

Dynamic Analysis and Simulation on Large Supporting Structure for Camouflage Mat

Ying Ying PEI, Zhen Tao XIA, Yu Yang WU, Hai Kuan WENG

Shanghai Institute of Spacecraft Equipment, No. 251 Huaning Road, Shanghai

Email: aileen_py@126.com

Abstract. A way of rapid assembling “entirety-turning” was presented in this paper, which could be used in supporting camouflage mats. A force model was described to predict the driving force of the whole structure. It was found that the expression of the driving force was related regularly to half of the number of rocking linkages and the number of connecting rods. The angle between the cable and ground β was smaller and smaller when the angle between the linkages and ground α was increasing, while the sum of angle α and angle β was larger and larger. The horizontal distance between the support rod and the nearest rocking linkage D affected the driving force of the structure. When the distance D was increasing, the needed force of turning will be larger.

1. Introduction

The usage of camouflage mat is one of the most effective and widely used ways of anti-reconnaissance [1]. The camouflage mat applies in various forms and environments, especially fieldwork [2,4]. The outdoor camouflage mat usually relies on large supporting structures, which have strong and steady supplies and make large inner spaces for heavy vehicles or installations [5]. Further, the building of these large supporting structures sometimes demands limited time and limited labors in various field environments [6]. In order to meet the demands of time and strength, a simple structure and a rapid assembly design are the key points of the application of the large supporting mechanism.

The four-bar mechanism is a common and reliable mechanical structure. Here, it was described that a combination of several four-bar mechanisms was used in the design of the large supporting structure for the outdoor camouflage mat. Through turning of the rocking beams the whole structure was propped up, putting up the camouflage mat which was prepared beforehand. The way of propping up mentioned here was called entirety-turning. In this study, the mechanical structure of entirety-turning was demonstrated in detail. The mathematic model of the supporting structure was described and the dynamic problems were discussed. The model of turning process of the whole structure was simulated. The dynamic analysis of the large supporting structure affects the direction of design and plays an important role in the later engineer application.

The entirety-turning was designed for rapid assembly and disassembly, as fig.1 showed. Four rocking linkages, which are from two plane linkage mechanisms, form a space like a cube. Several cubes compose a large inner space, and the rocking linkages and connecting rods work as support frames for the camouflage mat. The initial angles between the rocking linkages and ground are all close to 0° . Under the action of a force on the first connecting rod, the whole structure is put up, and the angle between the linkage and ground gets bigger until the linkage is perpendicular to the ground. In the practical use, the force on the first connecting rod was produced by a cable and a pulley which is hanging on the top of a support rod, as fig.1 showed.



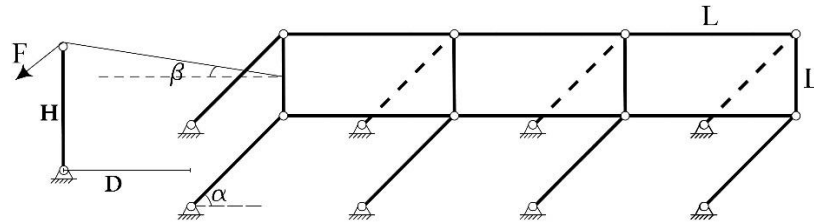


Figure 1 Schematic of entirety-turning the combination of several four-bar mechanisms for supporting camouflage mat

2. Theory

2.1 Mathematical Modeling

The height of the support rod is H , and the horizontal distance between the support rod and the nearest rocking linkage is D . The angle between the cable and ground is β ($45^\circ < \beta < 90^\circ$). The angle between the linkages and ground is α ($0^\circ < \alpha \leq 90^\circ$). The rocking linkages are as long as the support rod and the length of the connecting rod is L . It is supposed that the rocking linkages rotate at a constant speed slowly under the action of F . Here, the whole structure was made force analysis. In order to calculate the value of F , the force model was built and the expression of F was obtained.

According to torque equilibrium, a pair of the two rocking linkages in the symmetric positions which are furthest from the cable was made force analysis first:

$$F' \cdot H \cdot \sin \alpha = G_1 \cdot \frac{1}{2} H \cdot \cos \alpha + \frac{1}{2} G_2 \cdot H \cdot \cos \alpha \quad (1)$$

