Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI: 10.21474/IJAR01/18450
DOI URL: http://dx.doi.org/10.21474/IJAR01/18450

RESEARCH ARTICLE

SCREW DRUM STRUCTURAL PARAMETERS ANALYSIS ON PROPULSION PERFORMANCE IMPACT

Xuhan Zhang[1], Bingnan Xing[2], Jiandong Gao[3] and Wenxin Yang[4]

1. Shenyang Ligong University School of Mechanical Engineering, Shenyang, Liaoning 110159, China.
2. Chongqing Chang'an Wangjiang Industrial Group Co., Ltd. Nanjing Innovation Center, Nanjing, Jiangsu, 210014 China.
3. School Of Mechanical Engineering, Nanjing University Of Science & Technology Nanjing, Jiangsu, 210094 China.
4. Shenyang Ligong University School of Mechanical Engineering, Shenyang, Liaoning 110159, China.

……

Manuscript Info

Manuscript History
Received: 22 January 2024
Final Accepted: 24 February 2024
Published: March 2024

Key words:-
Screw Propeller, Locomotion Performance, Discrete Element and Multibody Dynamics Coupled Simulation

Abstract

Screw propeller can perform engineering operations in complex environments and have a wide range of applications. To improve its operational efficiency, it is necessary to analyze the influence of the parameters of the screw drum on the performance indicators of the operation, in order to confirm the structural parameters under the optimal operational efficiency. By coupling the Discrete Element Method (DEM) with RecurDyn, the simulation of the locomotion process of a screw propulsion mechanism in a sand environment is conducted. Output results such as travel speed, maximum traction force, and maximum torque are measured. Through computation, performance indicators including slip ratio, traction coefficient, and dimensionless power can be obtained. By coupling the Discrete Element Method (DEM) with RecurDyn, the simulation of the locomotion process of a screw propulsion mechanism in a sand environment is conducted. Output results such as actual speed, maximum traction force, and maximum torque are measured. Through computation, performance indicators including slip ratio, traction coefficient, and dimensionless power can be obtained. Analyzing the numerical indicators of the propulsion system, it is determined that the optimal structural parameters for the screw propulsion mechanism to operate in a sand environment are a helix angle of 40°, aspect ratio of 4, blade height ratio of 0.15, and the number of blades of 4.

……

Introduction:-

With the development and advancement of technology, people are further exploring nature and discovering abundant fishery and mineral resources in the intertidal environment. To exploit these resources, factories need industrial machinery that can operate normally in complex environments. Conventional industrial machinery typically relies on wheeled or tracked propulsion mechanisms as power sources. However, in such environments, these two propulsion mechanisms are prone to sinking, leading to a loss of mobility. The screw propeller can address the issue of industrial machinery losing mobility on beaches and tidal flats, serving as a specialized

Corresponding Author:- Xuhan Zhang
Address:- Shenyang Ligong University School of Mechanical Engineering, Shenyang, Liaoning 110159, China.

locomotion mechanism commonly utilized in fluidic mediums. Compared to conventional wheel propulsion mechanisms, the screw propeller features a higher ground pressure ratio 1and strong adaptability to the environment2, making it suitable for use in harsh environments such as beaches and marshes. The screw propulsion mechanism achieves forward propulsion by reversing the rotation of a pair of helical drums underneath the chassis, rotating in opposite directions. To steer, the drums need to rotate differentially3.

Due to the special locomotion and structural characteristics of the screw propeller, it is commonly applied in fields such as agriculture4 and beach rescue. The screw propeller was first applied to ground mobile machinery by Jacob Morath5. James and Ira Peavey6 first used a screw-propelled vehicle for logging and transportation of timber in mountainous areas in 1907. The earliest application of this type of mechanical structure in China was the hydroponic machine developed by Liu Mingxiang7 in 1987. In the same year, Fan Qizhou8 conducted thrust calculation and experiments on the screw propeller in driving in clay medium. Andrew Thoesen9 conducted a detailed analysis of the thrust of the screw propeller in granular media. By comparing simulations with experiments, he demonstrated that the spiral propulsion mechanism can accomplish challenging tasks.

