International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-07, Issue-04, JULY 2021

Modeling and Analysis of Wave Spring by Varying the Crest -Trough amplitudes

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Abstract - Springs are key members in suspension system and the existing models of helical springs are larger in size and solution for this is wave springs, which are precise flat wire compression springs that fit into assemblies that other springs cannot since the overall lengths and operating heights of wave springs are lower than those of conventional round wire springs. This will also reduce the part weight and raw material cost of every spring produced.

In the present work, the model of wave spring is done by using Catia V5 and then, the obtained model is analyzed using Ansys 15.0 to study the equivalent von-mises stresses and deformation distribution in the spring. A set of models were created with different amplitudes : crest to trough of successive turns, in a suitable range from 18mm to 26mm and analysis tests were carried to find the optimum pitch amplitude for the effective performance of the wave spring, which can leads to higher stiffness.

Key Words: Wave Spring, Amplitude, Structural Analysis.

I. INTRODUCTION

A wave spring is prepared by edge coiling method using pre hardened wire. In this type of springs, a wave like structure is provided through out the coil for spring effect. The number of coils can be provided to attain suitable stiffness. When compared to the helical coil springs the wave spring size is almost 50% less and thereby weight and production cost also reduces. Due to wave structure the load barring capacity increases.

II. OBJECTIVE

Thus taking into account the advantages of the wave spring over the traditional helical spring, in this present work, an attempt is made to create the model of the wave spring using Catia V5 and to analyse the effect of the wave spring performance by varying the amplitude of the wave structure in the spring by carrying structural analysis using Ansys 15.0.

III. MODELING OF WAVE SPRING USING CATIA V5

The modeling is done in CATIAV5, using which proper geometry is produced. The step by step procedure followed in creating the model of wave spring is shown in the following figures 3.1 & 3.2.

Initially the profile of the path of coil of wave spring is created with spline option. Then to create a sketching plane at the end of the created profile and to sketch the cross section of spring coil (rectangle). There after the cross section extruded through the spline profile to create the wave spring model.

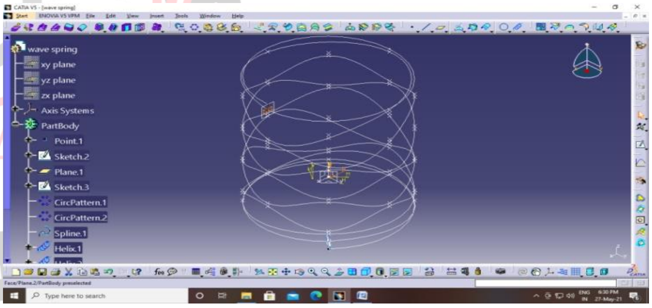

Fig. 3.1: Sketching of cross section of the spring coil

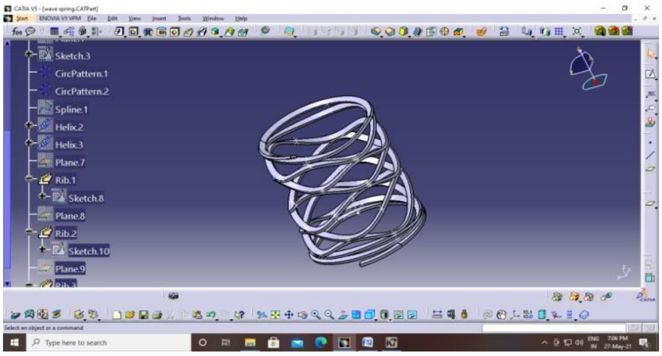

Fig. 3.2: Created wave spring model in Catia V5

The same procedure is repeated to create the following models of wave spring:

Model-1: Mean diameter: 80mm, Pitch 18mm, Cross section 2X4 mm rectangle

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Model-2: Mean diameter: 80mm, Pitch 20mm, Cross section 2X4 mm rectangle

Model-3: Mean diameter: 80mm, Pitch 22mm, Cross section 2X4 mm rectangle

Model-4: Mean diameter: 80mm, Pitch 24mm, Cross section 2X4 mm rectangle

Model-5: Mean diameter: 80mm, Pitch 26mm, Cross section 2X4 mm rectangle

IV. ANALYSIS OF WAVE SPRING

Step by Step Analysis Procedure (18mm Pitch Wave Spring-Model-1)

At first the structural analysis is to be chosen in Ansys 15.0. Then to select the material using "Engineering data" option. Thre after the following steps are to be followed to complete the analysis of the wave spring model.

Step 1: The Catia model is to be imported in igs format as shown in fig 4.1

Step 2: The model is divided in finite parts and meshed model is as shown in fig 4.2. The tetrahedron element shape is chosen for analysis.

