DYNAMIC BEHAVIOR OF ROPEWAY STRING

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Abstract: In this paper a new approach for dynamic behavior of a string is aimed to study lateral vibrations induced in an elastic ropeway string. We are going to deal with the dynamic behavior of a string. In hilly areas we have problem for traveling from one place to another. There we are using a rope drive system using a string as a rope. A ropeway is a type of maritime lifting gadget used to move light stores and hardware across waterways. Here, multiple ropeways are designed by using solid works and then analyzing with static, transient and dynamic boundary conditions. To suggest optimum materials for optimum ropeway string, 4 materials were chosen (SAE 1020, SAE1137, Al-17075, Al-7475) to analyze and study the dynamic behavior of ropeway string by knowing each material results, comparing with each other material results and then showing suitable tables and graphs, finally concluding thesis with optimum material with optimum ropeway string to improve the performance and their durability.

1. Keywords: String, Solid Works, Ansys Workbench, Natural Frequency.

2. Introduction: Since few years, the scientific interest for the dynamics of structures travelled by moving loads has growing considerably because of the design and the efficient construction of systems are able to reach high velocities. There are many literature mainly focused on the analysis of the dynamic response of beam and on elastic foundations when loaded under different points. A.J. Wallis Tayler [1] has studied the aerial or wire ropeways, their construction and management. Walter G. Booth [2] has designed and studied applications of the aerial ropeways. James M. W. and Brown john [3] determined the dynamics of an aerial cableway system. Jacques Dubuisson, Michel Cantin [4] examined slipping resistance of monocable aerial ropeway carrier grips. Andreas Pichler [5] has examined the dynamic behavior of the grip and the terminal equipment of a detachable monocable ropeway at the terminal entry. Mark Löhr, Adams [6] has performed the simulation for ropeway technology. Stephan Liedl [7] have computed the motions and forces in the rope system of aerial ropeways during operation. Alexander BorisoffKazakof [8] have proposed advances in engineering software for lift transportation systems. Marta Knawa and Danuta Bryja [9] have developed modeling problems of steeply inclined cableway subjected to moving load. Danuta Bryja and Marta Knawa [10] have explored Computational model of an inclined aerial ropeway and numerical method for analyzing nonlinear cable-car interaction. But dynamic behavior of string when it is subjected to moving mass is also important to study. In few areas mainly hill stations even for the short distances, there is a problem of electricity and travelling from one place to another. To overcome this difficulty, we can use rope drive (using string carrying mass attached to it) When a string is used as a rope then its dynamic behavior when carrying mass with it is to be studied carefully otherwise it may not give exact results. In this we are going to deal mainly with dynamic behavior of string under moving mass, required stiffness and vibrations of string etc.,

3. Problem formulation:
3.1 Arbitrary loads of ropeways: The below image shows the Single span circular ropeway span and the Loading parameters among brackets is indicated with Ls and the altitude difference is indicated with hs.
Figure 1 Ropeway of single span circular

Figure 2 Loads parameters

The total length of the bearing cable is indicated with the term of $s_i$ and the total length of traction cable is denoted with $s_0$ and it can be calculated completing the erection of the ropeway section formula, $V_{Bi}=V_{Ai}+qS_i$ ($i=1…m+1$)

Total length weight of cable is denoted with $q$ here. Here the altitude difference & spans of every section values are shown.

In this process the cross section area & modulus of elasticity is denoted with $E_A$, here superscripts are denoted with 1 or t represents the bearing cable or traction variables.

$$L_i = \frac{H_i}{q} \left[ \frac{qS_i}{E_A} + \text{asinh} \frac{V_{Bi}}{H_i} - \text{asinh} \frac{V_{Ai}}{H_i} \right]$$  \hspace{1cm} (1)

$$h_i = \frac{V_{Bi}^2 - V_{Ai}^2}{2qE_A} + H_i \left( \sqrt{1 + \frac{V_{Bi}^2}{H_i^2}} - \sqrt{1 + \frac{V_{Ai}^2}{H_i^2}} \right) \hspace{1cm} (i=1…m+1)$$  \hspace{1cm} (2)

where $L$ is length of the cable, $H$ is height of bracket on which string is mounted and $q$ is the total length weight of string.

3.2 Traction cable & bearing cable analysis: The combine interactivity between bearing cable & traction cable of one & only pass over ropeway is mostly cerebrate from the below steps

$$L_{i+1}^t - L_2 = 0 \hspace{0.5cm} h_{i+1}^t - h_i^t = (i=1…m+1)$$  \hspace{1cm} (3)

The below equation shows return traction cable

$$L_{m+2}^t - L_2 = 0 \hspace{0.5cm} h_{m+2}^t - h_2 = 0$$  \hspace{1cm} (4)

It is not necessary to know the loads movement from where to where in a one only pass over ropeway it is constant the value of total altitude variation & span, the addition of spans portion is same to complete horizontal span & the addition of altitude difference portion is same to complete altitude difference value

$$\sum_{j=1}^{m+1} l_j^t - L_2 = 0 \hspace{0.5cm} \sum_{j=1}^{m+1} h_j^t - h_2 = 0$$  \hspace{1cm} (5)