Research Subject:-

This paper focuses on the effect of changing the structural parameters of the screw drum on the propulsion performance of the screw propeller. By using numerical simulation techniques to measure data during the movement of different structural drums, the study aims to optimize the drum structure to improve propulsion efficiency. The schematic diagram of screw propeller is shown in Figure (1).

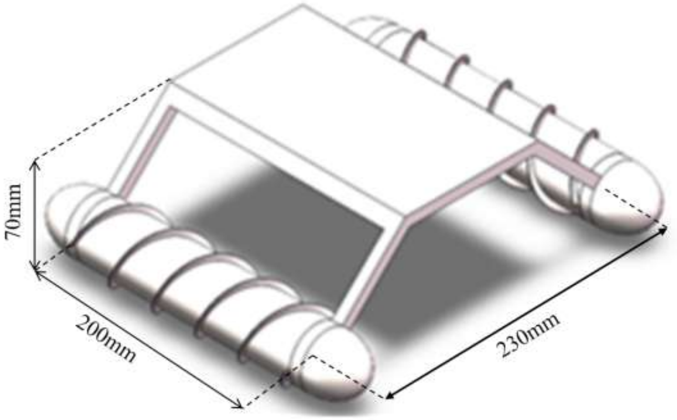


Figure 1:- Screw Propeller.

The performance indicators will be affected by the structural parameters such as the helix angle, aspect ratio, blade height ratio, and number of blades of the propeller. The helix angle affects the shape of the propeller blade, the aspect ratio is the ratio of the diameter of the propeller to its effective length, the blade height ratio is the ratio of the blade height to the propeller diameter, and the number of blades is the quantity of blades on one side of the propeller.

The performance indicators for a screw propeller include slip ratio, non-dimensional power, traction coefficient, and bumpiness. When a helical propulsion mechanism travels through a fluid environment, the actual velocity may be lower than the theoretical velocity. The indicator used to measure this phenomenon is the slip ratio (s_x), where a higher slip ratio at the same theoretical velocity indicates a lower actual velocity. The expression for the slip ratio10 is:

$$s_x = \frac{v_T - v_A}{v_T} \quad (1)$$

Where v_T is theoretical speed and v_A is actual speed.

The dimensionless power, denoted as (y), is used to measure the minimum power required for propulsion. A smaller dimensionless power ensures a greater distance traveled with the same amount of energy. The expression for the dimensionless power11 is:

$$y = \frac{2\pi n T}{W v_T} \quad (2)$$

Where n is rotation speed， T is maximum torque and W is Gravitational direction load.

The traction coefficient, denoted as (K), is the ratio of the traction force to the mass load. All other conditions being equal, a higher traction coefficient leads to better traction performance. The expression for the traction coefficient 12is:

$$K = \frac{D_{\mathrm{p}}}{W} \quad (3)$$

Where D_p is Maximum traction

The bumpiness, denoted as (S^2), is used to measure the roughness level during the operation of the propulsion mechanism. Its expression is:

$$S^2 = \frac{\sum_{i=1}^{m}(H_i - H_A)}{m} \quad (4)$$

Where m is Analysis steps, H_i is the horizontal height of the propulsion mechanism at the i-th analysis step and H_A is the average horizontal height of the propulsion mechanism

Simulation Analysis of Screw Drum Movement

Through the coupling simulation of the Discrete Element Method (DEM) software EDEM and the Multibody Dynamics (MBD) software RecurDyn, EDEM calculates the force and motion of sand grains when the screw propeller advances, while RecurDyn calculates the force and motion of the screw propulsion mechanism during advancement. The obtained data is then analyzed to evaluate the advancement effect. Simulation process is shown in Figure 2.

