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DEVELOPMENT OF CABLE DRIVE BASED LINEARLY DEPLOYABLE MECHANISM FOR IN SPACE DEPLOYMENT OF HELICAL ANTENNA

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Abstract: Cable drive is widely used in the deployment of large space payloads because of its lightweight and ability to transfer the load to distant points. This research work is dedicated to developing the cable-driven linearly expanding mechanism for deploying helical antenna in space. This work contains the development of two major subsystems 1. Design of cable winding winch to wind the cable properly and convert motor torque into cable tension force. 2. Design of cable-driven linearly expanding mechanism with locking system.
Keywords: Linear slides, linearly deployable mechanism, Cable winding device, Space antenna, helical antenna

I. INTRODUCTION

With advancements in space technologies the size of space payloads are getting larger and larger, such large structure cannot be mounted on the satellite directly due to volume constrain of the launch vehicle, so such structure must be folded and packed with satellite in launch vehicle and should deploy once satellite settles down in the orbit. So there need to attach one deployment mechanism to deploy such structure, one force transmission system/driving system to transfer force to various location of the deployable structure and one locking system to lock the fully deployed structure.

Xilun Ding et al [1] have developed one cable winding and retracting device for a 25.8m long telescopic boom used in a solar array. They used reciprocating screw for moving cable linearly while winch pulley rotates. Felix [2] has explored wide applications of cross-link mechanisms in space applications. Boa Hong et al [3] have used an elastic slit tube as a deployment mechanism. P. Kumar et al [4] have used a motor with constant rpm for deployment and retraction of the solar array and created the analytical model to determine the cable tension force.

II. DESIGN OF CABLE WINDING DEVICE

The required cable winding device need to wind short length of cable 2.5 m, there is no need to retract the cable. So novel approach is taken to design the winch mechanism with only required functionality to limit the weight. There is two ways to arrange cable on winch pulley 1. By moving the cable linearly while winch pulley rotates 2. By giving linear motion to the pulley along with its rotary motion. The option of moving the cable linearly will require the auxiliary system such as belt drive or CAM drive or reciprocating screw as describe by Xilun Ding et al [1] while giving linear motion along with rotary motion can be achieved easily by splitting winch shaft into two parts, first part to give rotary motion and second one with screw & nut to generate linear motion.

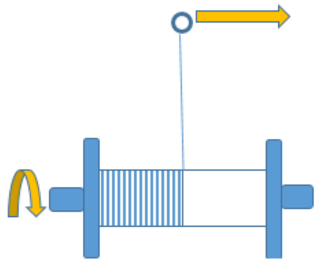

Figure 1 Cable arrangement by moving cable linearly

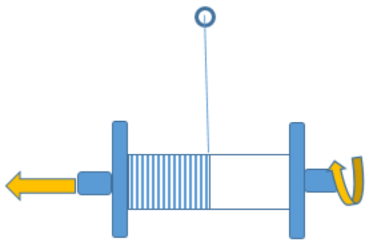

Figure 2 Cable arrangement by moving pulley linearly

Based on requirements the novel cable winding device was made with sufficient functionality. The said device is shown in fig 3. The designed cable winding device has one threaded bolt as a pulley shaft. The pulley is attached with this threaded bolt by a threaded nut, this arrangement provides linear motion during rotary motion. The hexagonal-shaped rode is used to give pulley rotary motion while being free to travel linearly.

