Mechanical Analysis and Structure Optimization of Lunar Soil Coring Mechanism

Qiuyi Fang[1,*] Qin Zhou[2], Jianguo Lv[2] and Jing Wang[3]
[1]Sergeant school of CAPF; #377 Tianmu Shan Road, Xihu District, Hangzhou, Zhejiang
[2]China University of Geosciences, Beijing; #29 Xueyuan Road, Haidian District, Beijing
[3]Sinomine Resource Exploration；#11 Changchunqiao Road, Haidian District, Beijing
Email: fangxiaoqiu@126.com

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Abstract: The soft bag lunar soil coring mechanism of turning inward type without sliding has the characteristics of simple structure, low power dissipation and well regolith bedding information-keeping. However, at the initial coring stage, the large pulling force and torque, which are resulted from the spiral movement of lunar soil around bit when it enters the holding-pipe, can consequently cause high power dissipation and bad regolith bedding information-keeping. In the paper, in order to achieve the goal of the minimum of pulling force and torque, a mechanical model representing the interaction of lunar soil on coring mechanism was established to analyze effects of structural parameters and drilling parameters on the pulling force and torque. The structural parameters of coring mechanism and drilling parameters were optimized. The results show that soft bag thickness and guide head radius have the greater impact on the pulling force and on the torque respectively. When the guide head radius is 0.5mm and the soft bag thickness is 0.2mm, the rope pulling force can reach its optimal value of 89N, which can greatly reduce the degree of torsion in the process of coring.

1 INTRODUCTION

Probing the moon’s material composition has great significance on studying the origin of the moon and the earth, the earth's climate, and the phenomena of tidal waters. Drilling and sampling the surface of the moon are prerequisite for achieving this research work (Yan et al., 2004).

There have been some successful sampling precedents of lunar soil abroad, however, coring methods and working mechanism of deep lunar soil coring domestically are still staying at theoretical and experimental research stage. In the Apollo program, for example, the core was extracted using a cemented carbide tube (The Apollo 17 mission” on http://spaceflight1.nasa.gov/history/apollo/). This device for sampling cores was easily operated but with poor bedding information (Berry, 1970). In the Luna24 program, the soft bag coring mechanism of turning inward type was initially applied and the core of 250cm depth can be successfully extracted with good bedding information-keeping (http://www.zarya.info/Diaries/Luna/Luna.php). Due to its good performance, such a turning inward type device will be a great potential, which is well worth being researched (Zhang, 2010). Some domestic scientific research units, such as Beijing Satellite Manufacturing Factory, Harbin Institute of Technology and China University of Geosciences, are also carrying out some researches (Duan et al., 2009). In terms of mechanical model, the mechanics characterizes of the drill (Li, 2012), the bit 0 Tang, 2012) and other structural joints have been mainly analyzed (Liu, 2011). The interaction among the inner parts of the core body, such as the soft bag, the holding-pipe, the drill rod and the lunar soil, in the drilling process is rarely analyzed. Little information is available. In the analysis of lunar soil coring mechanism mechanics characterizes,Wang Guoxin and others, from Beijing Satellite Manufacturing Factory,using a simplified mechanical model, has not considered the influence of the speed when soft bag turning in (Zhao et al., 2012). The effect of soft bag turning on regolith bedding information-keeping was not analyzed either (Wang, 2012). Although the researchers of Harbin Institute of Technology have a comprehensive study on the coring mechanism, the influence of the structural parameters and drilling parameters on sampling is not studied

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simultaneously (Gong et al., 2012). Especially in the initial stage of coring, the interaction among soft bag, lunar soil and coring mechanism is the most complex, which few studies have ever researched before.

In view of the above research, this paper carries out the mechanical model of the coring mechanism in the initial sampling stage and optimized of the core mechanism. Taking the minimum of the sample load and the torque as the optimization objective, the structure parameters and the drilling parameters are used as variables, then using the control variable method to analyze and get the optimal value.

2 THE COMPOSITION AND WORKING PRINCIPLE OF CORING MECHANISM

The coring mechanism mainly consists of hollow coring tool, drill bit, holding-pipe, soft bag, rope, sealing components and other appendages. Figure 1is the structure diagram.