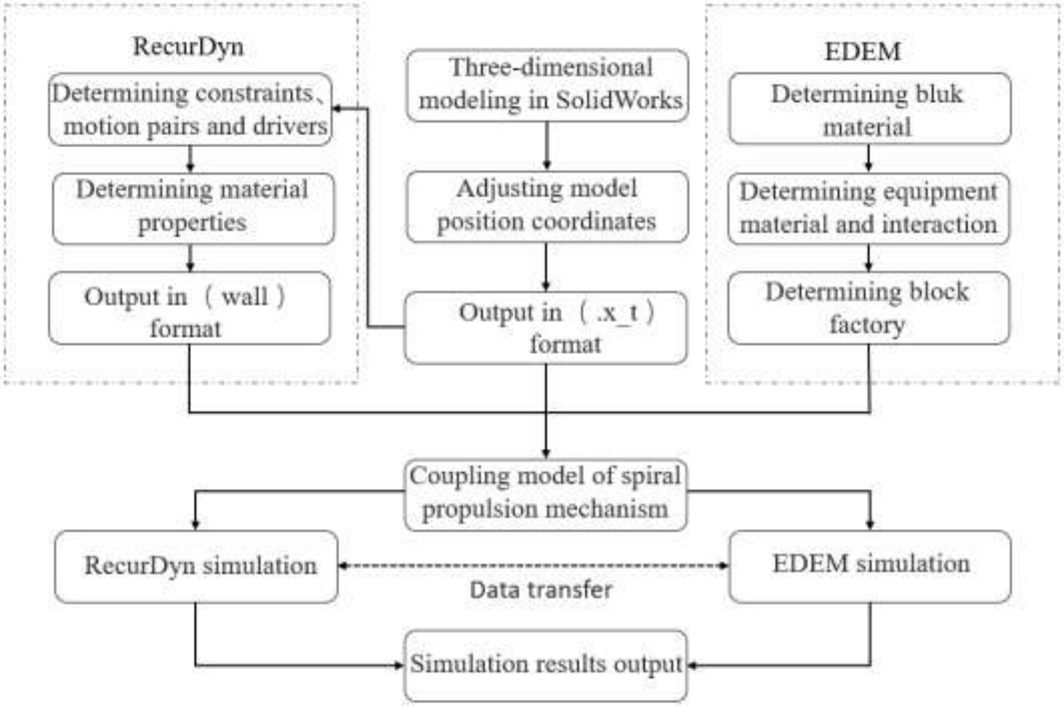


Figure 2:- Simulation Process.

Material properties are shown in Table 1, and contact parameters are shown in Table 2. The simulation domain ranges from 900mm*400mm*260mm, with a particle diameter of 3.5mm13 and a particle layer thickness of 80mm.

Table 1:- Material parameters.

Name	Poisson's ratio	Shear Modulus（pa）	Density（kg/m^3）
Sand	0.3	$1*10^8$	2650
TC4	0.25	$4.082*10^{10}$	4850
Box	0.25	$1*10^{10}$	2500

Table 2:- Interaction.

Name	Cofficient of restitution	Cofficient of Static Friction	Cofficient of Rolling Friction
Sand -Sand	0.6	0.53	0.08
TC4-Sand	0.6	0.45	0.05
Box-Sand	0.3	0.75	0.05

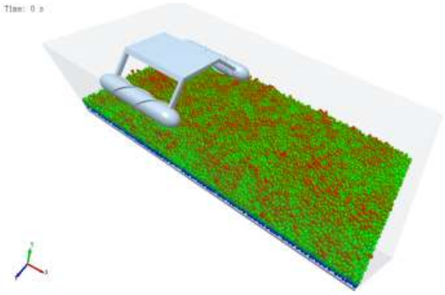
The simulation experiment numbers and corresponding parameters of the spiral drum are shown in Table 3.

Table 3:- Experimental Content.

