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Analysis and Design Updation of Aerial Monocable Ropeway Conveyors for Eliminating Recurring Failures and Downtimes

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Abstract— The skyscraping buildings in today's modern era have already been accepted as breath taking engineering wonders. All of these have been raised only because of reliable raw materials which mainly include the quality cement. MALABAR CEMENTS situated at Walayar is considered as one of the pioneers in cement production since 1978 in Kerala. Lime stone is one of the most essential raw materials in the production of cement which is carried from mines to the processing factory using aerial monocable ropeways at MALABAR CEMENTS, Walayar. The reliability & failure issues of this aerial monocable ropeway conveyors with detachable grips which play an integral part in the cement manufacturing process is a matter of prime concern in the industry. Considering the terrain slopes and ridges over the total span of 6.5km through which it is conveyed, it is hard time for the foremen and related workers to ponder over the frequently occurring failures. A survey was done on the failures over a period of five years for each part of the carriage and bucket system. The parts which are wearing out frequently are noted. And the parts which are closely related to downtime are found out and preliminary failure analysis is done. The survey shows that the most frequent failures occur as slipping of grips from the rope especially at the steeper towers. This causes large downtimes for the operations especially during the night hours when maintenance and repair are nearly impossible considering the terrain & unavailability of labour. This occurs due to the deficiency in gripping forces provided by the Belleville springs under the influence of gravity and carried load. The present study concentrates primarily on changes in Belleville spring configurations as the cost and downtimes involved in major design updations cannot be accommodated in the present scenario. The existing Belleville series spring configuration on clamping force analysis using ADAMS reveals that it is just sufficient to support the existing load and may not be sufficiently adequate at higher inclinations. Different configurations of Belleville springs were analyzed and series-parallel configuration was found to be more effective than the existing series configuration. The possibilities of geometry modification of grips to enhance the gripping behavior is also considered. Proposals for design updations was done.

Index Terms— Aerial Monocable Ropeway conveyors, Detachable grips, Bucket failures, Failure analysis, Design Updations .

I. INTRODUCTION

The competitive environment in today's modern world has put the manufacturing companies under immense pressure to produce and deliver their products in a timely manner. Although a major share of the capital is spent on buying and installing the machineries and subsystems that support the production, only very little attention is given on design updations and maintenance procedures to meet up with the ever increasing demand and production of their products. Considering the design limitations and lack of proper maintenance procedures that cause the machineries and subsystems to deteriorate easily in the harsh working conditions, the productivity of the whole plant is affected very badly.

Urbanization in the modern world has led to arising need of development of infrastructure. This has in turn lead to increasing demand for cement which is met by the cement production plants working round the clock everyday every year. These plants have machineries and subsystems which require timely design updations, maintenance and replacement of parts to improve energy efficiency so that the production continues uninterrupted and thus enhancing the productivity and efficiency.

The material handling systems play an important role in the cement production plants and failure of such systems and equipment will adversely affect the productivity. Among the different conveyor systems such as belt conveyors, chain conveyors, bucket conveyors, rope conveyors etc. that are used in the industry aerial rope conveyors are preferred. The reason behind this preference is the consideration of distance and the terrain through which the load or raw materials need to be carried. In a cement plant the limestone which is the most important raw material is carried from the quarries to the production unit using aerial ropeway systems.

The aerial ropeway systems although well developed as passenger carrying ropeway systems is in the need of further improvement as a material handling system in the industrial environment. The reliability and maintainability of such systems are of prime importance for the manufacturing plants and industries utilizing them. And it is high time to make some improvements in order to reduce the failure rates and improve efficiency of these systems. The timely design updations need to be given extreme importance so that the energy utilization in these systems can be optimized by preventing failures and thereby improving the productivity.

The challenging task for any engineer working with suggesting an optimized solution or updations for an existing system is the cost effectiveness and feasibility of the suggestion. It should be in such a way that the suggestions or updations can be merged into the existing system without requiring a replacement of the existing system as a whole by a new system. Updations done with such a concept in mind can reduce the economic burden which may be inflicted otherwise on the industry to a large extent.

The works in the field of design and development of aerial ropeway transportation systems are only very few. The amount of results and data available from these resources have been small yet useful in the progress of this project. One of such earliest of these literatures is a textbook named Aerial or wire rope-ways, their construction and management by A.J. Wallis Taylor [1] in early 1900's. This book describes the different components and their functioning along with their management procedures during those times. Walter G. Booth [2] in his thesis the design and application of aerial ropeways in 1965 investigated the different types of aerial ropeways used along with the load behavior of the different types of support towers. James M. W. Brown John [3] in 1997 investigated the dynamic vibrational behavior of the system and concluded that the behavior of the system at start-up and shutdown depends on the dynamics of the entire cable system including the cabins, suspension and haul rope as well as the performance of the motor and friction effects. Jacques Dubuisson and Michel Cantin [4] investigated the Slipping resistance of monocable aerial ropeway carrier gripsunder various conditions of loading.Andreas Pichler [5] studied the dynamic behavior of the grip and the terminal equipment of a detachable monocable ropeway at the terminal entry. Mark Löhr [6] conducted an Adams simulation for ropeway technology based on passenger ropeways having detachable cabins and investigated the loads and stresses occurring at the entry trumpet at station entry. Stephan Liedl [7] investigated the Motions and forces in the rope system of aerial ropeways during operation based on a reversible bicable ropeways using mathematical and computational program techniques which was later validated using a real time ropeway system. Alexander Borisoff Kazakoff [8] in 2012 published his work and experience in design of lift transportation systems and this investigation relates to design, manufacturing and mounting of different rope way transportation systems Marta Knawa and Danuta Bryja [9] investigated the Modeling problems of steeply inclined cableway subjected to moving load in 2009 based on bicable ropeways. Danuta Bryja and Marta Knawa [10] in 2009 investigated a Computational model of an inclined aerial ropeway and numerical method for analyzing nonlinear cable-car interaction based on bicable aerial ropeway systems. H.K.Dubey and Dr. D.V. Bhope [11] conducted the stress and deflection analysis of belleville spring using ANSYS- FEA for various ratios of D/d and h/t.KIRAN S [12] conducted a reliability evaluation and risk based maintenance in a cement plant at Malabar Cements Walayar in 2015.

This work focusses on suggesting the design updations to the existing material handling system which may lead to the improvement of productivity and energy efficiency of the same. A case study is done at Malabar cements Ltd, Palakkad, Kerala at the ropeway system. A model for improving the design of the system has been proposed.