Step 3: The fixed constraints are applied as shown in fig 4.3. The bottom end coil is fixed.

Step 4: The axial load is applied to the model at the top most coil turn as shown in fig 4.4

Step 5: Then to solve the problem using solver option.

Similar procedure is applied to all the models and results are discussed in the next section.

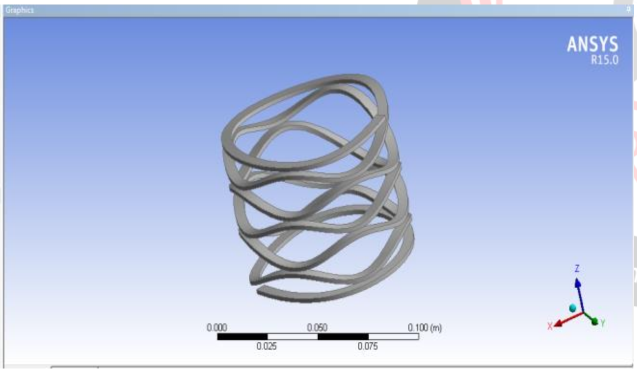

Fig. 4.1: The catia model of wave spring is imported to Ansys 15.0

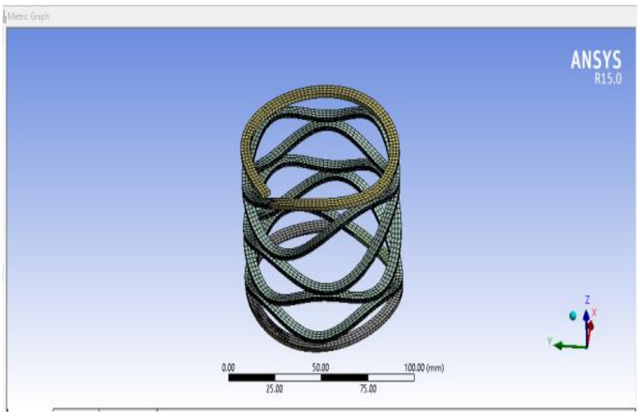

Fig. 4.2: Meshed model of Wave spring in Ansys 15.0

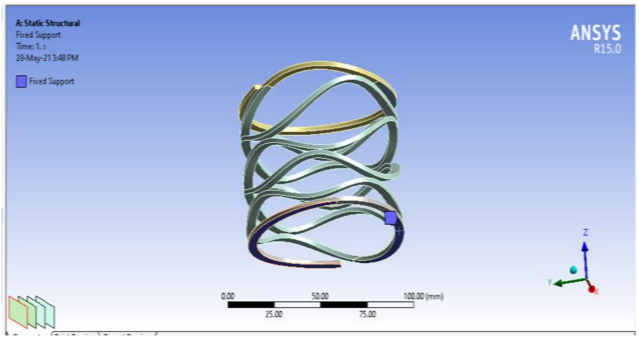

Fig. 4.3: Applying fixed constraints in Ansys 15.0

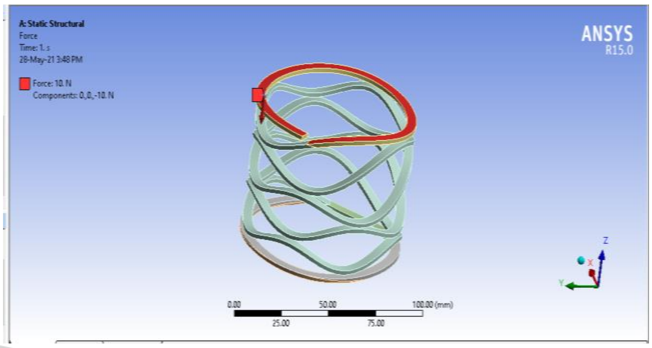

Fig. 4.4: Applying axial load to the model

V. RESULTS AND DISCUSSIONS

5.1 **Ansys Results of 18mm Pitch Wave Spring-Model-1**

The fig 5.1 shows the equivalent von-mises tress development in the wave spring with 18mm pitch(model-1). The resulring color image reveals that the stress distribution along the length of the spring coil are within satisfactory limits, exhibiting the moderate intensity of stress almost throughout the length of the spring. The maximum stress intensity developed is found to be 59.41MPa, is developed only in the zones, close to two extreme ends of the coils, where the wave like structure of coil starts to be normal helical coil, for the provision of load application. So only the red color representation is not visible in the resulting image, because as mentioned above, it occurs only at very minute area, the connection between wave structure coil and helical structure coil. Therefore, theses results giving valuable information, which further can be utilised, to improve the design of the spring coil for smooth transition between the two structures mentioned above, which there by can reduce the stress intensity to a reasonable level. Thus the wave structure spring can be utilised for further higher loads. Excluding those critical loaded zones, the maximum intensity of the stress developed is found to be represented with green color, which indicates that the maximum stress is around $\pm 33MPa$.