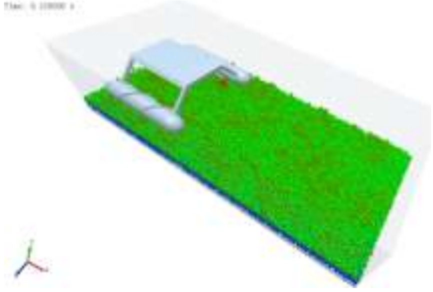
Experiment Number	Helix Angle	Aspect Ratio	Blade Height Ratio	Number of Blades
1	25°	4	0.1	2
2	30°	4	0.1	2
3	35°	4	0.1	2
4	40°	4	0.1	2
5	45°	4	0.1	2
6	30°	4	0.05	2
7	30°	4	0.15	2
8	30°	4	0.2	2
9	30°	4	0.25	2
10	30°	3	0.1	2
11	30°	3.5	0.1	2
12	30°	4.5	0.1	2
13	30°	5	0.1	2
14	30°	4	0.1	1
15	30°	4	0.1	3
16	30°	4	0.1	4
17	30°	4	0.1	5

By simulating with models 1 to 5, the influence of helix angle on the mechanical locomotion effect can be obtained; by simulating with models 2, 6 to 9, the influence of blade height ratio on the mechanical locomotion effect can be obtained; by simulating with models 2, 10 to 13, the influence of aspect ratio on the mechanical locomotion effect can be obtained; by simulating with models 2, 14 to 17, the influence of number of blades on the mechanical locomotion effect can be obtained.

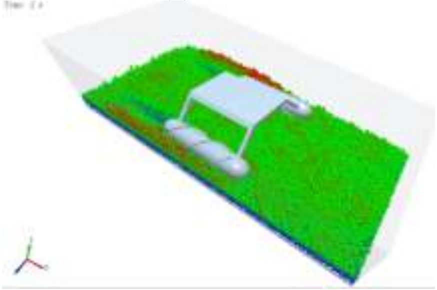
The coupled simulation process is illustrated in Figure 3. Figure 3(a) shows the initial state of the simulation, where the screw propeller is positioned above the granular environment, and the drum is not rotating. Figure 3(b) depicts the screw propeller falling onto the sand particles under the influence of gravity. Figure 3(c) shows the beginning of rotation of the screw drum, resulting in forward movement of the entire mechanism. Figure 3(d) represents the completion of the simulation.



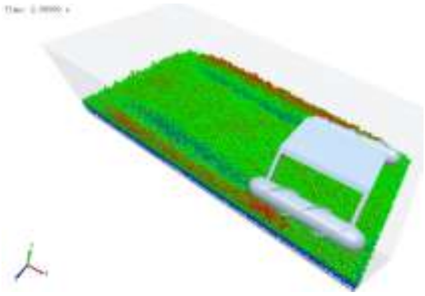
(a) t=0s



(b) t=0.1s



(c) t=2s



(d) t=3s

Figure 3:- Simulation results.

Coupled Simulation Results Analysis

Helix Angle on Propulsion Effect Influence

As the helix angle increases, the pitch of the drum also increases, resulting in a theoretical increase in speed at the same rotational speed. The simulation results are shown in Table 4.

Table 4:- Simulation Results of Helix Angle Variation.

Helix Angle	Slip ratio	Traction coefficient	Dimensionless power	Bumpiness
25°	32%	0.21	0.70	1.27
30°	39%	0.33	1.53	2.26
35°	43%	0.27	1.01	1.20
40°	64%	0.65	1.02	2.20
45°	53%	0.25	0.90	2.73

To obtain a clearer trend of changes, figure 4 is generated based on Table 4. As the helix angle increases, all measurement indicators except for the dimensionless power show an increasing trend. The dimensionless power is in a stable state at a helix angle of 35°~45°, with relatively low numerical values. Although increasing the helix angle results in a more pronounced increase in slip ratio, it also leads to an increase in lead, significantly boosting theoretical speed. Therefore, under the same rotational speed, increasing the helix angle does not cause a decrease in traveling speed. raction coefficient is used to measure the magnitude of traction force, mainly generated by cutting and squeezing sand particles by helical drum blades. It is a significant indicator, reaching its maximum value when the helix angle is 40°. The variation in bumpiness is quite pronounced, but it is kept within a relatively small range. After comprehensive analysis, it can be determined that the pushing effect of the spiral drum is optimal when the spiral angle is 40 degrees.