II. PROBLEM DEFINITION

The productivity of a cement plant depends immensely on the efficiency of material handling systems which carry the raw materials and finished products in the production plant. The efficiency of such systems depend up on their ability to work without failure using optimized amount of energy used by them. The aim of this project is to conduct failure analysis of the system and suggest design updations to improve efficiency by reducing the failure rates of the ropeway conveyor system and thus enhancing the optimum energy utilization and production capabilities of the plant.

The specific objectives of the work are as follows,

1. Analyze the existing design in detail and identify the frequently failing components.
2. To develop an alternate cost effective design for updating the existing system.
3. Analysis and comparison of the alternate design with the existing one to prove the effectiveness

The failures relating to electrical failures and human errors are not considered. The work is focused on cost effective updations of the existing design, thus it is limited to the operation phase.

III. THE AERIAL ROPEWAY SYSTEM

Aerial ropeway systems are considered among one of the simplest & powerful yet cost efficient mode of transport for transporting man or material in today's modern world. The ropeways overcome the conventional modes of transportation in many ways such as geographical and economic factors considering the time taken and the amount of load carried by them. The aerial ropeway systems can be classified as follows

1. Based on number of ropes operating in the system.
   a. Monocable ropeway system
   b. Bicable/Tricable ropeway systems.

In a monocable system, one rope serves to both support and control the carriers in transit. In a bicable/Tricable system, separate ropes serve the two functions: a static support rope or "track cable" and a moving "haul rope".

2. Based on type of grips
   a. Fixed grip type
   b. Detachable grip type.

A fixed grip is one that permanently connects a carriage vehicle to the cable. Because of this direct connection, stopping or slowing a fixed grip vehicle involves stopping or slowing the entire system. A detachable grip is one that can separate itself from the cable. The detachability allows a cabin to slow or stop within a station, without disrupting the flow of the entire system. Upon approaching a stop, a mechanism located at the station opens the grip and the vehicle is slowed by another mechanism. Passengers / load get on and off, the vehicle is re-accelerated to line speed, and while departing the grip is re-engaged. Generally fixed grip systems can achieve greater speeds but have other limitations such as longer wait times and reduced capacities, as compared to detachable grip systems.

A. The Components of Aerial ropeway system

The major components of the aerial ropeway system are as follows,

a. The stations

Minimum two stations are necessary for a ropeway system as one is situated at the starting point and one at the end of it.

b. The Drive system

Depending on the requirements of the installation, the drive system can be installed at the bottom or top station, designed as overhead or underground drive and used as drive or drive-tensioning station. It is composed of the drive, the service brake, safety brake and the gearbox.

c. The Towers

The towers are built in a robust manner as they have to bear the weight of the vehicles with passengers/loads. The towers need a transverse construction so that the cabins can travel on both sides of the tower. Support towers are made of steel in a tubular construction. These designs are useful especially in inaccessible area, where they are divided into small pieces and transported by helicopter and reassembled on site.

d. The Rope

Steel wire ropes lent their name to the ropeway systems. Ropes are made of strands that are twisted around the center of the rope core.

e. The roller batteries

The roller batteries function as the correct guiding of the carrying hauling rope along the line. They are composed of rollers. The quantity of rollers depends on the load that the rope is carrying.

f. The vehicles and grips

The vehicles carry the passengers/loads along the ropes between stations in a ropeway system. The vehicles are attached to the ropes by using fixed grips or detachable grips.

g. The control system

The control system monitors the security of the installation and its passengers/loads. The control panel provides real-time data and information necessary for the operation of the ropeways installations. This enables the immediate regulation of the service if necessary either manually or by automated mechanisms.

IV. A CASE STUDY AT A CEMENT PLANT

A case study has been done at Malabar Cements Ltd, Palakkad, Kerala. The study is focused on the ropeway conveyors in the cement plant. The special type monocable ropeways with spring-loaded grips are used for carrying the crushed limestone which is as shown in Figure 1. The rope conveyors connect the span of 6500 meters between the limestone mines and the processing factory. The conveyor contains almost 200 buckets over its entire span to transport limestone from mines to processing industry. The technical details of the ropeway is as given in Table 1. The buckets are linked to the steel ropes by a carriage system. The carriage system is attached to the rope by means of detachable grips as shown in Figure 5.2 with the force provided by the Belleville springs. The 6500 meter span between mines and factory is a geographically complex terrain. Many of the adjacent towers have steep variation in altitudes, and thus the ropes are inclined at certain angles relative to the horizontal. It is high time to be aware of the frequency of failure of the conveyor systems used in these kind of cement plants.

The carriage and bucket systems consists of 32 components as furnished in Table 2. The failure rates of these components have been found out based on available data and represented along.

This monocable ropeway system consists of the following components

a. Towers

The towers are mild steel latticed structures provided along the entire length of the ropeway at designed intervals for the purpose of supporting the carrying hauling rope. These are in total 62 towers. The towers are provided with cat heads, pedestals, trestle mounts, sheaves, spindles and depressor mounts.

Table 1 Technical details of the ropeway

Type of ropeway	Monocable detachable
Capacity of ropeway	200 buckets
Speed of the line	0.3 meter/sec
Material conveyed	Crushed limestone
Spacing between buckets	65 meter
Net weight in bucket	900 kg
Gross weight in bucket	1300 kg
Drive rating	125 Kilo Watt

Fig. 1 The aerial monocable ropeway system

Fig. 2 The carriage & detachable grip of the ropeway system

b. Loading station

The station is ground level reinforced concrete cement framed structure housing all the structures for supporting the main and parking rails, chain haulage track and bucket loading structures. The main drive is located at this station. A 1000 metric tonne bunker stores the crushed limestone. At the bottom of the bunker are two openings which feed two volume controlled chutes through pneumatically controlled gates. Further the loading station comprises of braking devices, pneumatic compressors, trolley, sprocket drive coupled to the brake sheave shaft, locking and unlocking module

c. Unloading station

The unloading station consists of locking module, unlocking module, launching device, parking rail for parking buckets.

d. Bucket carrier system.

The bucket carrier system consists of a set of spring twin detachable grip, Bucket hanger connected to the rope.

e. Telecommunication.

f. Remote control.

The present case study deals with the understanding of the existing system and suggesting cost effective updations for the design and optimum preventive maintenance schedule of the system to reduce the frequency of failures.