The soft bag is installed outside the holding-pipe, which is screwed inside the hollow rod through thread. When sampling, with the drill feeding, soft bag turns inward and wraps the soil gradually. The sample pushing into the soft bag with soft bag remains relatively stationary. After drilling, we can get a cylindrical lunar soil core wrapped by soft bag inside the holding-pipe.

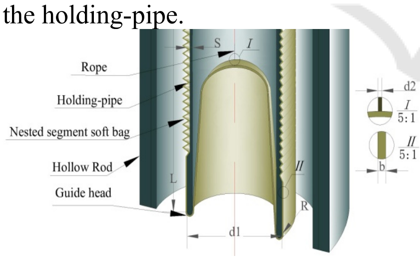

Figure 1: Structure diagram of coring mechanism.

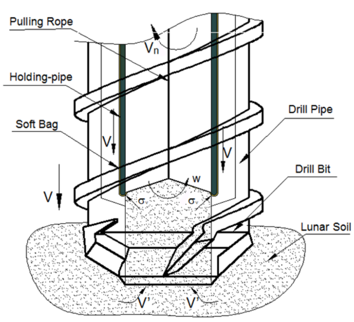

Figure 2: The interaction relationship between lunar soil and coring mechanism.

In the initial stages of drilling, due to the soil-breaking perturbations by drilling and the spacing between drill and holding-pipe, the lunar soil around the drill bit into the holding-pipe as the way of a spiral motion. Under the disturbance of lunar soil movement and the lateral pressure that lunar soil entering the coring mechanism on the soft bag, the resistance of soft bag turning inward and the trend of soft bag twisting are increased. The interaction relationship between the bit, lunar soil and coring mechanism in this stage is shown in Figure 2. Therefore, the force condition of soft bag around guide head is the key to affect the quality of sampling and the power dissipation.

3 MECHANICAL MODEL REPRESENTING THE INTERACTION BETWEEN LUNAR SOIL AND CORING MECHANISM AROUND THE GUIDE HEAD

Now suppose that the guide head has ideal structures and the soft bag is an absolutely flexible mechanism, which works as belt driving (Gong et al., 2012). Around the guide head, the soft bag is divided into circumferential infinitesimal and tangential infinitesimal to make the analysis on the internal and external forces. The forces like tangential tension of infinitesimal $T(\alpha)$, the frictional resistance of infinitesimal F_f and the circumferential tensioning force of infinitesimal$T_r(\alpha)$are shown in Figure 3 and Figure 4. The force equilibrium equations of soft bag were established (Wang, 2012; Cao and Gu, 2004).

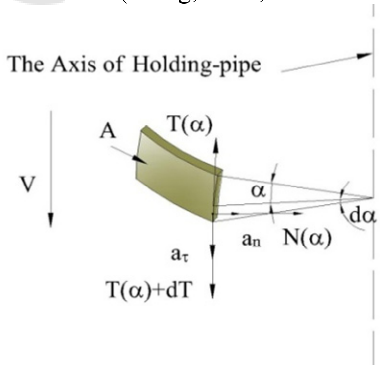

Figure 3: Infinitesimal radial force of soft bag.

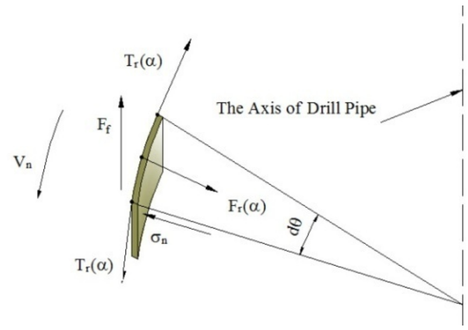

Figure 4: Infinitesimal circumferential force of soft bag.

The circumferential infinitesimal width of center angle *dθ* corresponds to the one of soft bag; the tangential infinitesimal can be obtained by continuously dividing the circumferential infinitesimal on length,which corresponds to the length of center angle dα.Then the soft bagsurface infinitesimal *ds* can be got. According to the derivation of Euler's formula, the dynamic equilibrium equation of *ds* was established (Cao and Gu, 2004)..

