and design economy.

The graph posted below, shows, variation between parameters i.e. curvature factor and wire diameter. As one start to falls down, invokes other to follow same characteristic path. The effect of residual stresses and stress concentration come arise due to spring geometry are the factors considered combinely under the effect of curvature factor. The effect of residual stresses considered acting in opposite direction the direction of stresses induced due to external load applied will be considered under head curvature factor will be null and void, as stress of different domain acting opposite each other will balanced with no traces of stress left behind to work further. In the case, when external load applied and stresses induced will added with residual stresses acing in same direction, the effect of additional stresses considered under curvature factor will be beneficial ad helpful in deriving the correct industrial design as per its need stated.



Graph (6.7)- Curvature factor vs. Wire diameter

6.8 Ultimate tensile strength vs Energy stored: Energy storage capacity will be the function of material ultimate tensile strength, which shows proportional relationship with every attempt of raising it further. It is material property which can be raised with put forth material under the sequence of operation right from alloy addition, heating and cooling under various medias present

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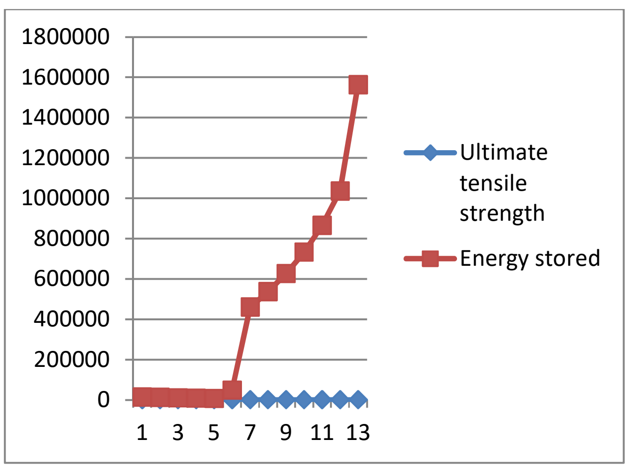
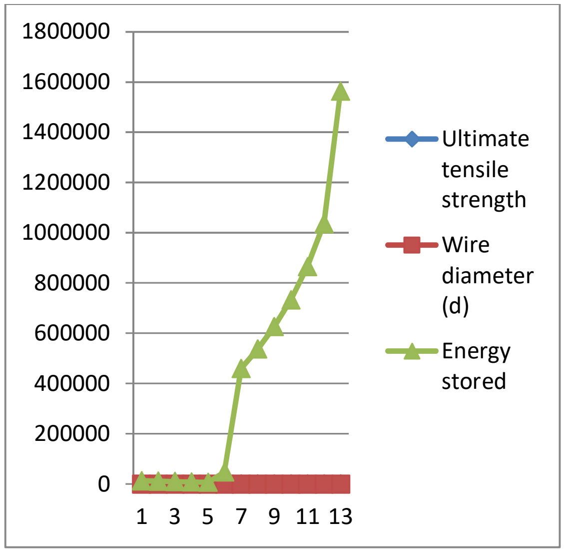


Graph (6.8)- Ultimate tensile strength vs Energy stored

6.9 Ultimate tensile strength vs Wire diameter vs Energy stored: The previous expression shows relation between material ultimate tensile strength and wire diameter which was directly proportional each other. Here the study between various parameters held together, material ultimate tensile strength, wire diameter and energy stored also shows direct proportioned relationship among each other expect wire diameter which when goes beyond one limit, leading structure fails as an immediate effect.

From posted graph below, it can be concludes that, for one particular range of diameter, structure even not able to handle applied load effectively, with increase in diameter it shows positive impact in terms energy storage, with further rise in this value material capacity of energy storage will start falling down again. But parameter like ultimate tensile strength shows its positive impact with respect to energy storage phenomenon, as it show's proportioned relationship among parameters under consideration and equation come valid till infinity.



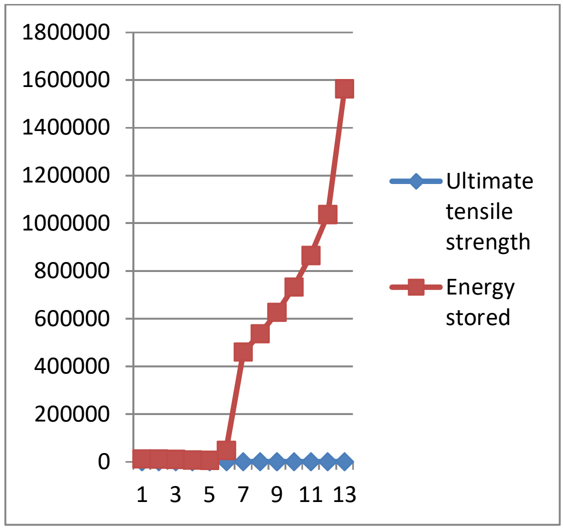
Graph (6.9)- Ultimate tensile strength vs Wire diameter vs Energy stored

It can be seen from the graph posted above, maximum energy storage capacity (1562582.478 N.mm) is registered at wire diameter (5.52 mm) for constant ultimate tensile strength (500 N/mm^2) of steel wire throughout the experiment.