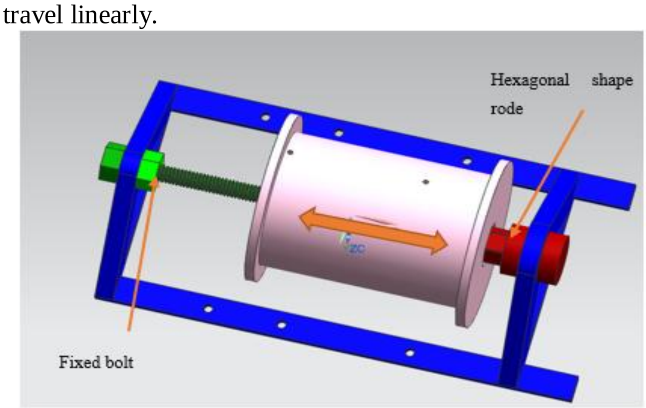

Figure 3 Cable winding Device

III. DESIGN OF LINEARLY DEPLOYABLE MECHANISM

Xilun Ding et al [1] has successfully deployed telescopic boom for a solar array. But the present application of deploying helical antenna doesn't have much high load application and the length of deployment is 2.7m. So the use of telescopic boom will unnecessarily increase weight. Also, the present design should be fabricated in non-metallic material as the metallic mechanism may produce electromagnetic noise which can affect the performance of the helical antenna. The fabrication of a non-metallic cylinder with high dimensional accuracy would be difficult and there may be a chance that deformation in the telescopic cylinder due to space environment may cause problems during deployment i.e. cylinder may get stuck into each other.

So novel approach of using a linear slide is taken to limit the weight. Also, the manufacturing of such slides will be easier than said telescopic boom cylinders. Each slide should be connected with slides beside it, for that roller plate block is designed which will connect two slides and it will allow and guide relative linear motion between two slides. Also, this roller plate block will have locating pin and locking pin to convert this deployable mechanism into the structure. After deployment each slide will act as a beam member, so the linear slides is been designed in the shape of the I-Beam section. Below fig. shows schematic of linear slide arrangement.

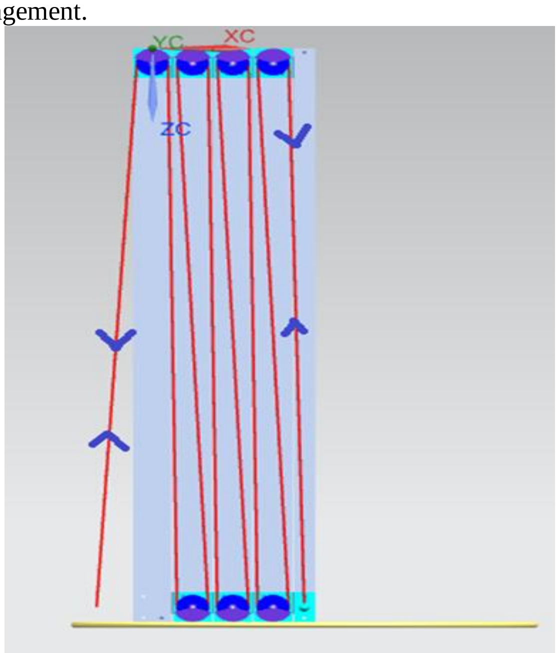

Figure 4 cable driven linear slide

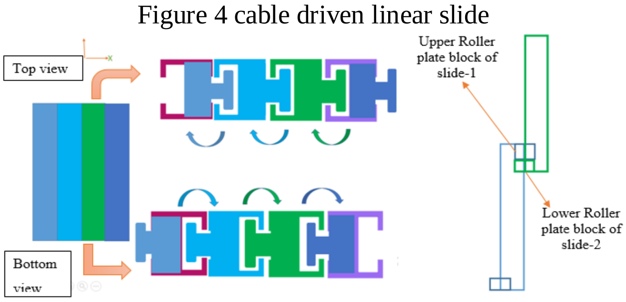

Figure 5 Schematics of linear slide arrangement

A. Guiding system

Based on the concept shown in the schematic diagram initially few conceptual designs were prepared and evaluated and few design decisions were made are listed in the table.