3.1 The Dynamic Equilibrium Equations of Infinitesimal

The radical and tangential force balance has been analyzed and expressed as equation 1:

$$\sum F_\tau = 0 : (T + dT)\cdot cos\frac{d\alpha}{2} = T \cdot cos\frac{d\alpha}{2} + f\cdot(dN + \sigma_n) - ma_\tau \quad (1)$$

$$\sum F_n = 0 : (T + dT)\cdot sin\frac{d\alpha}{2} + T \cdot sin\frac{d\alpha}{2} = dN + \sigma_n + ma_n \quad (2)$$

Let $N{=}dN + \sigma_n$, $a_\tau = a\cdot\sin\frac{d\alpha}{2}$, $a_n = a\cdot\cos\frac{d\alpha}{2}$

Based on the limit principle, we can get:

$$\cos\frac{d\alpha}{2}\sim 1, \sin\frac{d\alpha}{2}\sim\frac{d\alpha}{2}, \sin\left(\alpha+\frac{d\alpha}{2}\right)\sim\sin\alpha, \cos\left(\alpha+\frac{d\alpha}{2}\right)\sim\cos\alpha$$

Substituting them into equation (1) and (2), it gives:

$$N = T\cdot d\alpha - m\cdot a_n \quad (3)$$

$$dT = f\cdot N - m\cdot a_\tau \quad (4)$$

From the equation above, the relationship among tangential tension of infinitesimal can be got, the angle of guide head and the radial and tangential acceleration of soft bag:

$$dT = f\cdot(T\cdot d\alpha - m\cdot a_n) - m\cdot a_\tau \quad (5)$$

Among them, $m = \rho\cdot(R\cdot d\alpha)$ (*ρ is the* linear density of soft bag(axial direction)).

By dividing $d\alpha$ on both sides of the equation, we can get:

$$\frac{dT}{d\alpha} = f\cdot(T\cdot d\alpha - \rho Ra_n) - \rho Ra_\tau \quad (6)$$

According to the boundary conditions when soft bag turning inward, we can get soft bag tension boundary value in the infinitesimal direction, namely:

When $\alpha = 0$, $T_{(0)} = F_1$, the friction between soft bag and the outside wall of holding-pipe;

When $\alpha = \pi$, $T_{(\pi)} = F_2$, the pulling force of rope.

In the integral form of (6):

$$F_2{=}fe^{f\pi}\cdot\left(F_1 - \rho Ra_n - \frac{1}{f}\cdot\rho Ra_\tau\right) + \rho Ra_n + \frac{1}{f}\rho Ra_\tau \quad (7)$$

F_1 is the friction between soft bag and the outside wall of holding-pipe;

The formula (7) provides a theoretical basis for mechanical analysis of soft bag turning inward. It shows the dynamic relationship between the pulling force of rope and the wrap angle of soft bag, with the acceleration of soft bag's movement, and gives the quantitative relationship among force, friction, the radius of guide head and the linear density of soft bag intuitively.

3.2 The Mechanical Model of Pulling Force of Soft Bag Turning Inward at the Initial Stage

In the initial stages of drilling, due to the soil-breaking perturbations by drilling and the spacing between drill and holding-pipe, the lunar soil around the drill bit verb into the holding-pipe as the way of a spiral motion. Relative to the smooth transition of coring, the resistance of soft bag overturning increases. The friction is relatively the largest during the process of coring. At the same time, because of the soft bag with a maximum acceleration in this stage, the external force that needed is greater as well. Based on the analysis above, the forces of the soft bag at this stage are the most complicated, the mechanical analysis of the stage is representative.

The following will give the unfolding calculation of the formula(7), to provide a basis for optimizing the coring mechanism by analyzing the pulling force of rope's mechanical relations between structural parameters of coring mechanism, drilling parameters and physical characteristics of lunar soil.

(1) Calculate the radial tightening force of soft bag

The formulas and relations between the radial tightening force and the circumferential tensioning force are expressed as follows:

$$\begin{cases} F_r = 2T_r \cdot sin\dfrac{d\theta}{2} \\ T_r = E_L \cdot A \cdot \dfrac{d_1/2 - d_0/2}{d_0/2} \\ A = dl \cdot b \end{cases} \tag{8}$$

A. In the guide head, the radial tightening force of soft bag:

$$d_1/2 = d_0/2 + R + R \cdot \cos(\alpha + d\alpha) \tag{9}$$

Therefore:

$$\begin{cases} T_r = \dfrac{2E_L bR \cdot [1 + \cos(\alpha + d\alpha)]}{d_0} \cdot dl \\ F_r = T_r \cdot d\theta \end{cases} \tag{10}$$

$$dN_1(\theta, \alpha) = F_r \cdot \cos\left(\alpha + \frac{d\alpha}{2}\right) \tag{11}$$