6.10 Reduced Ultimate tensile strength vs Energy storage capacity of spring structure: Like the way increased ultimate tensile strength also enhances spring capacity of energy storage, the proportioned relationship still valid in the case parameters value taken down. The value of ultimate tensile strength taken down beyond one permissible limit will lead the spring structure not capable to sustain applied loading magnitude.

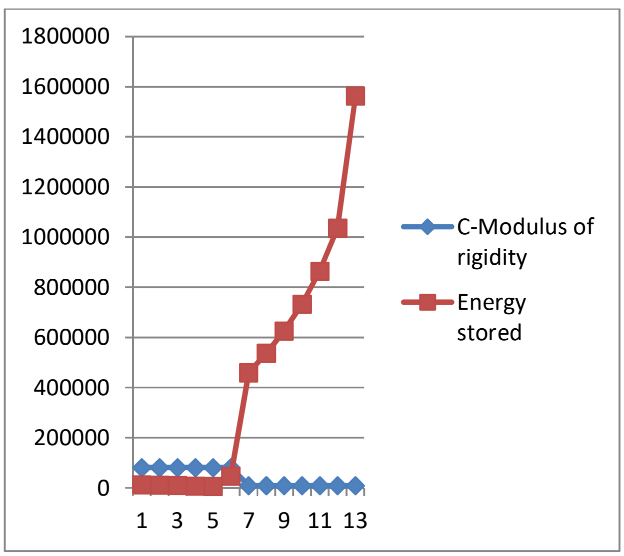
Ultimate tensile strength is the further function of spring wire diameter, so in view spring design for maximum energy storage capacity, the required material ultimate tensile strength will be the function of precise wire diameter selected after repetitive design iterations performed to freeze the optimized parameters.

Wire tensile strength respond negatively for wire diameter maintained less than (0.2 mm) and more than (0.8 mm), the observation is picked up from reference book of Machine Design (Third edition), by Prof. V. B. Bhandari.



Graph (6.10)- Reduced Ultimate tensile strength vs Relevant spring energy storage capacity

6.11 Modulus of Rigidity vs Spring Energy Storage capacity: Modulus of rigidity is the ratio of shear stress vs shear strain of material body under the consideration of its deformation capability analysis in terms of applied shear loading and ultimately shear strain induced as because of that. The relationship can be encapsulated in terms the graphical results as follows,



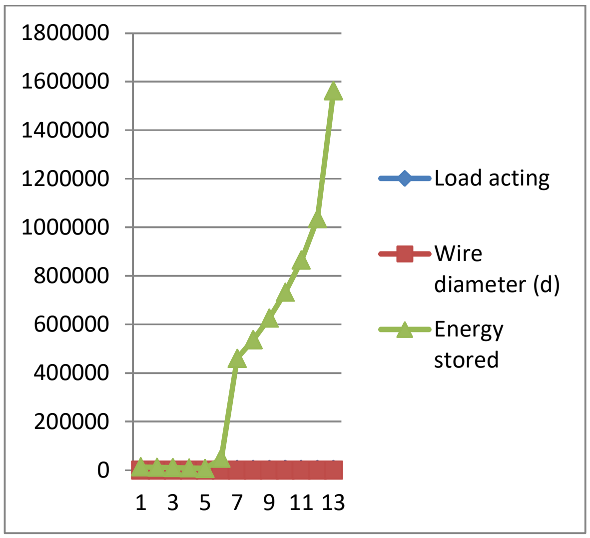
Graph (6.11)- Modulus of Rigidity vs Spring Energy Storage Capacity

From graph, thing is very clear, the energy storage capacity of sprig material for what geometrical shape it has formed will goes reducing with increased value of its modulus of rigidity and condition also be true vice versa.

For modulus of rigidity (G = 81370 N/mm^2), the energy storage capacity is noted down around (6789.43 N.mm or Joules). The capacity of spring energy storage found increasing further (Up to 1562582.478 N.mm or Joules) with modulus of rigidity value taken down to (G = 1000 N/mm^2).

While selecting value for material modulus of rigidity the focus should made on attributes (Basic Engineering Elastic Properties) neither their value should such a high which would resist spring deformation with less flexibility structure imparted for energy storage nor it should allow structure to deform to the extent of failure due to capacity of energy storage exceeds its maximum permissible limit.

6. 12 Load acting vs Wire diameter vs Energy stored: As per discussed during beat number (01 and 09) of the same research paper, the energy storage capacity and wire diameter shows proportioned relation up to one particular limit (The details of optimum wire diameter is discussed in beat number (10)), beyond or below one specific value for wire diameter, spring energy storage capacity or shocks and load absorption capacity will start to falling down or spring is not just capable of handling the applied loads.