Also the color representation indicates that along the width of the coil, green color is identified at the middle with light blue/green at the edges. This is well desired, because it represents that the edges are less stressed than that of the middle portion along the width of the coil. In conventional helical coiled springs, the coil leads to twisting in addition

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ISSN : 2454-9150 Vol-07, Issue-04, JULY 2021

to compression, which leads to additional stresses at the edges, whereas in this case the stress development shows that the spring is under compression, dominating the twisting action, which gives higher capability to bear the load. This can be confirmed by having dark blue color representation along the edges of the coil, which can be observed by maximising the resulting picture.

The fig 5.2 shows the total deformation development in the 18mm pitch wave spring model-1. The resulting color picture reveals that the deformation decreases from loaded end to fixed end. Also it can be observed that the deformation is less at the regions, where the trough and crest of corresponding coils get in contact with each other. Thus it reveals that the load is transferred from top to bottom through these connections and the load barring capacity depends mainly on the length of the coil between the supported regions, which are mentioned above. Thus the length of the coil between those contact areas acts like a simply supported beam carrying the load. The maximum deformation developed in this model-1 is found to be 5.15mm, which was observed at the loaded end.

The fig 5.3 shows the safety factor attained in wave spring with 18mm pitch (model-1). The resulting color image shows that the entire length of the coil of the spring is under higher level of safety factor. But the critical value of safety is shown only at small region where the wave structure coil is transformed to helical coil structure, which is at the ends of the spring. Other than that the most of the coil is under the safety factor higher than 5. So by further careful modification , achieving still smoother transition between the wave structure and helical structure, the critical safety factor can be improved further. The critical safety factor in this model-1 is found to be 4.2079. The remaining entire length of the coil of spring is with same level of safety, having higher safety at the edges of the spring and with moderate safety factor at the middle of the coil along its width.

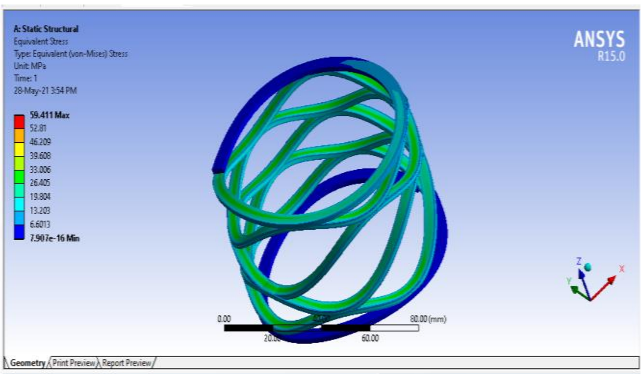

Fig. 5.1: Equivalent Von-mises Stress distribution in18mm pitch Wave spring-Model-1 in Ansys 15.0

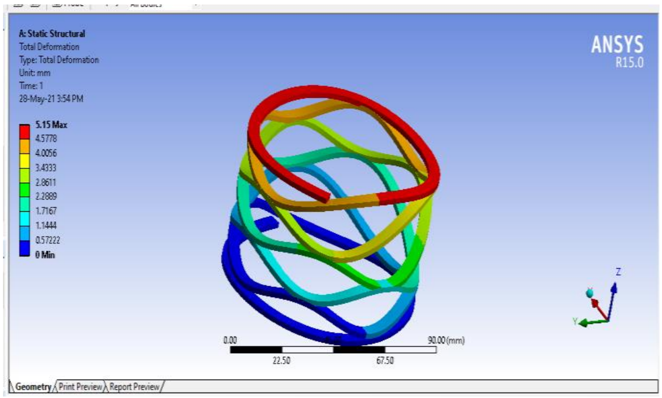

Fig. 5.2: Total deformation development in18mm pitch Wave spring-Model-1 in Ansys 15.0