B. Outside the holding-pipe, the radial tightening force of soft bag:

$$\begin{cases} T_r = \dfrac{E_L b \cdot (d_1 - d_0)}{d_0} \cdot dl \\ F_r = T_r \cdot d\theta \end{cases} \tag{12}$$

$$dN_2(\theta, \alpha) = F_r \tag{13}$$

Therefore, the maximum radial tightening force of infinitesimal is:

$$\begin{aligned} dN(\theta,\alpha) &= dN_1(\theta,\alpha) + dN_2(\theta,\alpha) \\ &= F_r \cdot \cos\left(\alpha + \frac{d\alpha}{2}\right) + F_r \end{aligned} \tag{14}$$

$$\begin{aligned} N(\theta,\alpha) &= \int_0^{\frac{\pi}{2}} \int_0^{2\pi} \int_0^{\pi \cdot [d_1 - 2R(1+\cos\alpha)]} \frac{2E_L bR \cdot (1+\cos\alpha)}{d_0} d\alpha \cdot d\theta \cdot dl + \int_0^{2\pi} \int_0^{\pi \cdot d_1} \frac{E_L b \cdot (d_1 - d_0)}{d_0} d\theta \cdot dl \\ &= BR(d_1 - 4R) + Bd_1 \Delta x \left(B = \frac{2\pi^2 E_l b}{d_0}, \Delta x = d_1 - d_0 \right) \end{aligned} \tag{15}$$

Integrating the force in the axial direction, can get the total radial tightening force of soft bag N (z):

$$\begin{aligned} N(z) &= \int_0^{\frac{\pi R}{2}} BR \cdot (d_1 - 4R) \cdot dz + \int_0^L Bd_1 \cdot \Delta x \cdot dz \\ &= \pi BR^2 (d_1 - 4R) + Bd_1 L \cdot \Delta x \end{aligned} \tag{16}$$

(2) Calculate the lateral pressure σ_z of the lunar soil

The lateral pressure σ_z of the lunar soil at any depth can be equivalent to the earth pressure at rest, and σ_z is proportional to its self-weight σ_v, which can be expressed as (Chen et al., 1994):

$$\sigma_z = k_0 \cdot \sigma_v \tag{17}$$

Where,

k_0—Coefficient of earth pressure at rest, the relations between k_0 and internal friction angle of lunar soil approximated as (Zhang, 2000): $k_0 = 1 - \sin\varphi$

σ_v — The gravity stress of lunar soil, $\sigma_v = a \cdot \int_0^z \pi z \cdot \frac{(d_1 - 4R)^2}{4} \cdot \rho(z) dz$

(In which, $\rho(z)$ — The spontaneous stacking density of lunar soil (Qin, 1998), $\rho(z) = \frac{1.92(z + 12.2)}{z + 18} (g/cm^3)$ is the best estimate; a —The gravitational acceleration of Moon (Zheng et al., 2004), $a = \frac{g}{6}$;)

Substituting them into the formula of σ_v to calculate the gravity stress of lunar soil:

$$\sigma_v = 80g\pi(d_1 - 4R)^2 \cdot \left[(z^2 + 12.2z) \cdot ln(z + 18) - 12.2\, ln(z + 18) - \frac{2z}{z + 18} \right] \tag{18}$$

Since this is a mechanical analysis for soil-breaking critical state when drilling, the value of σ_v can be simplified as:

$$\sigma_v = 16.74\pi \cdot (d_1 - 4R)^2 \cdot g$$

$$\sigma_z = (1 - \sin\varphi) \cdot \sigma_v = 16.74g\pi(1 - \sin\varphi) \cdot (d_1 - 4R)^2 \tag{19}$$

(3) Calculating the pulling force

The total pressuresthat soft bag roleson holding-pipe is the sum ofthe radial tightening force and the lateral pressure of lunar soil:

$$\begin{aligned} N &= \sigma_z + N(z) \\ &= k_0 \cdot \sigma_z + \frac{\pi}{2} BR^2 \cdot (d_1 - 4R) + Bd_1 L \cdot \Delta x \end{aligned} \tag{20}$$