F' denotes the driving force of the furthest pair of rocking linkages. G_1 is the weight of a connecting rod; G_2 the weight of a rocking linkage. According to Equ.1, the equation of F' referring to α can be written as follow:

$$F' = \frac{1 \cos \alpha}{2 \sin \alpha} \cdot (G_1 + G_2) \quad (2)$$

The angle between the cable and ground β is related to the angle α , and according to the graphic relationship showed in figure 1, it can be described as

$$\beta = \arctan \frac{1 - \sin \alpha}{D/H + \cos \alpha} \quad (3)$$

Based on the theoretic analysis and deduction, in the entirety-turning way, the total driving force of the system with four pairs of rocking linkages F can be calculated as follow:

$$F = \frac{\cos \alpha}{\sin(\alpha + \beta)} \cdot (4G_1 + 10G_2) \quad (4)$$

From the form of equation 4, it can be seen that as the number of pairs of rocking linkages increasing the expression of the total driving force F varies regularly. According to the results, it is summarized that F is a function of the numbers of the rocking linkages and the connecting rods:

$$F = \frac{\cos \alpha}{\sin(\alpha + \beta)} \cdot \left(\frac{1}{2} n G_1 + m G_2 \right) \quad (5)$$

Where, n is the number of the rocking linkages, and m is the number of the connecting rods. From Equation 5, it could be seen that the driving force of the whole structure was related to the number of pairs of the rocking linkages. The weight of connecting rods affected directly the driving force and half of the weight of rocking linkages did as well, because the revolute joint of the rocking linkages was set on ground.

2.2 Parameters Setting

According to the demands of fieldwork, the structure of camouflage mat is supposed to supply a barrier-free work space, which reaches to 24 meters across, 8 meters wide and 6 meters high. In the entirety-turning mechanism, it is arranged that the length of rocking linkages H is 6 meters and the one of connecting rods L is 8 meters. The number of pairs of rocking linkages is 4, which means there are 8 ones in the structure.

2.3 Simulation

It is supposed that the value of the driving force F keeps a constant along the cable. The initial angle between the linkages and ground α in the practice is about 2 degrees. The rocking linkages are made of carbon fiber and each weighs 15KG. The connecting rod weighs 11kg which is lighter, because of the rocking linkages need higher strength. The distance D , number n and number m have relationships with the driving force F , so it is simulated to compare the effect of different parameters. In this part, through subdivision method, the driving force F was solved each step. With the changing of related parameters, the theoretical results were obtained step by step.

3. Results and Discussion

3.1 The angle between the cable and ground β

As pulling the cable up, the angle between the linkages and ground α was varying. The Fig. 2 showed that as the angle α was increasing, the angle between the cable and ground β was decreasing. When the rocking linkages go vertical to the ground, the cable becomes horizontal gradually. The physical meaning of the sum of angle α and angle β is the angle between the cable and the rocking linkage, which was bigger and bigger with the increasing of angle α . The sum of angle α and angle β affects the driving force of the cable. The initial value of angle β has a relationship of the length of rocking linkages H and the horizontal distance between the support rod and the nearest rocking linkage D , which can be seen in Equ.3.

3.2 The effects of the distance D

The horizontal distance between the support rod and the nearest rocking linkage decides the application point of the driving force, so the value of the distance D will affect the magnitude of the one. Fig.3 showed when the system contain 8 rocking linkages and 10 connecting rods, the force is smaller and smaller with the increasing of angle α . The maximum of the driving force comes up at the beginning of the process of turning. When the distance D is zero, the driving force is smaller. As the distance D increases, the force of the whole turning process is larger and larger, and the value reaches to 450kgF with the distance D of 3 meters, which is about 100kgF bigger than the one with 0 meters. It is obviously seen that the smaller the distance D is, the less the force is needed. However, in practice the distance D is always larger than 0. So it is better to reduce the distance horizontal D and keep the straight-line distances between the support rod and the two nearest rocking linkages equal.