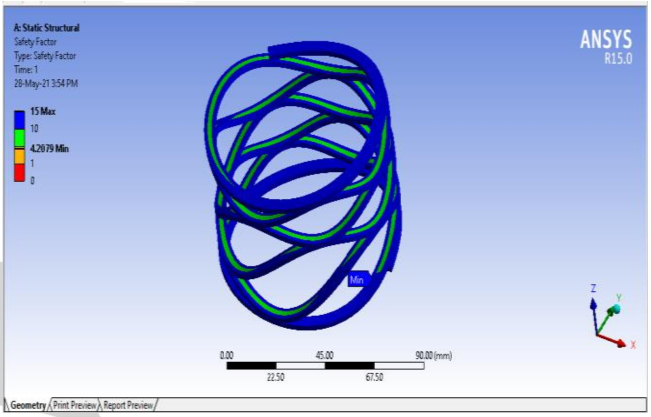

Fig. 5.3: Safety Factor attained in18mm pitch Wave spring-Model-1 in Ansys 15.0

5.2 Ansys Results of 20mm Pitch Wave Spring-Model-2

The fig 5.4 shos the von-mises stress distribution in 20mm pitch wave spring model-2. The resulting color image shows that the pattern of stress distribution is similar to that of model-1, but with slight variation. Though the color representation seems to be same as in previous model, it can be observed in maximising view, that the green color which exhists at the middle of the coil along its width is not continious, i.e partial and full vanishing can be observed. This indicates that the stress intensity got reduced and the load is uniformly throughout the width of the coil. This trend improves the load barring capability of the spring. The maximum von-mise stress developed in this model-2 is found to be 53.26MPa, which is 10.34% lower than that of model-1. Even in this model also, it can be observed that the maximum stress intensity with red color representation was not visible in the diagram, because of the same reason mentioned in the previous section. Therefore, excluding those region of joining connection between the wave like structure and helical structure, the maximum intensity of the stress can be found to be reduced to a maximum extent.

The fig 5.5 shows the deformation development in the wave spring model-2 with 20mm pitch. The resulting color image shows that the distribution of deformation follows the same trend as previous model, with decreasing magnitude from loaded end to fixed end. This supports the the statement: the deflections travels from loaded end to fixed end. The

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maximum deformation developed in this model is found to be 4.971mm, which is 34.6% lower than that of the model-1.

The fig 5.6 shows the safety factor attained in wave spring model-2. The pattern is same as in previous model. The critical safety factor attained in this model is 4.693, which is found to be 11.5% higher than that of the previous model-1. As mentioned in the previous section, excluding the critical zone of connection between the wave structure and helical structure, the minimum safety factor attained in this model can be above 5. Therefore, this gives clear indication to take care of that transition between structures at the end of the spring for further strengthening the spring capacity.

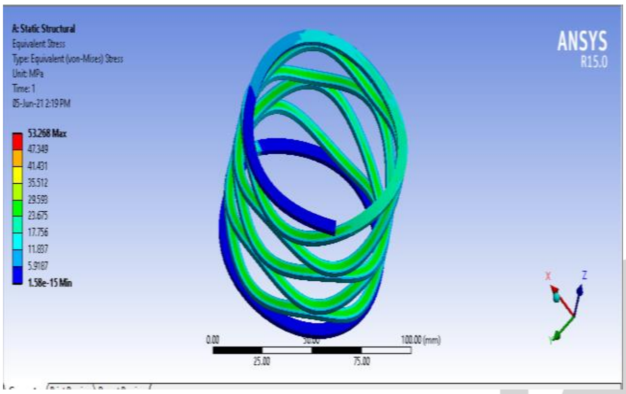

Fig. 5.4: Equivalent Von-mises Stress distribution in 20mm pitch Wave spring-Model-2 in Ansys 15.0

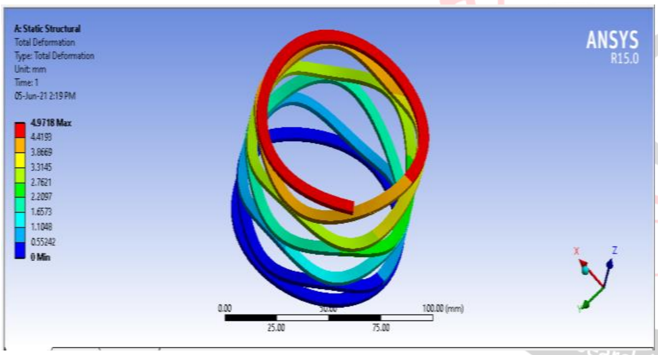

Fig. 5.5: Total deformation development in20mm pitch Wave spring-Model-2 in Ansys 15.0