Then the maximum static friction force of soft bag turning inward in the initial stage can be got:

$$\begin{aligned} F_1 &= f \cdot N \\ &= f \cdot \left[\pi BR^2 \cdot (d_1 - 4R) + Bd_1 L \cdot \Delta x + 16.74g\pi(1 - sin\,\varphi) \cdot (d_1 - 4R)^2 \right] \end{aligned} \tag{21}$$

Substituting (21) into (7) gives the pulling force of rope F_2:

$$F_2 = fe^{\pi f} \cdot \left[\pi BR^2 \cdot (d_1 - 4R) + Bd_1 L \cdot \Delta x + 16.74g\pi(1 - sin\varphi) \cdot (d_1 - 4R)^2 - \rho Ra_n - \frac{1}{f} \rho Ra_\tau \right] + \rho Ra_n + \frac{1}{f} \rho Ra_\tau \tag{22}$$

Equation (22) gives a calculation formula of pulling force of rope in the initial stage. This also links the pulling force with structure parameters and drilling parameters.

3.3 Analytical Model of Soft Bag Torque

At the beginning of coring, the lunar soil entering the soft bag has acircular motion tendency. Under the effect of sliding friction force, which was caused by the lunar regolith and soft bag, soft bag will come about twisting phenomenon. This will affect the bedding information of sampling. For the phenomenon above, building the analytical model of soft bag torque is of great significance for optimizing the structural parameters of coring mechanism (Fei et al., 2008)

(1) Calculate the torque T_1

T_1 is generated bythe radial tightening force of soft bag and the centripetal force of ROP. The infinitesimal torque generated by the radial tightening force of infinitesimal is:

Calculate centripetal force:

$$F_n = 4\pi^2 \cdot V_n^2 \cdot d_1\rho \cdot (R \cdot d\alpha) \tag{23}$$

Where, F_r is the radial tightening force of soft bag in guide head. The tangential friction F_f that aroused by the centripetal force and the radial tightening forceoutside the holding- pipe wall can be expressed as:

$$F_f = f \cdot (F_n + F_r) \tag{24}$$

The torque caused by F_f can be expressed as:

$$T_{r1} = F_f \cdot \frac{d_1}{2}$$
$$= f\frac{d_1}{2} \cdot \left[4\pi^2 V_n^2 d_1\rho \cdot (R \cdot d\alpha) + B\pi R^2 \cdot (d_1 - 4R)\right] \tag{25}$$

Integrating the torque, the total torque generated by the radial tightening force of soft bag can be got:

$$T_{r1} = fd_1 \cdot \left[\frac{\pi}{2}BR^2 \cdot (d_1 - 4R) + \int_0^{\pi/2} 2\pi^2 \cdot V_n^2 d_1\rho R \cdot d\alpha\right]$$
$$= fd_1 \cdot \left[\frac{\pi}{2}BR^2 \cdot (d_1 - 4R) + \pi^3 \cdot V_n^2 d_1\rho R\right] \tag{26}$$

(2) Calculate the torqueT_2

The sliding friction force, which produced by the lunar regolith and soft bag, can be expressed as:

$$F_f = \mu_{yr} \cdot \sigma_n$$
$$= \mu_{yr} \cdot (1 - \sin\varphi) \cdot 16.74\pi \cdot (d_1 - 4R)^2 \cdot g \tag{27}$$

(μ_{yr}: The friction coefficient between lunar soil and soft bag)

To make the central axis of holding-pipe as the axis, the torque T_2 is generated by F_f as follow:

$$T_2 = F_f \cdot \frac{d_1}{2}$$
$$= \mu_{yr} \cdot (1 - \sin\varphi) \cdot 16.74\pi \cdot (d_1 - 4R)^2 \cdot g \cdot \frac{d_1}{2} \tag{28}$$

(3)Calculate the total torque T

The algebraic sum of T_1 and T_2 is the total torque:

$$T = T_1 + T_2$$
$$= fd_1 \cdot \left[\frac{\pi}{2}BR^2 \cdot (d_1 - 4R) + \pi^3 \cdot V_n^2 d_1\rho R\right] + 167\pi \cdot \mu_{yr} \cdot (1\_sin\varphi) \cdot (d_1 - 4R)^2 \cdot g \cdot \frac{d_1}{2} \tag{29}$$

The value of torque will represent the extent of soft bag twisting directly, the smaller of T, the more conducive to coring, and vice versa. The parameters that influence T are given by formula (29), such as f, E_l, b, d_l, L, d_0, V_n..