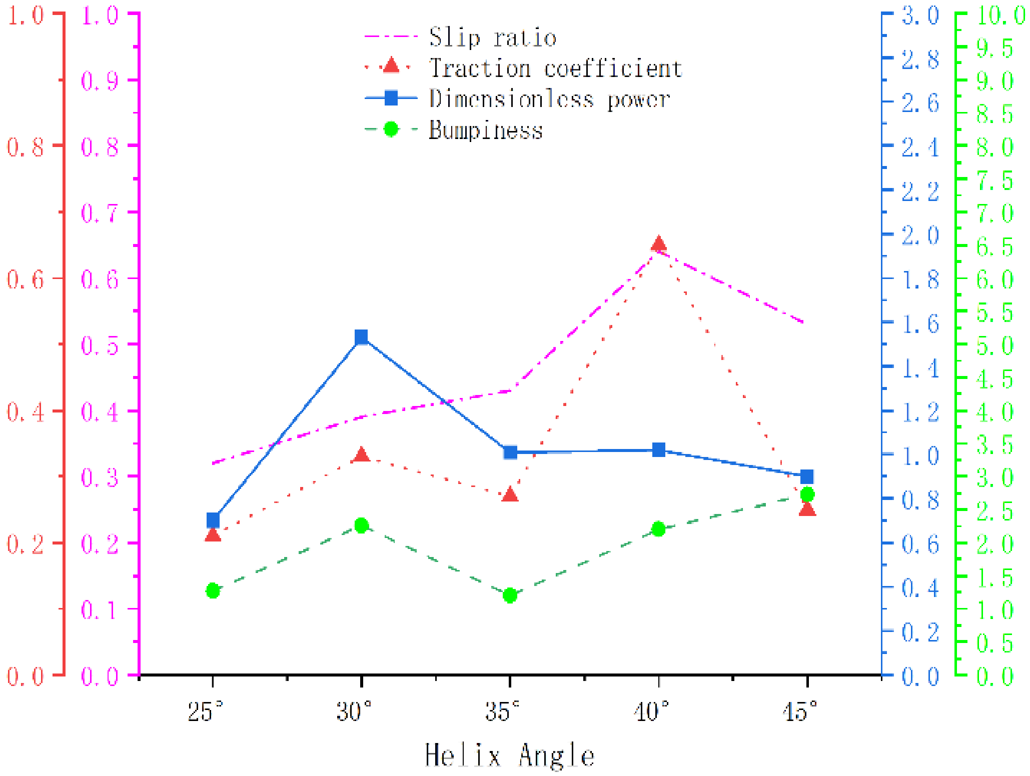


Figure 4:- Simulation Results of Helix Angle Variation.

Aspect Ratio on Propulsion Effect Influence

When the aspect ratio changes, the drum diameter changes accordingly, and important structural parameters such as fan blade height and pitch based on the drum diameter will also change. The simulation results are shown in Table 5.

Table 5:- Simulation Results of Aspect Ratio Variation.

Aspect Ratio	Slip ratio	Traction coefficient	Dimensionless power	Bumpiness
3	41%	0.23	1.10	3.29
3.5	38%	0.23	0.99	1.63
4	39%	0.33	1.53	2.26
4.5	41%	0.24	0.95	0.68
5	44%	0.21	3.22	1.10

To obtain a clearer trend of changes, figure 5 is generated based on Table 5. It can be observed intuitively that the slip ratio and traction coefficient have not undergone significant changes,that means the aspect ratio has a minimal impact on the conversion rate and traction coefficient. As the aspect ratio increases and the drum diameter decreases, the dimensionless power rises significantly within a certain range, leading to an increase in the required propulsion power; however, the bumpiness decreases slightly. The reason for this phenomenon is that as the drum diameter decreases, the contact area between the drum and the sand particles also decreases. As a result, the overall propulsion mechanism descends, similar to a ship sailing in the ocean where a deeper draft can provide greater stability. When the aspect ratio is 4.5, the locomotion performance is better.