Graph (6.12)- Load acting vs Wire diameter vs Energy storage capacity of spring material

The graph analysis shows, for wire diameter (5.5 mm) the energy storage capacity of spring is recorded highest i.e. (1562582.78 J) which later seems fallen down (6789.43 J) with wire diameter reduced to value (9.77 mm).

7 Result, Discussion and Conclusion drawn from the study: The successful implementation of mathematical model and graph studied obtained subsequently following results were obtained which disused with respect to definite conclusion derived from each one of them as follows,

(Note: All parameters effects are studied out with respect to spring capacity of energy storage under gradual load applied and type of geometry spring is designed with.)

Sr. No.	Spring Parameter studied	Parameter behavior conclusion drawn	Optimized parameter range/Specific parameter value proposed
1	Wire diameter (d-mm)	Wire diameter (d = 9.77 mm and 12 mm gives out positive result In terms the energy storing capacity (6789.43 J) and (48307.677 J) respectively. Which keeps spring performance boost up every time, but result will fall to take down this capacity as spring diameter exceeds the value (d = 13mm). The highest energy storage capacity is found at wire diameter (d = 5.5 mm), i.e. (1562582.478 J).	Energy storage = (1562582.478 J) for wire diameter (d = 5.5 mm).
2	Mean coil diameter (D-mm)	The spring structure shows good dimensional stability and energy absorption capacity up to (D = Mean coil diameter = 33.17 mm) beyond which spring structure tends to bend in lateral direction leading become unstable in terms load sustaining capacity.	Energy storage = (1562582.478 J) for wire diameter (D = 33.17 mm).
3	Spring stiffness (K_{stiff})	Increased spring stiffness reduces energy storage capacity and vice versa. The spring stiffness, (K_{stiff} = 92 N.mm) will lead structure to store maximum energy amount (8486.79 N. mm). The maximum energy storage capacity has found maximum at spring stiffness (1.99), but for corresponding value spring stability against failure needs to be analyzed at priority basis.	Energy storage = (1562582.478 J) for wire diameter (K_{stiff} =1.99 mm).
4	Spring adjacent turn gap (mm)	Minimum spring turn adjacent gap maintained will ensures maximum spring deformation and thus maximum energy storage capacity of spring material under loading consideration.	Energy storage = (1562582.478 J) for Spring adjacent gap maintained (0.1 mm).
5	Number of active turns in spring (N)	The spring capacity of deformation under applied loading will found increases with increase in number of active turns of spring structure.	Energy storage = (1562582.478 J) for number of active turns of spring (8).
6	Curvature factor to accommodate stress concentration and residual	Curvature factor will consider effect of stress concentration induced due to type of geometry material has imparted with, same time it do consider effect of material residual stresses. In consideration of all these factors, safety of wire will be defined	Generally value of curvature factor will consider (K=1.25) during spring structure design and stresses analysis

	stress effect ($K_s K_r = K$).	in terms correct wire dimension assumed to support the spring structure throughout loading. The equation is again valid, i.e. more will wire diameter ensures more material safety but beyond one specific limit it falls down with reducing spring structure energy storage capacity.	induced due to applied loading throughout its operational journey.
7	Ultimate tensile strength (S_{ut}-N/mm^2)	The material energy storage capacity is found increasing with respect to increased value of material ultimate tensile strength, the reverse of hypothesis is also stays valid.	Energy storage = (1562582.478 J) for material ultimate tensile strength (S_{ut}-500 N/mm^2).
8	Material Modulus of Rigidity (C-N/mm^2))	The increased value of material modulus of rigidity though going to stabilize the structure, it will not allow material to deform under applied loadings to the best of its capacity thus it shows inverse relation with respect to material energy storage capacity.	Energy storage = (1562582.478 J) for material modulus of rigidity (C-10000 N/mm^2).
9	Applied load vs wire diameter which keeps increase in gradual manner (N)	Load sustaining capacity of material tends to increase with respect to wire diameter, but beyond one specific limit its capacity will goes down, may leading that structure towards failure.	The highest energy storage capacity (1562582.478 J) is recorded at wire diameter (d = 5.5mm), which parallely dealing with highest load sustaining capacity (2500 N).

8. Future scope of the study: The current research paper focusing on the aspects like optimized parameters selection (Best possible value which would help in the storing maximum spring energy and can respond to any dynamic condition under study). While making selection for parameters value, only maximum energy storage capacity relevance has considered irrespective of its effect on the behavior of other co linked parameters and thus on overall spring structure and its safety.

The work study can further extended in finding the right parameter value (Which are must be same, the one set of values obtained during this research paper writing) along with 100% assurance given about spring safety and its long reliable consistent performance maintained for all the time.

9. References:

1. A Text book of “Design of Machine Elements” by Dr. V B Bhandari, ISBN-13: 978-0070681798, Tata MacGraw Hill publication, 3rd Edition.
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3. A Text reference book on “Machine Design” by Dr. D K Aggrawal & Dr. P C Sharma, ISBN-10: 8185749094, S K Kataria & Sons publication (2010).