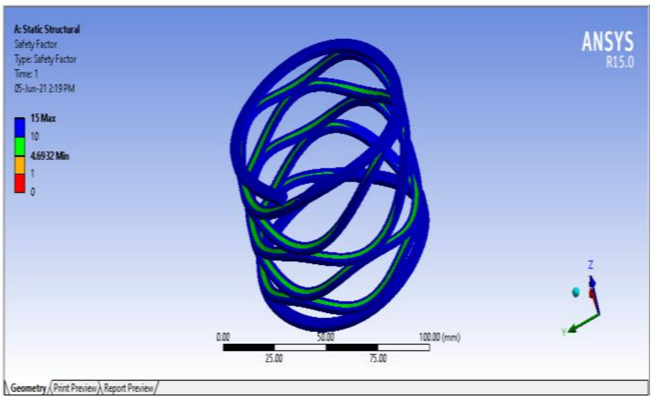

Fig. 5.6: Safety Factor attained in20mm pitch Wave spring-Model-2 in Ansys 15.0

5.3 Ansys Results of 22mm Pitch Wave Spring-Model-3

The fig 5.7 shows the von-mises stress distribution in the wave spring with 22mm pitch, model-3. The resulting color image, though follows the pattern of distribution in the previous model, a peculiar trend can be observed. The origin of maximum stress intensity in the previous models was found to be at the connectionof the wave like structure and normal helical structure, which is generally at the ends of the spring. Where as in this model, that critical zone was disappeared, may be due to suitable pitch value, which gives suitable provision for smooth transition between those two structures. Due to this reason, the maximum stress developed mentioned with red color is identified throughout the length of the spring. The maximum intensity developed in this model-3 is found to be 30.631MPa, which is 48.4% lower than that of model-1 and 42.5% lower than that of model-2. Also it can be observed very clearly that the red color is not appearing continiously along the length of the spring, i.e; breaks can vbe observed, even which follows a trend with red color appearance at the locations where the successive axial crest and trough meets. This strengthen the statement that load is carried through these contact locations right from top to bottom. This trend can not be seen in normal helical spring, therefore the wave sopring can have higher load withstand capability due to the presence of these contact supoorts through out the spring.

The fig 5.8 shows the deformation developed in the wave spring with 22mm pitch, model-3. The resulting color image represents that the pattern is similar to that of previous models, with decreasing magnitude from top to bottom. The maximum deformation developed is found to be 5.1127mm, which is 0.7% lower than that of model-1. Though reasonable amount of decrease in stress is found, the same level of effect is not found in the deformation of this model. The reason may be once again the same, i.e; the maximum deformation is found to be developed only at the loaded end and which is again depends on the transformation of the wave structure to helical structure. When this transition takes place a deviation occurs regarding the space between adjacent coils of the spring and in this it may have result in higher space between the coil of helical structure and next corresponding coil of wave structure. Therefore, this gives once again a clear indication, regarding the care to be taken in design of the spring coil to avoid those disturbances in the continuity of the coil.

The fig 5.9 shows the safety factor attained in the wave spring model-3 with 22mm pitch. The pattern of safety factor achieved follows the same trend as previous models, with critical value of 8.1617, which is 93.9% higher than that of model-1 and 73.9% higher than that of model-2. As mentioned above the transition between wave structure and helical structure has taken smoothly, which there by avoids the critical zones and thereby the safety factor was enhanced.

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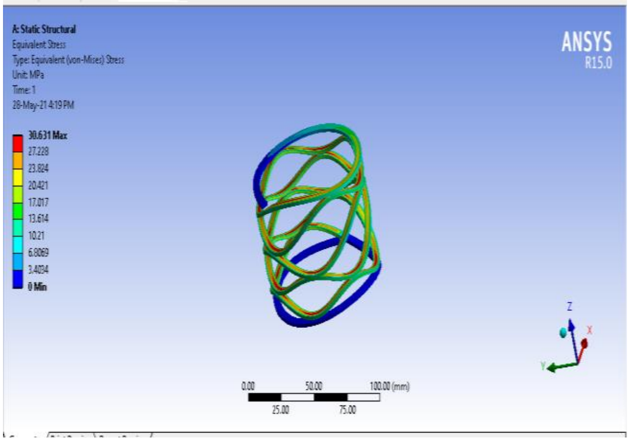

Fig. 5.7: Equivalent Von-mises Stress distribution in22mm pitch Wave spring-Model-3 in Ansys 15.0

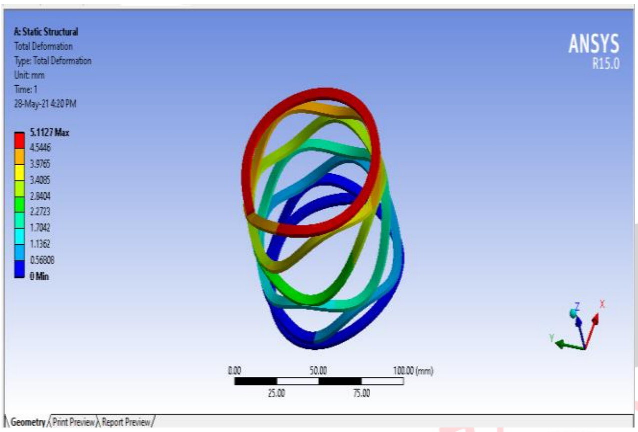

Fig. 5.8: Total deformation development in22mm pitch Wave spring-Model-3 in Ansys 15.0