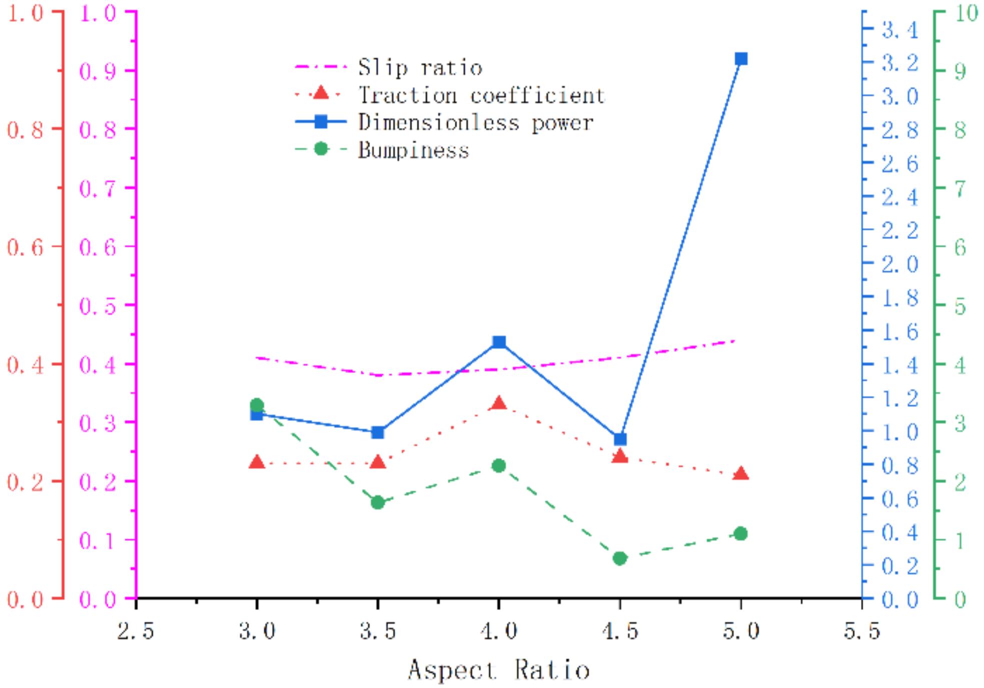


Figure 5:- Simulation Results of Aspect Ratio Variation.

Blade Height Ratio on Propulsion Effect Influence

The blade height ratio to drum diameter is a structural parameter that measures the height of the rolling fan blade based on the drum diameter, but larger fan blades are not necessarily better. The simulation results are shown in Table 6.

Table 6:- Simulation Results of Blade Height Ratio Variation.

Blade Height Ratio	Slip ratio	Traction coefficient	Dimensionless power	Bumpiness
0.05	62%	0.45	1.21	1.74
0.1	39%	0.33	1.53	2.26
0.15	32%	0.35	0.93	2.98
0.2	31%	0.27	1.14	1.71
0.25	34%	0.37	2.04	0.67

Through Table 6, it can be seen from Figure 6 that as the blade height ratio increases, the slip ratio and dimensionless power exhibit a trend of initially decreasing and then increasing; the bumpiness shows a trend of initially increasing and then decreasing; the traction coefficient can also be roughly regarded as initially decreasing and then increasing, but it is relatively high when the blade height ratio is 0.15; through comprehensive analysis of the performance indicators, it is determined that the blade height ratio of 0.15 yields better propulsion performance.