3.3 Constant loads of Space: Here we have m+1 equation due to unchanged values of traction cable when it is pulled by load

$$\sum_{j=1}^{m+1} S^t_j - S^G_i = 0 \hspace{0.5cm} \sum_{j=1}^{m+1} S^G_j - S^G_m = 0 \hspace{0.5cm} (i=0…m-1)$$  \hspace{1cm} (6)

4. Materials and methodology:

4.1 Materials:

| Material | SAE1020 | SAE1137 | Al-7075 | Al-7475 |
|----------|---------|---------|---------|---------|
| Young’s modulus | $2*10^{11}$ Pa | $200*10^8$ Pa | 71.7*10^9 Pa | 70.3*10^9 Pa |
| Poisson’s ratio | 0.29 | 0.29 | 0.33 | 0.33 |
| Yield strength | 394.70 Mpa | 500 Mpa | 503 Mpa | 450 Mpa |
| Density | 7870 Kg/m$^3$ | 7800 Kg/m$^3$ | 2810 Kg/m$^3$ | 2810 Kg/m$^3$ |
5. Methodology:

5.1 Solid works process: In this thesis solid works software is used to develop the both ropeway strings, in this process the mean diameter of total number of strings is consider as 12mm. To create ropeway string here extrude option were used to generate, and here 1000mm is consider to be total length of the string, and after creating the sketcher need to check whether it is completely closed or not if there is any open ends need to fix them to closed loop to convert the sketcher into 3D object, and here need to remember one more thing that is the sketcher is don’t have any overlapping it means the sketcher should not pass on other sketcher. After creating all these sketches the image shows the final image of the circular straight string and helical twisted string.

![Figure 3 Straight string model](image1)
![Figure 4 Helical twisted string model](image2)

5.2 Ansys process: Select ANSYS workbench and then click static structural module to do analysis process which is shown in below image. After selecting static analysis module now enter the material properties of SAE 1020, SAE 1137, Al 7075, Al7475 and those values are given below. After completing design in solid works now the final model were imported into ANSYS workbench and the model is showing in below image, to import into ANSYS workbench here the object should be in either .iges or .step file format only.

5.2.1 Straight ropeway string Meshing: To calculate the results here need to apply boundary conditions on it, before applying boundary conditions first of there should be a contact between each string so that the load will transfer from one end to other end, this meshing will create intersections and cross connection in between them so that by that contact the load can transfer throughout the object.

5.2.2 Boundary conditions: Here force is consider to as boundary condition on it and here Fixing both ends by using fixed support option then after apply Force 430 N apply then solve the results of deformation, stress, strain, safety factor, this 430N is maximum limit to apply on circular string, at this loading the safety factor is nearby 1.5 only, so that it is consider to be maximum allowable load on this circular string without any breakage on it.

![Figure 5 Straight rope way string meshing](image3)
![Figure 6 Straight rope way string boundary conditions](image4)

5.3 Straight ropeway string results:

5.3.1 Material SAE1020
5.3.2 Material Al-7075

5.4 Tables: The following table shows the results of straight ropeway string for different materials

| Material | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|----------|----------|----------|--------|--------|
| Deformation (mm) | 6.401 | 6.4014 | 18.333 | 17.975 |
| Stress (Mpa) | 260.51 | 260.5 | 261.97 | 261.9 |
5.5 Graphs: The following graphs illustrate the results of Straight ropeway string for different materials

|          | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|----------|----------|----------|--------|--------|
| Strain   | 0.0013025| 0.0013025| 0.0037265| 0.0036537|
| Safety factor | 1.5151     | 1.9193    | 1.7178  | 1.9201  |

6. Helical twisted ropeway string:

6.1 Helical twisted rope string meshing: To calculate the results here need to apply boundary conditions on it, before applying boundary conditions first of there should be a contact between each string so that the load will transfer from one end to other end, this meshing will create intersections and cross connection in between them so that by that contact the load can transfer throughout the object.

6.1.1 Helical twisted ropeway string boundary conditions: Here force is considered as boundary condition on it and here Fixing both ends by using fixed support option then after apply Force 450N apply then solve the results of deformation, stress, strain, safety factor, this 450 N is maximum limit to apply on helical twisted string, at this loading the safety factor is nearby 1.5 only, so that it is consider to be maximum allowable load on this helical twisted string without any breakage on it.
6.2 Helical twisted string ropeway results:

6.2.1 Material SAE1020

![Figure 17 Material SAE1020 Deformation](image1)

![Figure 18 Material SAE1020 Stress](image2)

![Figure 19 Material SAE1020 Strain](image3)

![Figure 20 Material SAE1020 Safety factor](image4)

6.2.2 Material Al-7075

![Figure 21 Material Al-7075 Deformation](image5)

![Figure 22 Material Al-7075 Stress](image6)