A. *Factors leading to failure*

The ropeway system can fail in many ways; Bucket breakdown, tower breakdown, rope failure etc. To improve the efficiency of the system it is essential to minimize the frequent modes of failure. From the survey, it has been found that the bucket failures are the frequent mode of failures that mainly contributes to the termination of process. The bucket failures are due to the slippage of the carriage-bucket assembly in the ropes. The fishbone diagram as shown in Fig. 5.6 clearly illustrates the failures leading to grip slippage.

Previous studies in the field along with the failure data and stoppage time data collected over a period of nearly 3 years show that the failure of the system due to slippage of carriages arises due to inadequate gripping forces provided at the grips. The fault tree for the inadequate gripping forces [13] can be represented as follows,

From the failure data in Table 2 and fault tree analysis for inadequate gripping forces it is seen that Belleville spring is the most vulnerable component to failure. So the design modification of these springs which provide the gripping forces is to be considered for further analysis.

The possibility to improve gripping by providing modifications to the geometry of the moving jaw is also considered in the further analysis.

V. MODELING, SIMULATION AND ANALYSIS

A. *Tools Used*

The aerial monocable ropeway carriage system is modelled, simulated and analyzed using the following tools.

a. CATIA V6

CATIA (Computer Aided Three-Dimensional Interactive Application) started as an in-house. CAD/CAM/CAE software in 1977 by French aircraft manufacturer Avions Marcel Dassault, to develop Dassault's Mirage fighter jet. It was later adopted in the aerospace, automotive, shipbuilding, and various other industries.

CATIA enables the creation of 3D sketches, 3D parts, sheet metal composites, and mechanical assemblies. The software also provides advanced technologies for mechanical surfacing and tooling design. It provides tools to complete product definition, including functional tolerances as well as kinematic definitions.

In this project CATIA has been used to create the 3D model of the carriage system used in the aerial monocable ropeway The part and assembly drawings collected from the Malabar Cements have been used to create the various parts and their assembly using CATIA software. The actual photograph of the carriage system has been illustrated in fig. 5 while the CATIA models are as shown in fig. 6 and fig. 7.

Table 2 Components and their failure rates

Sl no.	Part no.	Part name	Failures	Failure rate (per day)
1	64111425	BELLEVELLE SPRING	4350	4.67
2	5006308	BEARING 6308	177	0.19
3	64111399	BOXHEAD FOR BUCKET CARRIAGE	31	0.03
4	64111490	BRIDGE FOR BUCKET CARRIAGE	222	0.23
5	64111200	BUCKET	62	0.06
6	64111210	BUCKET HANGER	12	0.03
7	64111485	BUSH FOR BUCKET HANGER SP.DIA 45	219	0.23
8	64111365	BUSH 1 FOR MOVING JAW(BIG)	530	0.56
9	64111370	BUSH 2 FOR MOVING JAW (MED)	650	0.69
10	64111371	BUSH 3 FOR MOVING JAW (SMALL)	930	1
11	64111496	CATCH ARM	38	0.04
12	64111380	DRAWBAR FOR DETACHABLE GRIP	184	0.19
13	64111405	DRAW BAR PIN FOR CARRIAGE	39	0.04
14	64111360	FIXED JAW	194	0.20
15	64111211	HANGER BEARING	87	0.09
16	64111390	HINGE BLOCK	25	0.02
17	64111395	HINGE BLOCK PIN	106	0.11
18	64111410	HOLD DOWN ROLLER WITH SPINDLE (CASTLENUT)	260	0.27
19	64111475	JAW PIN	279	0.3
20	64111400	HINGE PIN BUSH	0	0
21	64111222	LOCKNUT FOR CARRIAGE ROLLER.	0	0
22	64111319	MAIN ROLLER BEARING HOUSING WITH NUT	113	0.12
23	64111318	MAIN ROLLER NUT	86	0.09
24	64111355	MOVING JAW	100	0.10
25	64111426	MS PLATE WASHER FOR CARRIAGE	264	0.28
26	64111398	PART FOR BOXHEAD	30	0.03
27	64111320	SIDE ROLLER BEARING HOUSING	105	0.11
28	64111205	SPINDLE FOR BUCKET HANGER	105	0.08
29	64111220	TONGUE	512	0.55
30	64111298	TONGUE PIN	1245	1.33
31	64111471	D-SHACKLE FOR BUCKET	510	0.54
32	48740095	CIRCLIP INTERNAL B95 1S3075	260	0.27

a. ADAMS

` ADAMS (Automated Dynamic Analysis of Mechanical Systems) is the most widely used multibody dynamics and motion analysis software in the world. ADAMS helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

ADAMS multibody dynamics software enables engineers to easily create and test virtual prototypes of mechanical systems in a fraction of the time and cost required for physical build and test. Unlike most CAD embedded tools, ADAMS incorporates real physics by simultaneously solving equations for kinematics, statics, quasi-statics, and dynamics. Utilizing multibody dynamics solution technology, ADAMS also runs nonlinear dynamics in a tiny fraction of the time required by FEA solutions. Loads and forces computed by ADAMS simulations improve the accuracy of FEA by providing better assessment of how they vary throughout a full range of motion and operating environments.

The carriage system modelled in CATIA is simulated in ADAMS and the clamping forces provided by the various Belleville spring configurations are found out so that the grip slippage does not occur in the system. The simulations are carried out in the ADAMS software module known as ADAMS VIEW.

c. ANSYS

ANSYS (Analysis System) is a computer-aided engineering software (CAE) which provides comprehensive finite element analysis (FEA) tool for structural analysis, including linear, nonlinear and dynamic studies. The engineering simulation product provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems. In addition, ANSYS offers thermal analysis and coupled-physics capabilities