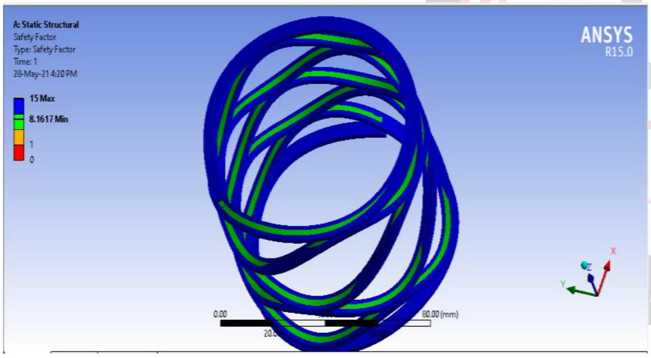

Fig. 5.9: Safety Factor attained in22mm pitch Wave spring-Model-3 in Ansys 15.0

5.4 Ansys Results of 24mm Pitch Wave Spring-Model-4

The fig 5.10 shows the von-mises stress distribution in the wave spring with 24mm pitch, model-4. The resulting color image shows that the stress distribution follows the same trend as in previous model, but stil with lower intensityies. It can be observed clearly in the image, the transition between wave structure and helical structure, is under lower stress development, which can be seen with light blue/green color. Also it can be observed that the maximum intensity of stress which is in red color representation is more precisely reduced. Also the edges of the coil through out the length is highlited with green color, which is indicates further reduction in stress intensity, compared to previous model-3. The maximum stress developed in this model is found to be 28.64MPa, which is 51.8% lower than the model-1 and 6.4% lower than the model-3. This further reduction in stress intensity, Compared to the model-3 is may be due to increase in pitch value, which increases the inclination of the coil. This higher inclination of coil decreases the angle between the load direction and coil length direction. Due to this the component of the load along the length of the coil increases, which there by transmits higher part of the load to next contact region (between crest and trough). Therefore the stress intensity decreases in the coil of the spring.

The fig 5.11 shows the deformation developed in the wave spring model-4 with 24mm pitch. The distribution of deformation along the coil of the spring is similar to the previous models, with a maximum magnitude of 4.7414mm, which is 7.2% lower than that of model-3.

The fig 5.12 shows the safety factor attained in the model-4. Compared to previous model, the maximum portion of the spring model is under higher sfaety factor. Whereas in the previous models, the midlle portion of the spring (along the width), throughout the length of the spring is highlighted with green color, representing with moderate safety factor. But in the present model the green color is almost vanished just highlighting very less region that to at the location of contact of crest and troughs. This shows that the load barring capacity is highly improved in this model with critical safety factor of 8.7277, which is 6.93% lower than that of the model-3. Though it seems to be around 7% improvement in qualitywise, but quantity wise it is highly improved with almost approximately with less than 5% of area is under critical safety compared to the model-3.

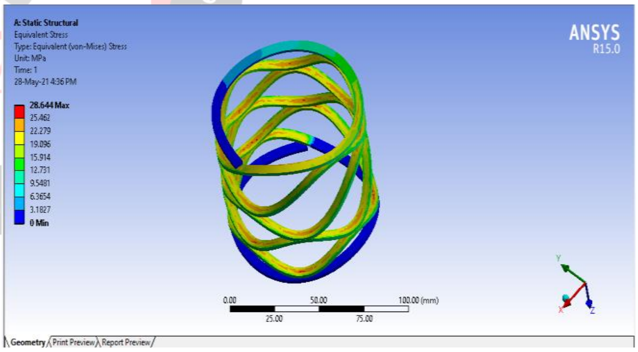

Fig. 5.10: Equivalent Von-mises Stress distribution in24mm pitch Wave spring-Model-4 in Ansys 15.0

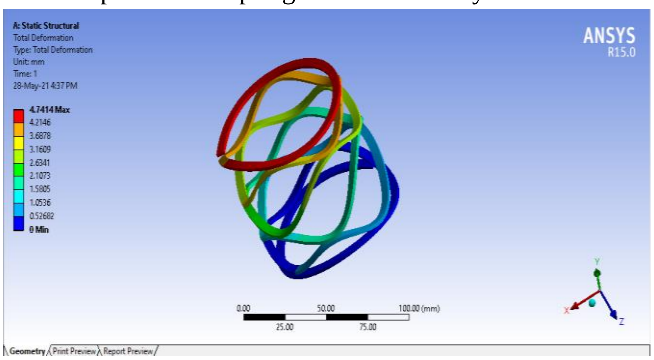

Fig. 5.11: Total deformation development in24mm pitch Wave spring-Model-4 in Ansys 15.0