4 ANALYSIS OF THE INFLUENCE OF PARAMETERS ON PULLING FORCE AND SOFT BAG TORQUE

The analysis of regression of the dynamic model has been made to figure out the law representing the influence of structural parameters on the soft bag torque and the hauling cable pulling force. Then the structural parameters of the simulation coring mechanism have been optimized to achieve the goal of minimizing the resistance force of the soft bag when overturning and the torque T.

Based on the models of F_2 and Torque:

$$\begin{cases} F_2 \propto \left(\dfrac{f, E_l, R, b, d_1, L, \varphi, \rho, a_n, a_\tau}{d_0}\right) \\ T \propto \left(\dfrac{f, E_l, R, b, d_1, \varphi, \mu_{yr}, V_n}{d_0}\right) \end{cases}$$

The parameters of f, R, b, d_1, L, d_0 will be analyzed through numerical simulation. When in different drilling rates, the corresponding accelerations of soft bag in critical states can be obtained in experimental data. (Let the friction angle of lunar soil is 40°, friction coefficient between soft bag and lunar soil is 0.75 (Slyuta, 2014), the value of drilling depth is 0m, elastic modulus E_l around 17.8Gpa, linear density ρ is 100g/m (Wang et al., 2001).)

Based on the spatial constraint condition of the coring mechanisms used in China third lunar exploration project and the drilling parameters of Luna-24 used in former Soviet, the constraint condition of basis data can be expressed as follows:

$$\begin{cases} 0.15mm \le b \le 1mm \\ 0.5mm \le R \le 2mm \\ 0.171 \le f \le 0.385 \\ 14.5mm \le d_0 \le 23mm \\ 0.3mm \le \Delta x \le 4mm \\ 10mm \le L \le 20mm \\ 5cm/\min \le V \le 50cm/\min \\ 60r/\min \le V_n \le 500r/\min \end{cases}$$

Using the method of regression analysis, a goal function with different ranges has been obtained within differentparameters. In order to ensure that the impact of the parameters on the objective function is comparable, when the objective function is changed in the range of the corresponding parameters, the values of the other parameters are not optimized.Influence of various parameters on the tension F_2.

(1) The influence of parameters on F_2

It shows that $F_2(s)$ is related to f, R, b, d_1, L, d_0. Specially, the value of F_2 has a compound relationship with f, d_1 and the fillet radius R. Unlike guide head radius R, the parameters of b, L, a_n and $a_\tau$are proportional to F_2. Figure 5 plots the relationship between different parameters and the pulling force of rope.

The results show that the greatest varying range of F_2 occurs at the range of soft bag thickness, at which the varying ranges of f, b and d_0 will decrease. In addition, d_1 has the least influence on the range of F_2.

(2) The influence of parameters onT

The function of T(s) shows the relations between torque T and f, b, d_1, d_0, b and V_n. Among them,b is proportional to T in linear relationship. In addition, d_0 is inversely proportional to T. Figure 6 shows the relationship between different parameters and the torque of soft bag.

The results show that the greatest varying range of T occurs at the direction of the fillet radius, at which the varying ranges of f, b and $d_0$will successively decrease. In addition, d_0 has the least influence on the range of T.

(3)The optimization of structural parameters and drilling parameters

By the analysis above, the influence of different factors on the objective function is at different levels,the results show that the structural parameters of coring mechanism and the drilling parameters have a certain proportion of influence on both pulling force of rope and soft bag torque, which should be paid an equal attention on design and optimization.

Based on the results above, the values of the parameters of f,R,b,d_1,and L will decrease with the increasing d_0, which benefits for coring. Therefore, when the values of structural parameters and drilling parameters are taken the optimal values, as shown in Table 1, the coring mechanism optimized.