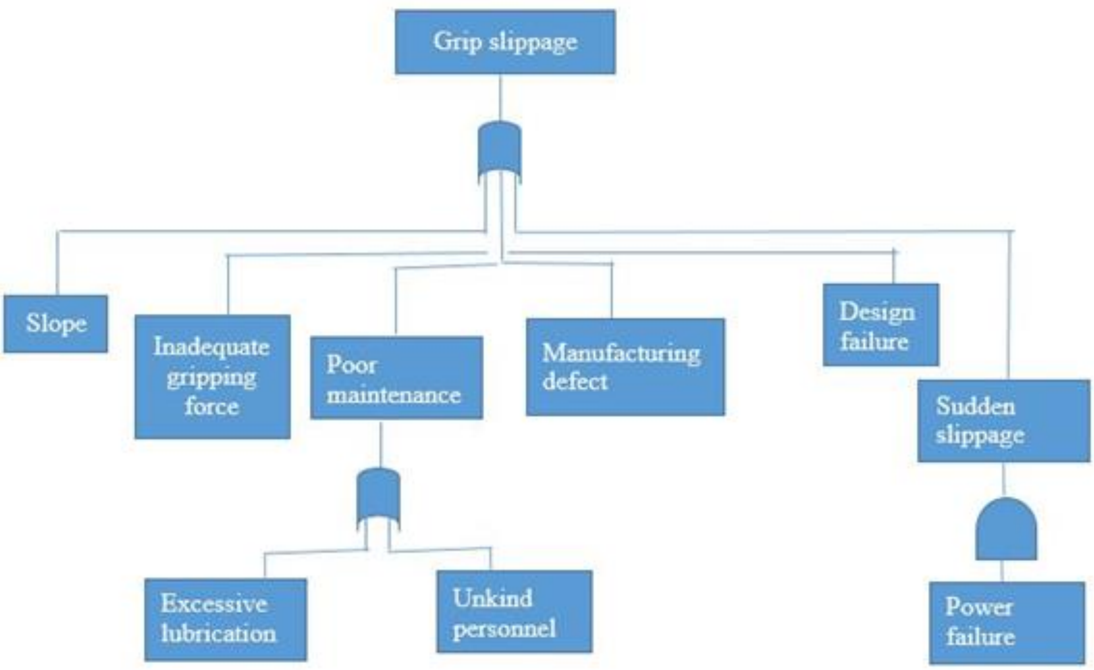

Fig. 3 Fish bone diagram of the slippage of carriages in rope [13].