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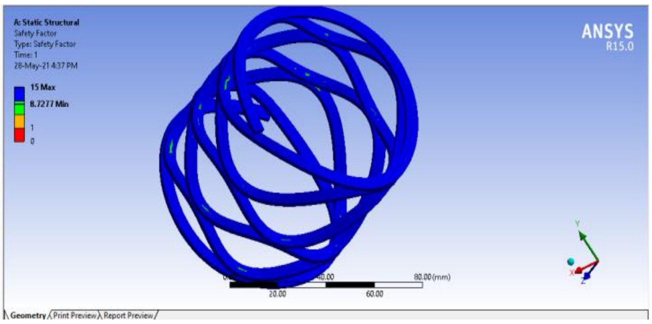

Fig. 5.12: Safety Factor attained in24mm pitch Wave spring-Model-4 in Ansys 15.0

5.5 Ansys Results of 26mm Pitch Wave Spring-Model-5

The fig 5.13 shows the von-mises stress distribution in the wave spring model-5 with 26mm pitch. The resulting color images represents that stress intensity is reduced to a maximum extent with a maximum intensity of 28.53MPa. Though this is just 0.3% lower than that of the previous model-4, it can be observed that approximately just less than 10% of area is under higher stress intensity (red color representation), compared to model-4. Even this can be seen only at the loaded end, which can not be avoided. Therefore the complete spring is under sfae zone. But at the same time a new pattern of distribution of the stress is observed in this model-5, i.e; the light red color representation on the coil at th inner edges, which indicates that the coil is under twisting action, which increases the stress at the dges of the coil cross section. Therefore considering very little reduction in stress intensity and development of higher stresses at the edges, giving an indication to avoid further increasing of the pitch of the spring.

The fig 5.14 shows the deformation development in the wave spring model-5. The resulting color image shows that the pattern is similar to the previous models, with decreasing magnitude from loaded end to fixed end. The maximum deformation developed in this model is found to be 4.5mm, which is 5.05% lower than that of model-4. Also it can be observed that the connection of wave structure and helical structure can not be identified with any particular color representation in the diagram .This indicates that the transition from wave structure to helical structure has taken place perfectly without any disturbances.

The fig 5.15 shows the safety factor attained in the wave spring model-5. The resulting color image shows that the complete spring is under maximum safety factor except the starting of the spring, where it is loaded. Thus it is proved that the spring achieved its maximum capability, but with a critical safety factor of 8.7616, which is just 0.38% higher than that of the model-4. But considering the amount of area under critical safety, the model-5 is under higher safe than that of model-4.

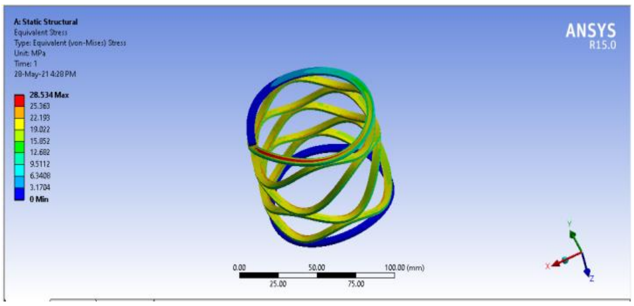

Fig. 5.13: Equivalent Von-mises Stress distribution in26mm pitch Wave spring-Model-5 in Ansys 15.0

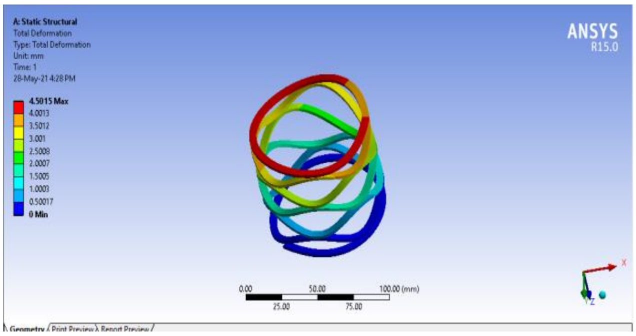

Fig. 5.14: Total deformation development in26mm pitch Wave spring-Model-5 in Ansys 15.0

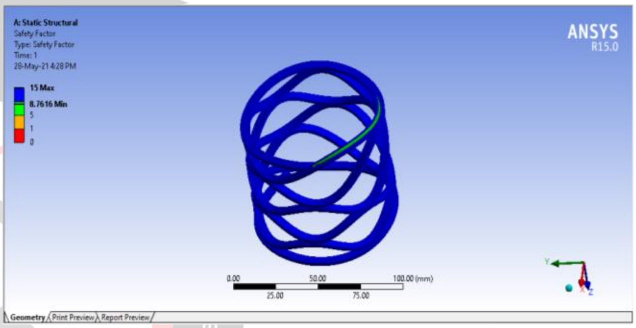

Fig. 5.15: Safety Factor attained in26mm pitch Wave spring-Model-5 in Ansys 15.0

5.7 Effect of Pitch on Stress and Deformation of Wave Spring

The fig 5.16 shows the effect of the pitch on the stress development. The fig shows that the maximum stress development in the spring decreases with increase of the pitch of the wave spring. Also it can be seen that increasing of pitch up to 22mm gives reasonable amount of decrement in the stress intensity, but there after the effect is less.