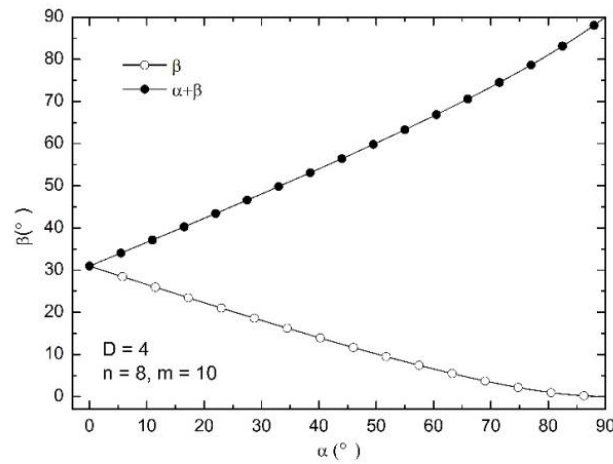


Figure 2 The variation trend of Angle β and the sum of angle α and angle β

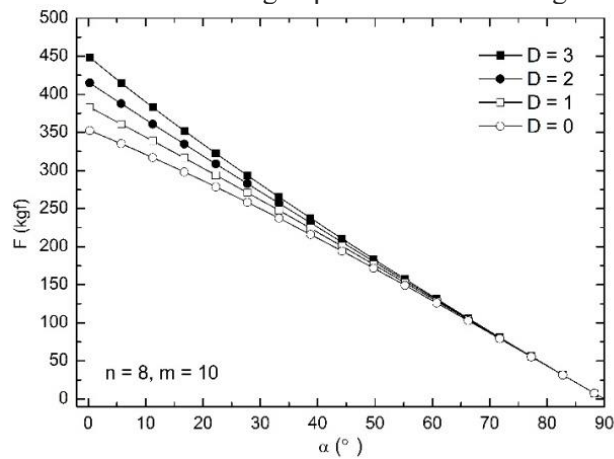


Figure 3 The variation trend of the turning force F when the distance D was changing

3.3 The driving force in different systems

When the length of the supporting structure for camouflage mat is changing, the numbers of rocking linkages and the connecting rods will vary as well as the driving force. Fig.4 showed the different results in different systems with the same distance D equal to 4 meters. When the total length of the supporting structure is 8 meters, the maximum of force is about 210 kgF. The maximum value of the force increases to about 350 kgF with the total length of 16 meters, and about 485 kgF with the total length of 24 meters. In Equ.5, it is demonstrated the value of force is related with the number of linkages and rods. The longer the supporting structure spans, the larger the driving force is.

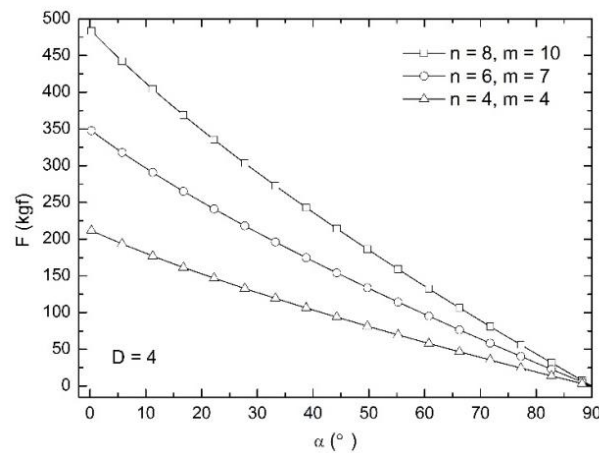


Figure 4 The variation trend of the turning force F when the number of pairs of the rocking linkages was changing

In practical application, the results of the theoretical model were verified. The whole structure was built according to the mentioned design in this paper, and the electronic tension meter was used in practice to measure tensile force of the rope tied as Figure 1. The electronic tension meter was placed on the rope near the force point. And when the rocking linkage was rising and the angle between the linkages and ground α increasing, the value showed on the electronic tension meter was smaller and smaller. The initial value showed at the beginning of the process should be the maximum force. In the application the horizontal distance between the support rod and the nearest rocking linkage D was set 4 meters. And the number of the rocking linkages n and the number of the connecting rods m were changing in three experiments, respectively, 4 and 4, 6 and 7, 8 and 10. The values showed on the electronic tension meter were collected each time. When n was 4 and m was 4, the maximum value of force was 233.1kgF. The value in every experiment was showed in Table 1. According to the Figure 4, it was seen that the theoretical value was smaller than the experimental data. The friction force and some other effect factors were not included in the mathematic modeling which was built in ideal conditions. Therefore, the practical value of force was bigger than the theoretical value. However, the error was permissible in the engineering applications.

Table 1 Comparison Between Numerical and Experimental Results

| n and m | $n=4$ | $n=6$ | $n=8$ |
|---------------------------------------|-------|-------|--------|
| | $m=4$ | $m=7$ | $m=10$ |
| The maximum test value of force (kgF) | 233.1 | 238.5 | 535.4 |

4. Conclusion

In this paper, an entirety-turning way of building a supporting structure for camouflage mat was mentioned, and a theoretical model of turning process was described to predict the driving force of the structure. The simulation software was used to analysis the effects of different parameters. The angle between the cable and ground β is in inverse to the angle between the linkages and ground α , while the sum of angle α and angle β in direct proportion to angle α . The horizontal distance between the support rod and the nearest rocking linkage D has an obviously effect on the driving force of the structure. When the distance D is increasing, the needed force of turning will be larger no matter how much the angle α is. And here, the theoretical driving force is calculated in detail in the case of three lengths of the supporting structure, 8 meters, 16 meters and 24 meters. The results will be taken account in the practice of this design. And the mechanical model of the process which predicts the accurate value

of the needed force can help to give guidance to the engineering application.

References

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