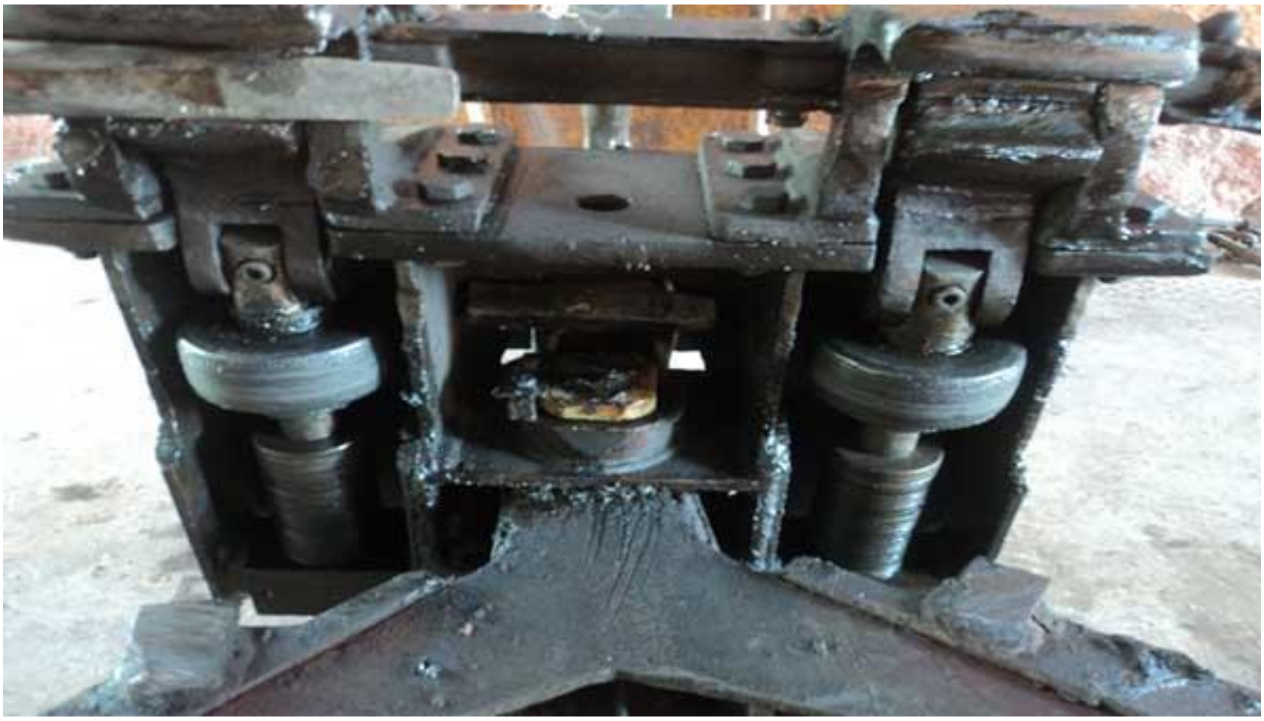

Fig. 5 Actual photograph of the Carriage assembly

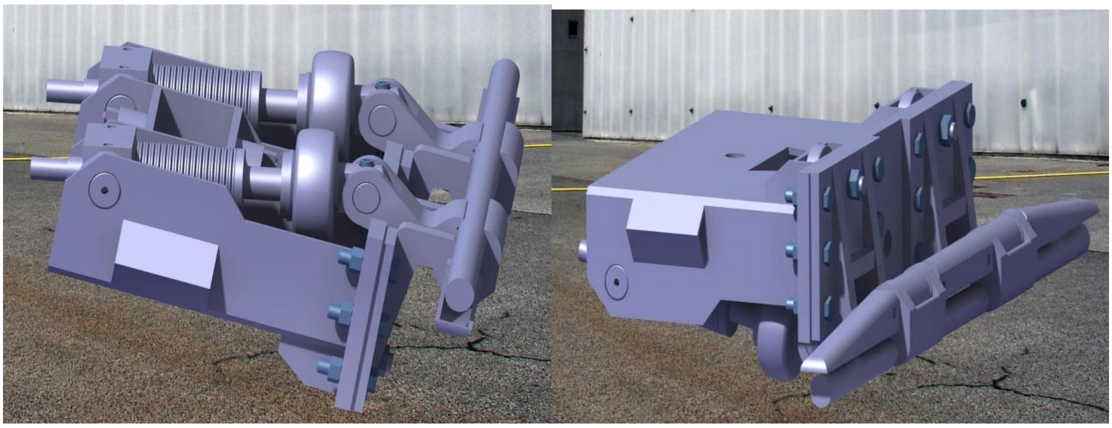

Fig. 6 CATIA Model of the Carriage assembly

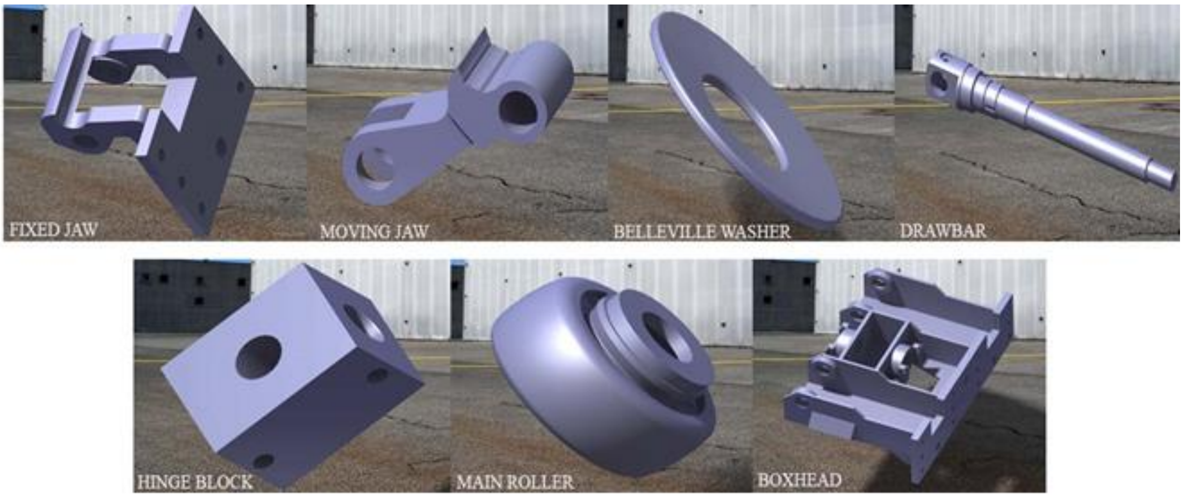

Fig. 7 CATIA Model of the important parts in the Carriage assembly

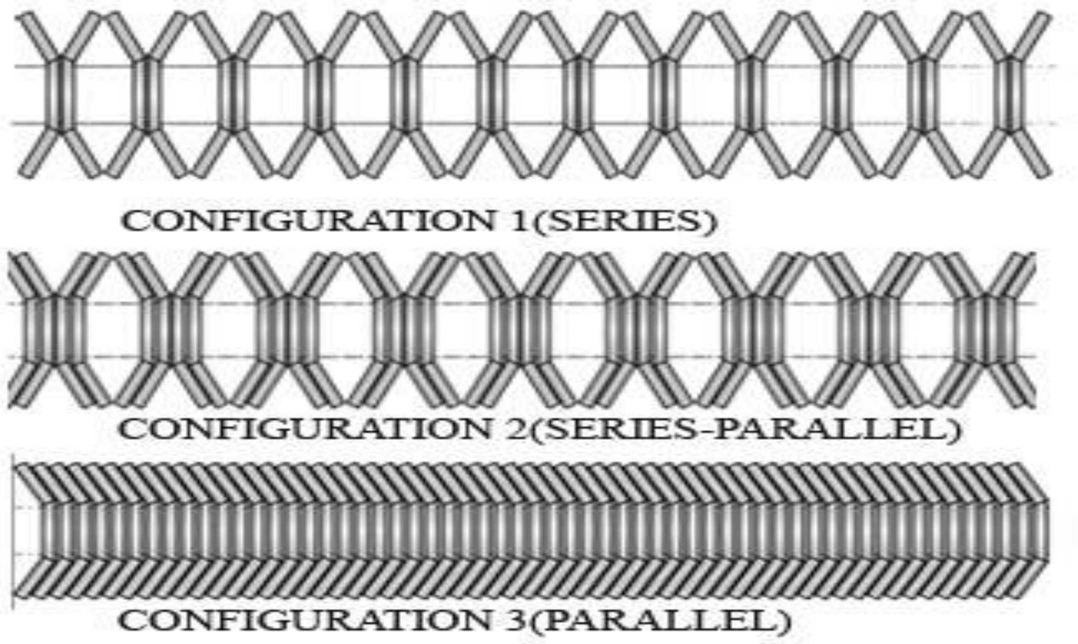

Fig. 8 Belleville spring configurations used

From the plots above we can see that in all the cases the clamping force increases gradually till the grips come in full contact with the rope and there after it remains constant. Also we can see that the clamping forces vary with the difference in configurations where the configuration 1 gives the lowest while configuration 3 giving the highest. Here the configuration 2 with an average value of 13900 N per stack seems to be the most suitable and cost effective alternative for the configuration 1 with an average of 5800 N per stack. The configuration 3 may be conveniently ignored because of the enormously high average value of 1.8 e+05 per stack which may cause damage to the rope material. The results of simulation for configuration 1 and configuration 2 are consolidated in table 3.

Table 3. Simulation results for configuration 1 and configuration 2

CONFIGURATION	CONFIGURATI ON 1	CONFIGURATI ON 2
Assumed Friction Coefficient	0.18	0.18
Inclination of Ropeway(Degrees)	30	30
Rope diameter(mm)	40	40
Weight of Carriage system(Kg)	350	350
Pay Load (Kg)	800	800
Maximum pay load possible (Kg)	960	2500

The configuration 2 can be used for withstanding a maximum load of approximately 2500 Kg using the pair of grips in the carriage system.

The results of spring forces obtained from ADAMS is used for stress analysis using ANSYS.The shear stresses occurring at the rope during gripping were analyzed and following results were obtained.

The maximum allowable shear stress for the wire rope is obtained as 105 Mpa and is obtained as follows,

Yield strength σ_y = 210 Mpa

Maximum allowable shear stress,

$$\tau_{max} = \frac{\sigma_y}{2} = 105 \text{ Mpa}$$

From the analysis using ANSYS, the values of maximum shear stress obtained for the various configurations are listed in Table 4.

Table 4. Maximum shear stress

Spring configurations	Maximum Shear Stress (Mpa)
Configuration 1	35.34
Configuration 2	84.68

We can clearly see that the values obtained through ANSYS simulation for configuration 1 and configuration 2 does not exceed the theoretical values. This indicates that the usage of configuration 2 as replacement to configuration 1, which is the existing configuration, is safe considering the material damage for the rope due to gripping.

i. Clamping forces –Calculated Values

The Belleville spring calculations are done manually using the equations given below and the calculated spring data is represented in Table 5.