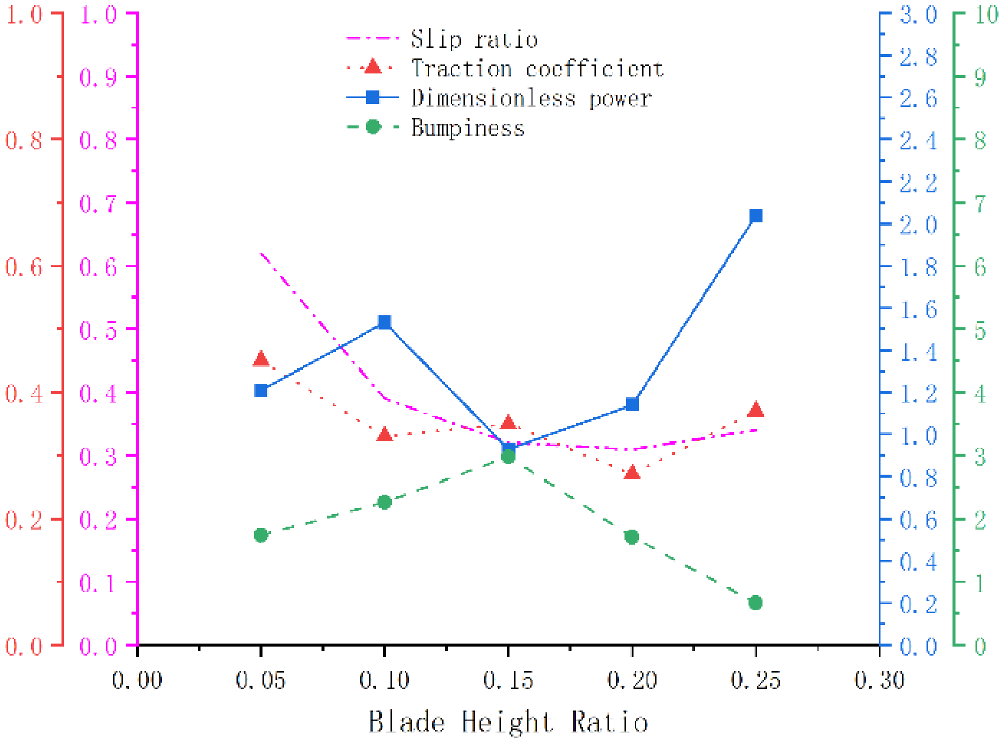


Figure 6:- Simulation Results of Blade Height Ratio Variation.

Number of Blades on Propulsion Effect Influence

When the number of fan blades changes, the spacing between adjacent blades also changes accordingly, leading to variations in the complexity of sand movement and thus affecting the propulsion efficiency. The simulation results are shown in Table 7.

Table 7:- Simulation Results of Number of Blades Variation.

Number of Blades	Slip ratio	Traction coefficient	Dimensionless power	Bumpiness
1	67%	0.23	0.67	3.25
2	39%	0.33	1.53	2.26
3	37%	0.34	0.84	0.75
4	31%	0.38	1.03	0.98
5	30%	0.71	2.45	0.23

Through Table 7, it can be observed from Figure 7 that as the number of blades increases, both the slip ratio and bumpiness intensity decrease significantly, while the traction coefficient increases noticeably. However, there is no obvious contrasting trend between the dimensionless power variation and the increase in the number of blades. In order to ensure relatively small dimensionless power with a higher traction coefficient and smooth propulsion process, the optimal number of blades is determined to be 4.