Table 1 Design requirements and solution

	REQUIREMENTS	POSSIBLE SOLUTION
1	Assembly flexibility to overcome fabrication tolerances	Adjustable and fixable supporting roller
2	Flexibility during operation to handle surface irregularity and deformation	Spring loaded roller
3	Ability to handle small forces without deformation	Flexible roller with pre-compression

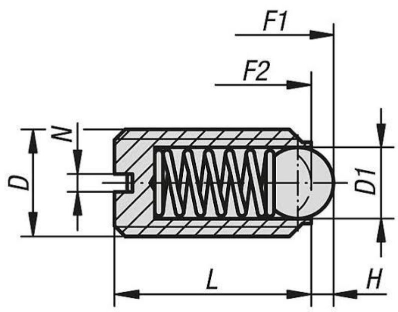

Figure 6 schematic of spring loaded ball plunger

The major challenge this mechanism is to face is of handling surface irregularity and deformation due to space environmental effects. For that, the some flexibility is needed. The normal spring-loaded roller will give deformation for even small force also, such deformation will result in the tilt of linear slide structure. So spring-loaded ball roller plunger with pre-compression force is used in the present design. So, a spring-loaded ball roller plunger is selected as a rolling element that provides stability and flexibility when required.

Table 2 compression of spring for given force

	Force	Δx	
F0	0	0	X0
F1	8	0	X1
F2	14	0.8	X2

$$F_1 = k * X_1 \quad \& \quad F_2 = k * X_2$$

$$F_2 - F_1 = k * (X_2 - X_1)$$

$$F_2 - F_1 = k * \Delta X$$

For acting force F compression will be

$$X = \frac{F}{k}$$

$$X = \frac{F}{\frac{(F_2 - F_1)}{\Delta X}}$$

$$X = \frac{F}{(F_2 - F_1)} * \Delta X$$

Figure 7 Compression of spring for given force

This ball plunger has a thread on its outer body, by that it will be mounted on roller plate. Also, as it is mounted as screw it can be adjusted during assembly. There are six ball plungers in one roller plate and there will be two roller plates in one slide assembly namely the upper roller plate of slide-1 and the lower roller plate of slide-2 as shown in fig. Together this twelve ball roller plunger forms the translation joint between two slides. So there will be only one DOF freedom i.e. translation in Z will be allowed. In case any surface irregularity or deformed surface comes it will generate the force on the ball roller spring once the generated force gets higher then pre-compression force spring will compress slide will travel smoothly.

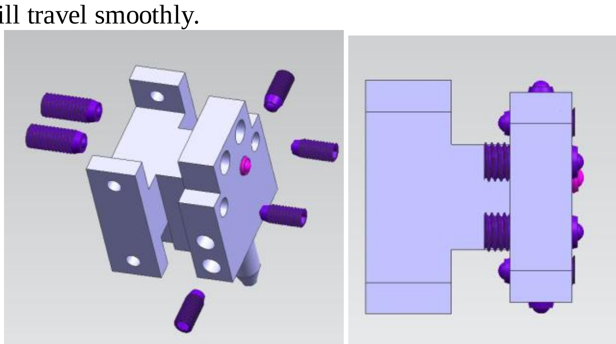
Figure 8 ball plunger assembly in roller plate

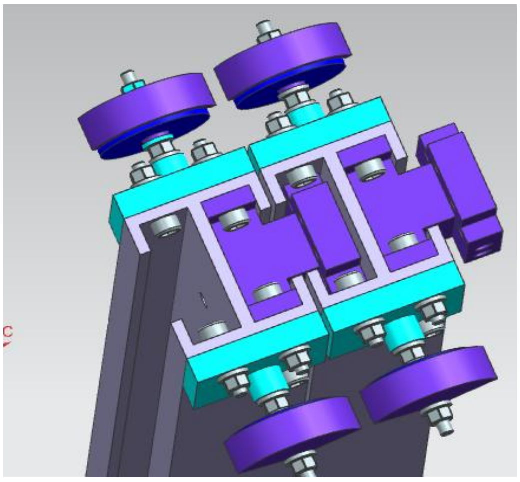
Figure 9 designed roller plate assembly

B. Cable and Pulley system

In the pulley system, it is not feasible to use bearing at its shaft from the weight pint of view. So the pulley wheel is directly in contact with the pulley shaft. It will create friction at the line contact between shaft and wheel. So, some amount of force will get used up in overcoming such frictional torque. Also in this pulley system, there are seven pulleys in series. So force toward the cable end will reduce drastically.