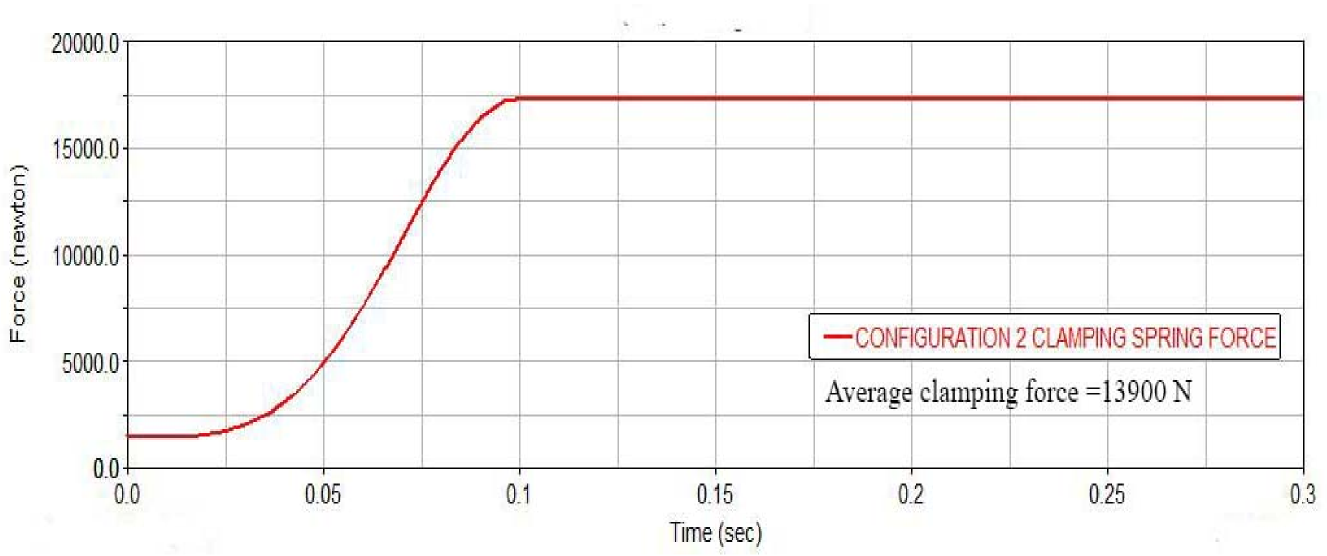

Fig. 9 Clamping force of configuration 1

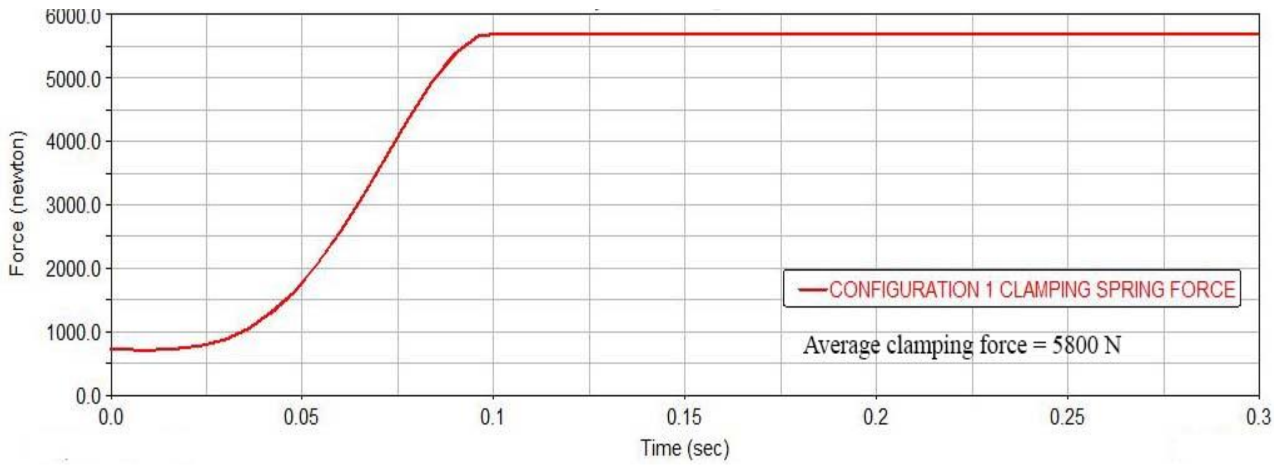

Fig. 10 Clamping force of configuration 2

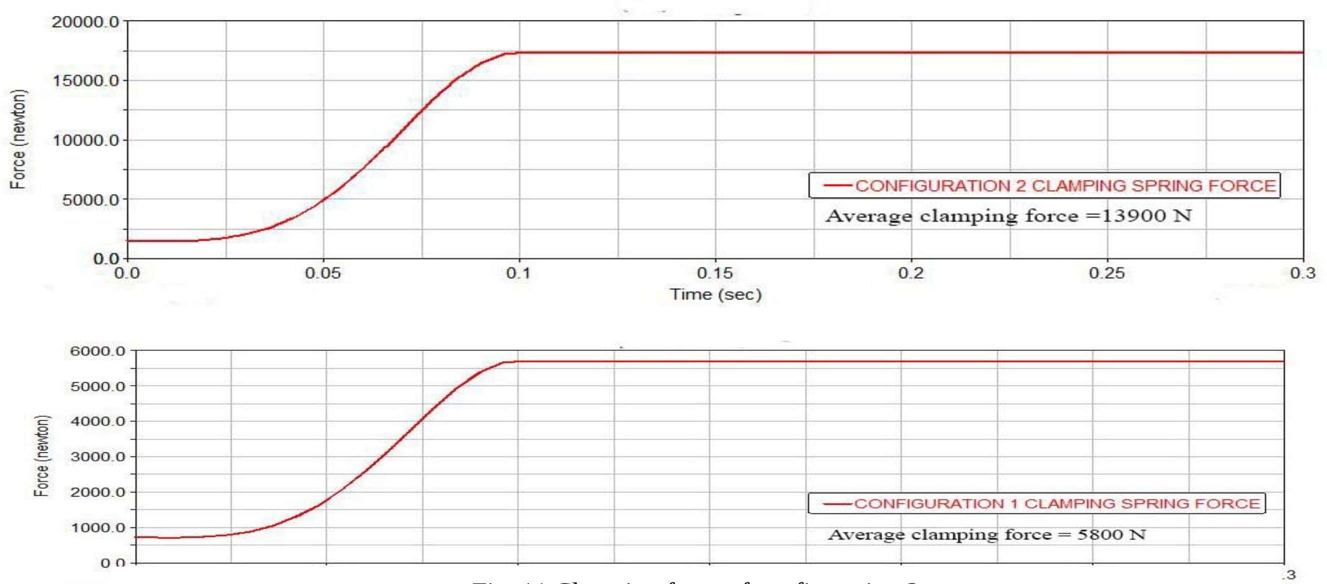

Fig. 11 Clamping force of configuration 3

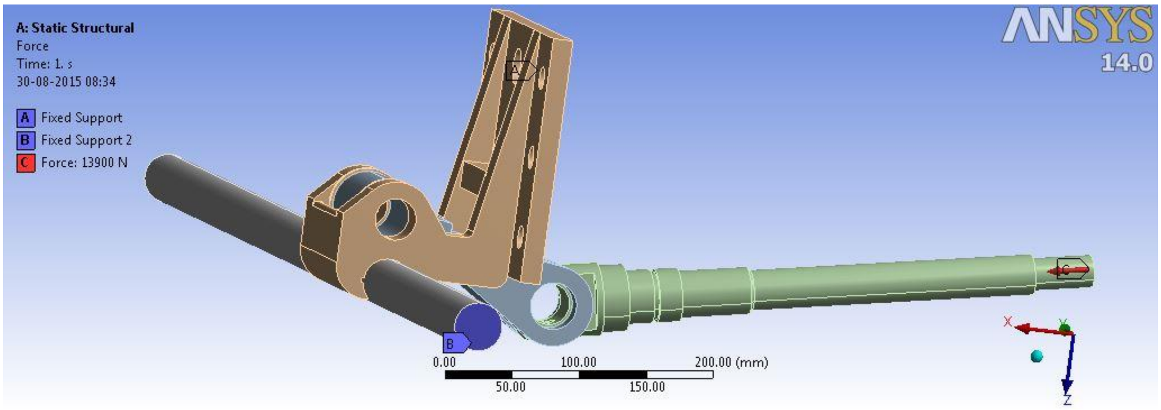

Fig 12 Application of Forces and constraints using ANSYS Workbench

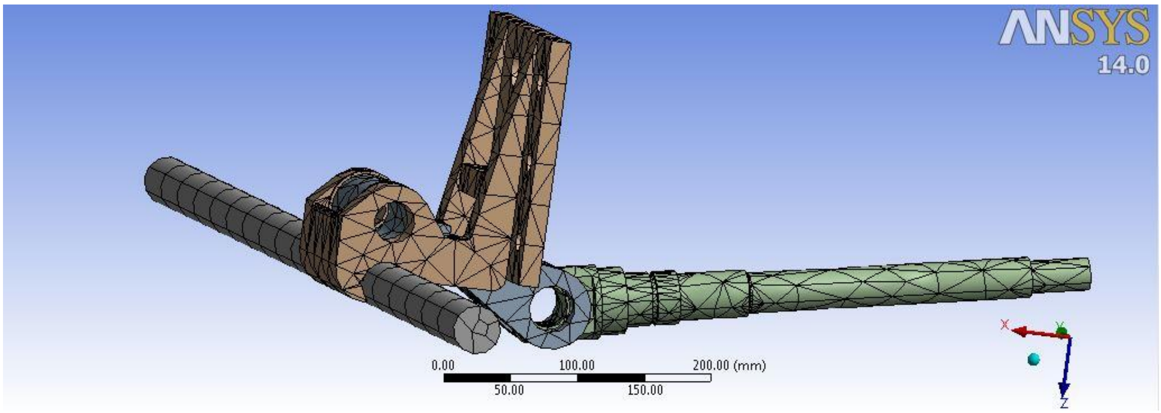

Fig. 13 Meshed Geometry

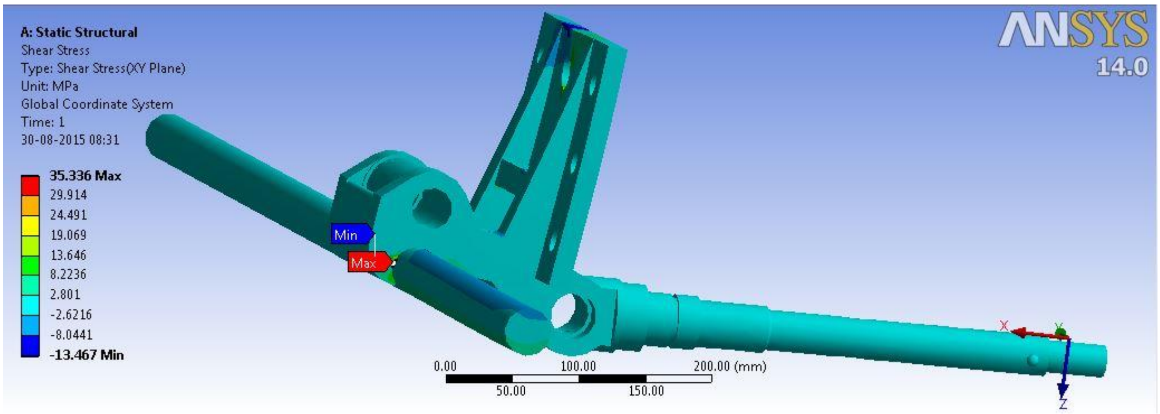