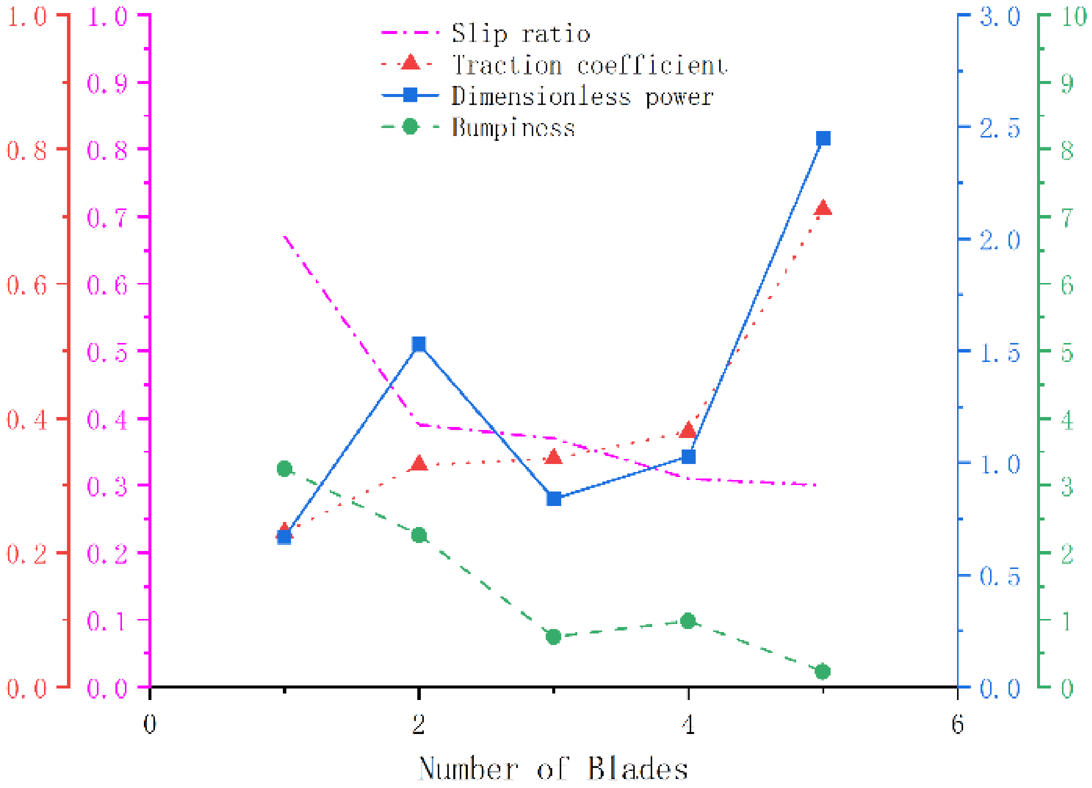


Figure 7:- Simulation Results of Number of Blades Variation.

Conclusion:-

The screw propulsion mechanism can travel normally in sandy environments, and as the drum rotates, particles will accumulate towards the surface of the drum in the direction of rotation.

When the structural parameters of the drum are changed, the efficiency of the screw propulsion mechanism changes significantly. To ensure that the propulsion mechanism has lower slip ratio, dimensionless power, roughness, and higher traction coefficient, the helix angle is set to 40°, the aspect ratio is 4, the blade height ratio is 0.15, and the number of blades is 4.

References:-

1. 郭峰. 推拉式气垫运载平台的行走理论研究[D].吉林大学,2002.
2. I M Bartenev,Bartenev I M,Malyukov S V,Malyukova M A. Forest fire extinguishing: theoretical study of the screw drum parameter influence on the efficiency of a forest fire soil-sweeping machine[J]. IOP Conference Series: Earth and Environmental Science,2020,595(1).
3. 郭晓林,刘杰,赵炎等.螺旋推进车研究现状概述[J].农业装备与车辆工程,2014,52(04):14-17+27.
4. Startsev A S,Demin E E,Shardina G E,Nesterov E S,Razdobarova M N. Theoretical study of a sunflower harvester operation equipped with an auger reel[J]. IOP Conference Series: Earth and Environmental Science,2022,979(1).
5. Vandome A F, Mcbrewster J, Miller F P. Screw-propelled vehicle[M]. Alphascript Publishing, 2010.
6. Peavey I Q A. Snow-locomotive: US, US 864106 A[P]. 1907.
7. 刘明相,王德骥.双轴差距螺旋水耕机[J].农村实用工程技术,1991(02):26.
8. 樊启洲,邵耀坚.螺旋滚筒在粘土上推进力的研究[J].拖拉机与农用运输车,1998(04):20-24.
9. Andrew Thoesen,Sierra Ramirez,Hamid Marvi.Screw-Powered Propulsion in Granular Media: An Experimental and Computational Study[C]//.2018 IEEE International Conference on Robotics and Automation (ICRA).,2018:4283-4288.
10. 冯闯闯,周勇,涂鸣,柯烩彬,陈行,吴昊,焦俊.螺旋推进式挖藕机的设计与试验[J].甘肃农业大学学报,2020,55(

04):191-199.
11. Dugoff H, Ehlich I R. Model tests of bouyant screw rotor configurations[J]. Journal of Terramechanics, 1967, 4(3):
12. 张克健.车辆地面力学[M].国防工业出版社,2002.
13. 张锐,韩佃雷,吉巧丽,等. 离散元模拟中沙土参数标定方法研究[J]. 农业机械学报,2017,48(3):49-56.