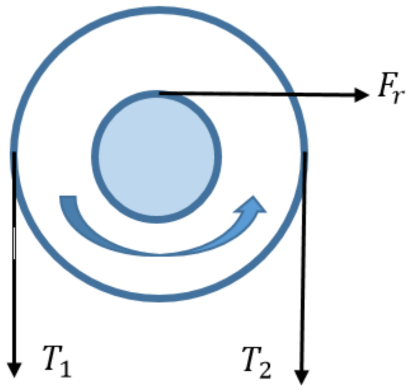

Figure 10 friction in pulley

$$F_1 = k * X_1 \quad \& \quad F_2 = k * X_2$$

$$F_2 - F_1 = k * (X_2 - X_1)$$

$$F_2 - F_1 = k * \Delta X$$

For acting force F compression will be

$$X = \frac{F}{k}$$

$$X = \frac{F}{\frac{(F_2 - F_1)}{\Delta X}}$$

$$X = \frac{F}{(F_2 - F_1)} * \Delta X$$

The calculation for finding force at the cable end is given. And one arithmetic model is created to find how much of minimum force should be given on the winch side such that at the other end of cable system sufficient force to overcome the friction between the last two linear slides can be generated. This arithmetic model is shown in the table.

Table 3 Arithmetic calculation for force at the cable end point

R	Pulley Radius			10.00
r	Pulley shaft Radius			4.00
μ	Friction coefficient			0.15
λ	$(R - \mu r)/(R + \mu r)$			0.89
	INPUT TENSION FORCE		**OUTPUT TENSION FORCE**	
PULLEY-1	T1	50	T2	43.02
PULLEY-2	T2	43.02	T3	37.02
PULLEY-3	T3	37.02	T4	31.85
PULLEY-4	T4	31.85	T5	27.41
PULLEY-5	T5	27.41	T6	23.59
PULLEY-6	T6	23.59	T7	20.29
PULLEY-7	T7	20.29	T8	17.46

C. Locking system

The locking system will lock the linear slide once fully deployed. Slides already have only one DOF translation in Z due to ball rollers. In the locking system review, Rohinton [2] described the use of locating pin before locking pin can ensure proper locking. This design used two such locating pins with a tapered tip, one on each roller plate i.e. Upper and lower plate. This guiding pin restricts the five degrees of freedom namely 1. Translation in x-axis 2. Translation in y-axis 3. Rotation about x-axis 4. Rotation about y-axis 5. Rotation about the z-axis. The remaining DOF of translation about the z-axis will be restricted by the locking pin. The arrangement of locating and locking pin is shown in Fig.

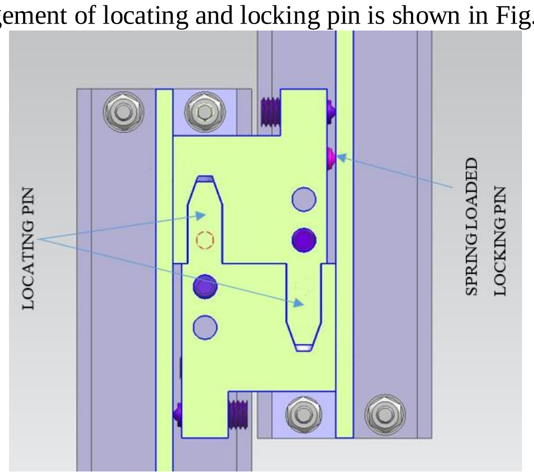

Figure 11 Cross sectional view of roller plate

IV. CONCLUSION

The novel cable winding device and cable-driven linear slides are presented in this work. The cable winding device was developed in a way to fulfill given requirements with the least component and complexity. And the linear slide was reimagined to provide one DOF with little flexibility to overcome any dimension inaccuracy or deformation. The locking system to effectively convert mechanism into the structure designed.

Figure 12 Fabricated linear slide

V. ACKNOWLEDGMENT

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