Fig. 14 Shear stress distribution in configuration 1

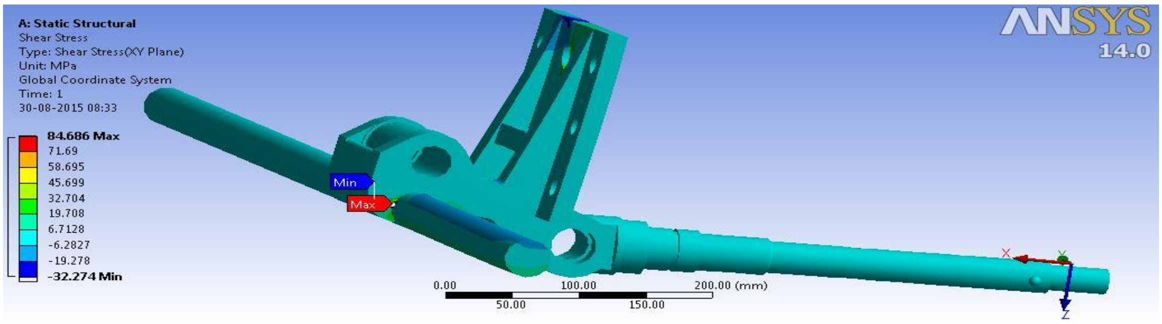

Fig. 15 Shear stress distribution in configuration 2

Table 5. Calculated spring data

CALCULATED DATA	Configuration 1	Configuration 2	Configuration 3
force per stack of spring (N)	6348.9	14014	2.1 e+005
spring rate (N/mm)	7417	7417	7417
spring rate of stack(N/mm)	218.914	924.95	444745
spring work of stack(N mm)	2275.55	4688.64	135970.45