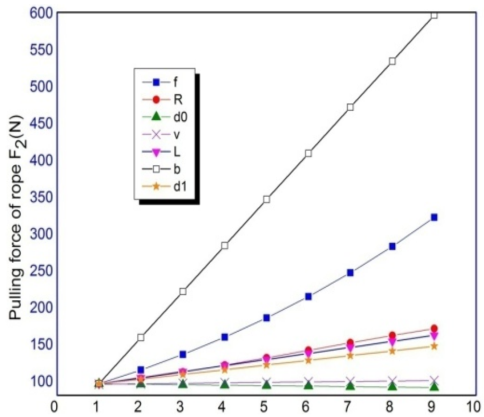

Figure 5: The relation curve between the structure parameters and the objective function F2.

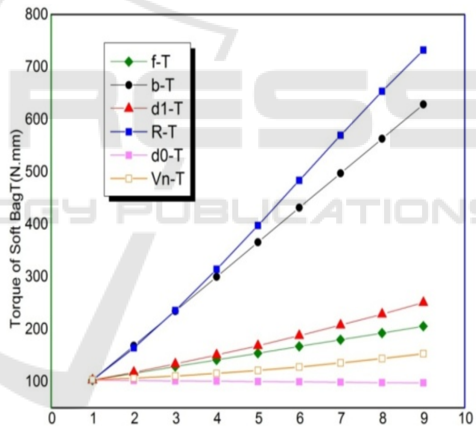

Figure 6: The relation curve between the structure parameters and the objective function T.

Note: In Figure 5 and Figure 6, the coordinates of the X axis are equal to eight aliquots for each parameter.

In practice, we need to balance the various parameters according to the working conditions and constraints. We can further verify the optimization results with the experimental results, then to adjust the optimization scheme.

Table 1: The value of structural parameters and drilling parameters before and after optimization.

Parameters	Un-optimized	Optimized
The friction coefficient of soft bag and Holding-pipe • f	0.296	0.171
Guide head radius • R/mm	1.5	0.5
Soft bag thickness • b/mm	0.75	0.15
Holding-pipe outerdiameter • d_1/mm	23	15
The length of nested segment soft bag • L/mm	15	10
Soft bag diameter at natural state • d_0/mm	20	14
Penetration rate • $V(mm/min)$	500	80
Revolution rate • $V_n(r/min)$	120	60

Note: The un-optimized value comes from the experiment when the coring mechanism was taken to verify the feasibility.

5 CONCLUSIONS

1. The influences of structural parameters and drilling technology on coring mechanism at the critical state of static-motion have been comprehensively analyzed in this paper. The mechanical model has been established representing the force at the beginning between soft bag overturning and lunar soil. In other words, a dynamic equation has been established to represent the overturning movement of the soft bag and a torque model representing.

2. Based on results of the proportion of influence of different factors on pulling force and torque, it shows that the soft bag thickness is the most influential factor on pulling force, and guide head radius is the most influential factor on torque. Among the factors of drilling technology, drilling rate has little influence on pulling force while the revolution rate has greater influence on soft bag torque.

3. The conclusion can be achieved after optimizing the mechanical model: When the s guide head radius is 0.5mm, soft bag thickness is 0.15mm, holding-pipe outer diameter d_1 is 15mm and soft bag diameter at natural state d_0 is 14mm, the energy consumption is lower and sample bedding is better.

LIST OF SYMBOLS

d_1: Holding-pipe outer diameter	$T_r(\alpha)$: Infinitesimal circumferential tensioning force
d_2: Rope diameter	$d\alpha$: The angle between infinitesimal and the axis o pipe
d_0: Soft bag diameter at natural state	F_f : Infinitesimal frictional resistance
b: Soft bag thickness	σ_n: Lunar soil lateral pressure
s: Holding-pipe thickness	$F_r(\alpha)$: The radial tightening force of soft bag
R: Guide head radius	ρ :The linear density of soft bag(axial)
L: The nested segment length of soft bag	E_l: The circular elasticity modulus of soft bag
V , V_n: Penetration rate, revolution rate	α: The wrap angle of soft bag around guide head
A: Cross-sectional area of infinitesimal	k_0: Coefficient of earth pressure at rest
a_τ : Tangential acceleration of soft bag movement	σ_v: The gravity stress of lunar soil
a_n: Radial acceleration soft bagmovement	$\rho(z)$: The spont stacking density of lunar so
$T(\alpha),T(\alpha)+dT$: Infini tangential tension	a: Gravitational accelera Moon

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