![Figure 23 Material Al-7075 Strain](image7)

![Figure 24 Material Al-7075 Safety factor](image8)

6.3 Tables: The following table shows the results of helical twisted ropeway string for different materials
Table 3 Helical twisted ropeway string results

| Material          | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|-------------------|----------|----------|--------|--------|
| Deformation (mm)  | 2.3689   | 2.3689   | 6.8794 | 6.745  |
| Stress (Mpa)      | 257.85   | 257.85   | 255.12 | 255.21 |
| Strain            | 0.0012893| 0.0012893| 0.003629| 0.0035581|
| Safety factor     | 1.5307   | 1.9391   | 1.7639 | 1.9716 |

6.4 Graphs: The Following graphs illustrates the results of helical twisted ropeway string for different materials

Graph-5 Helical twisted string deformation

Graph-6 Helical twisted string stress

Graph-7 Helical twisted string strain

Graph-8 Helical twisted string safety factor

7. Transient analysis:

7.1 Transient analysis boundary conditions: In this transient analysis module different type of load values applied at different time period, here 43 seconds of time is taken to apply 430N of load on it, and each step is increment of 5secs in time period, and 50N in load steps.
7.2 Straight ropeway transient analysis results:

7.2.1 Material SAE1020

![Figure 26 Material SAE1020 Deformation](image1)

![Figure 27 Material SAE1020 Stress](image2)

![Figure 28 Material SAE1020 Strain](image3)

![Figure 29 Material SAE1020 Safety factor](image4)

7.3 Helical twisted ropeway transient analysis results:

7.3.1 Material SAE1020

![Figure 30 Material SAE1020 Deformation](image5)

![Figure 31 Material SAE1020 Stress](image6)
8. Results and discussion of static analysis:

8.1 Following table shows the static analysis results of straight ropeway string for different materials

| Material   | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|------------|----------|----------|--------|--------|
| Deformation (mm) | 6.401    | 6.4014   | 18.333 | 17.975 |
| Stress (Mpa)    | 260.51   | 260.5    | 261.97 | 261.9  |
| Strain          | 0.0013025| 0.0013025| 0.0037265| 0.0036537|
| Safety factor   | 1.5151   | 1.9193   | 1.7178 | 1.9201 |

8.2 Following table shows the static analysis results of helical twisted ropeway string for different materials

| Material   | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|------------|----------|----------|--------|--------|
| Deformation (mm) | 2.3689   | 2.3689   | 6.8794 | 6.745  |
| Stress (Mpa)    | 257.85   | 257.85   | 255.12 | 255.21 |
| Strain          | 0.0012893| 0.0012893| 0.003629| 0.0035581|
| Safety factor   | 1.5307   | 1.9391   | 1.7639 | 1.9716 |

9. Results and discussion of modal analysis:

9.1 Following table shows the modal analysis results of straight ropeway string for different materials

| Material   | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
|------------|----------|----------|--------|--------|
| Mode1 (Hz) | 56.518   | 56.772   | 56.449 | 55.896 |
| Mode2 (Hz) | 74.643   | 74.977   | 74.269 | 73.54  |
| Mode3 (Hz) | 145.68   | 146.33   | 145.72 | 144.29 |
9.2 Following table shows the modal analysis results of helical twisted ropeway string for different materials

| Table 7 Modal analysis of helical twisted ropeway string |
|-----------------------------------------------|
| Material | SAE 1020 | SAE 1137 | AL7475 | AL7075 |
| Mode1 (Hz) | 94.525 | 94.948 | 92.863 | 93.783 |
| Mode2 (Hz) | 95.155 | 95.981 | 93.464 | 94.39 |
| Mode3 (Hz) | 206.47 | 207.4 | 203.23 | 205.24 |
| Mode4 (Hz) | 208.21 | 209.15 | 204.9 | 206.93 |

10. Conclusion:
In this thesis both straight and helical twisted ropeway strings were designed and analyzed with static and dynamic boundary conditions with 4 different materials, from analysis results it is showing that 1m straight rope way string straight can withstand up to 430 N only when it made up of SAE 1020, at this boundary condition the minimum safety factor is near to 1.5, so that this is the maximum limit which the rope way can bear, in similar case helical twisted rope string can withstand up to 450N, it means by using helical twisted rope string the strength nearly increases up to 4 to 5% approximately with same material properties.

When comparing all other materials results SAE 1137 has better strength values compare to SAE 1020 and this material can withstand more load and it can produce more durability, in same way among AL7075 has highest strength compare to AL7475, by comparing 4 materials results, AL7075 has taken 1st position and then SAE 1137 has taken 2nd place in terms strength properties.

By knowing only static analysis it is not the way to decide an optimum rope structure or material for it, so that dynamic analysis is also carried on for each material and calculated natural frequency results, from the results SAE 1137 & AL7075 has better natural frequency values.

Finally thesis can concluded with helical twisted with SAE 1137 or AL7075 materials are more optimum, in this case each material has their own advantages and limitations, so that according to requirement it can possible to choose required material.

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