$$K_1 = \frac{1}{\pi}\cdot\frac{\left(\frac{\delta-1}{\delta}\right)^2}{\frac{\delta+1}{\delta-1}-\frac{2}{\ln\delta}} \quad \textbf{(2)}$$

$$K_2 = \frac{6}{\pi}\cdot\frac{\frac{\delta-1}{\ln\delta}-1}{\ln\delta} \quad (3)$$

$$K_3 = \frac{3}{\pi}\cdot\frac{\delta-1}{\ln\delta} \quad (4)$$

$$K = \frac{4E}{1-\mu^2} * \frac{t^3}{K_1.D_e^2}\left[\left(\frac{h_o}{t}\right)^2 - \left(3\frac{h_o}{t}\cdot\frac{s}{2t}\right) + \frac{3}{2}\left(\frac{s}{t}\right)^2 + 1\right] \quad (5)$$

$$F = \frac{4E}{1-\mu^2} * \frac{t^3.s}{K_1.D_e^2}\left[\left(\frac{h_o}{t}-\frac{s}{t}\right)\cdot\left(\frac{h_o}{t}-\frac{s}{2t}\right)+1\right] \quad (6)$$

D. Modified clamp

i. Inducing roughness to the contact surface

The grip contact surface is modified by inducing roughness using 1mm grooves to the moving jaw contact surface. The modified grip is as shown in figure 16.

The modification by inducing roughness using 1mm grooves to the moving jaw contact surface showed only a slight improvement in gripping behavior of the system. The simulation using ADAMS showed that it can withstand a load of upto 820 kg with current inclination of

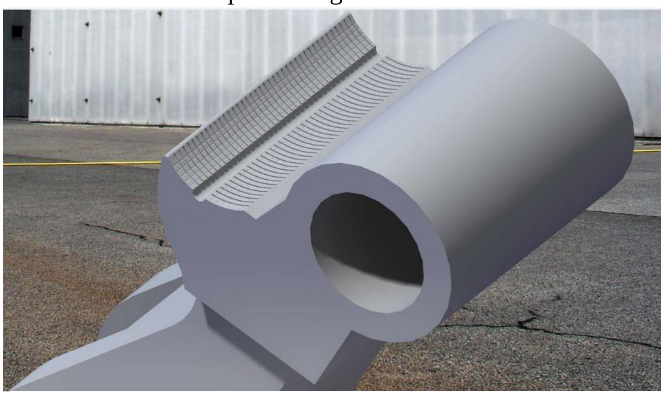

Fig. 16 Inducing Roughness to contact surface

30 degrees.

ii. By tapering the contact surface of the jaws

The grip contact surface is modified by inducing 2 degrees of taper to the jaw contact surfaces. This is done to modify the line of action of the gripping force which is expected to provide increased gripping by reducing the slippage. The schematic of the modified jaw is as shown in figure 17.

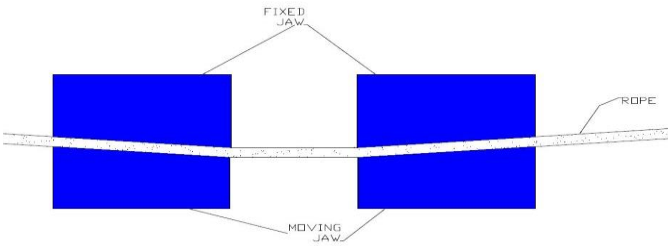

Fig. 17 Inducing taper to contact surface of the Jaws

The modified grip on simulation using ADAMS showed slight improvement in gripping behavior of the system. The simulation carried out as flexible assembly showed that the system was able to withstand an approximate maximum load of 980 Kg with the current inclination of 30 degrees. With the modified grip and the spring configuration 2 used together, the system was seen to withstand an approximate maximum load of 2545 Kg.

VI. CONCLUSIONS

Quality cement is one of the most important raw materials in the creation of sky-scraping buildings which are considered as the engineering marvels of modern era. Lime stone is one of the most essential raw materials in the production of cement and it is carried from mines to the processing factory using the aerial monocable ropeways at MALABAR CEMENTS, Walayar. The reliability & failure issues of the aerial monocable ropeway conveyors with detachable grips which play an integral part in the cement manufacturing process is a matter of prime concern in the industry. The aerial ropeway conveyer system studied here spans over a length of 6.5 Km with steep terrain slopes and ridges which makes it difficult for the foremen and related workers to ponder over the frequently occurring failures.

The survey done here based on data available on the failures over a period of five years for each part of the carriage and bucket system shows that the most frequent failures occur as slipping of grips from the rope especially at the steeper towers. This causes large downtimes for the operations especially during the night hours when maintenance and repair are nearly impossible considering the terrain & unavailability of labour. Some of the suggested design updations and improvements in the preventive maintenance schedule is summarized as follows.

The Belleville spring configuration 1 (Series) when changed to configuration 2 (series-parallel) may lead to increased gripping force and load capacity of the system. The gripping force was found to increase to an average value of 13900 N from 5800 N per stack of spring and this improved the load capacity to almost 2500 Kg from 800 Kg without slippage during simulation. While considering the material capabilities the stress analysis using ANSYS reveals that the configuration is safe for usage without damaging the rope material. The geometry modification by inducing roughness in the jaw contact surfaces using grooves was found to improve the gripping behaviour only marginally.

The geometry modification by inducing 2 degrees of taper to both the jaw contact surfaces which modifies the line of action of the gripping force was also analysed .It was seen that the maximum load capability increased to 980 Kg and this jaw modification when used along with the spring configuration 2 was able to withstand a load of 2545Kg without slippage during simulation.

These design updations may prove cost-effective and advantageous for the improvement of the system which can be implemented without much change in the existing system.

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