The minimum stress intensity of 28.53MPa is developed in the 26mm pitch wave spring, which is 51.97% lower than that of in 18mm pitch wave spring (highly stressed model).

The fig 5.17 shows the effect of the wave spring pitch on deformation in the spring. The graphical result shows that the deformation decreases with increase of the pitch of the wave spring. Especially it can be seen that the deformation decreases is at higher rate with increase of pitch beyond 22mm in the considered range.

The minimum deformation of 4.5015mm is developed in the 26mm pitch wave spring, which is 12.6% lower than that of in 18mm pitch wave spring (highly deformed model)

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ISSN : 2454-9150 Vol-07, Issue-04, JULY 2021

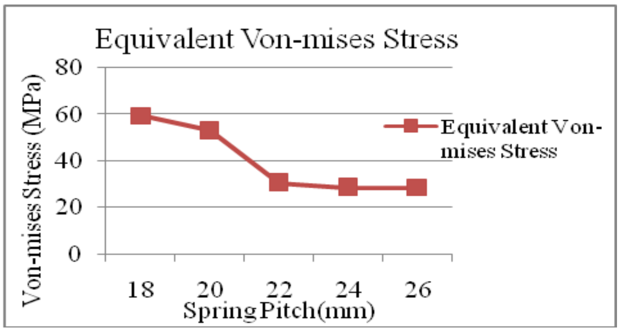

Fig. 5.16: Effect of the spring pitch on the von-mises stress development

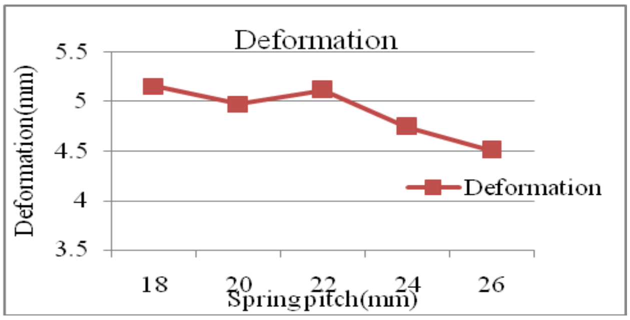

Fig. 5.17: Effect of the spring pitch on the maximum deformation

The fig 5.18 shows the effect of the wave spring pitch on the safety factor of the spring. The fig shows that safety factor increases drastically with increase of pitch from 18mm to 22mm and there after it is less influenced by the pitch.

The maximum critical safety factor of 8.7616 is attained in the 26mm pitch wave spring, which is 108.2% higher than that of 18mm pitch wave spring (low safe model).

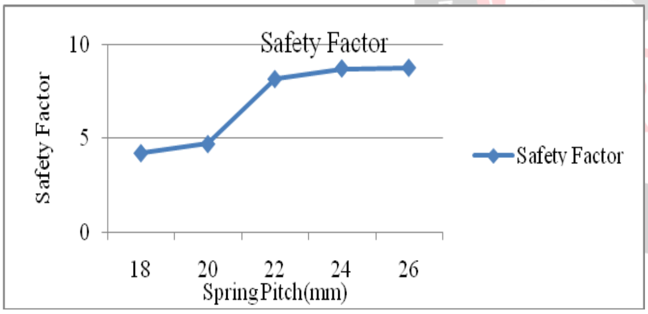

Fig. 5.18: Effect of the spring pitch on the safety factor of the spring

VI. CONCLUSIONS

The following conclusions were drawn from the series of analyzing tests carried on wave spring models with different pitch amplitude (between crest and trough of corresponding coils) values.

- The equivalent von-mises stress in the wave spring decreases with increase of the spring pitch. The stress intensity is higher especially for the wave springs with pitch value less than 22mm.
- The deformation in the wave spring decreases with increase of the spring pitch.
- The critical safety factor in the wave spring increases with increase of the spring pitch.
- The ends of the wave spring, especially at the transition region between wave structure and normal helical structure is critical in the development of higher stress and deformations. Thus higher care is needed in the design of this connection region, for optimum spring performance.

Thus concluding with, the wave spring model-5 with spring pitch 26mm is found to be optimum among all the analyzed wave spring models.

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 DOI : 10.35291/2454-9150.2021.0371 © 2021, IJREAM All Rights Reserved.