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Analysis and Verification on Mechanics Mechanism for Flat Digging of Grab

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Abstract. The research on digging resistances is the key to designing the grab, improving the grab's structure and realizing the automatic flat digging of grab dredger. This article focuses on the mechanical analysis and experimental research of grab's flat digging combining with theoretical calculation and experiments in dredging process. The theoretical digging resistances in both horizontal and vertical directions have been investigated in mathematical model. With the help of flat digging experiments, the forces on hoist rope and closing rope have been recorded. Then, work out the horizontal and vertical digging resistances based on moment balance. Since a good agreement is achieved between the theoretical calculations with the corresponding independent experimental results, the research has been verified and provides technical support for flat digging in dredging process.

1 Introduction

The research on digging resistances is the key to designing the bucket, improving the bucket's structure and realizing the automatic flat digging of grab dredger[1].Achievements on both experimental studies and theoretical calculations have been investigated in grab's mechanical mechanism. These just established a good foundation for the wide application of the grab[2].The scholar Miedema analyzed the relation between the interaction of grab's grasping force and resistance and grab's structure parameters[3].Qianxin Xiao, Qiren Chang et al. worked out the dredging curve of scissors grab by calculating grab drag resistances[4]. The work by Guangsong Guo et al. derived the equation of grab blade path based on primarily investigating mining forces and mining resistances[5]. The calculations of the excavation resistances and model tests have been worked out by Haining Zhang, after exploring the properties of dredging materials[6].

This article focuses on the mechanical analysis and experimental research of grab's flat digging combining with theoretical calculation and experiments in dredging process. The theoretical digging resistances in both horizontal and vertical directions have been investigated in mathematical model. With the help of flat digging experiments, the forces on hoist rope and closing rope have been recorded. Then, work out the horizontal and vertical digging resistances based on moment balance. Since a good agreement is achieved between the theoretical calculations with the corresponding independent experimental results, the research has been verified and provides technical support for flat digging in dredging process.

2 Analysis on flat digging for mechanics mechanism of grab

2.1 The excavating process of a grab clamshell

As shown in Figure 1, the dredging process of a clamshell could be divided into five steps.First, the hoist wires lower the grab to the bottom. Then, the closing winch drives the closing wire to close the grab. After the bucket is complete closed, the hoist winch and the closing winch work at the same time to lift the grab and swing to the barge or hopper. Finally, lowering the filled bucket into the barge or hopper and opening the bucket by releasing the closing wire[7]. The operation above is discontinuously and cyclic.

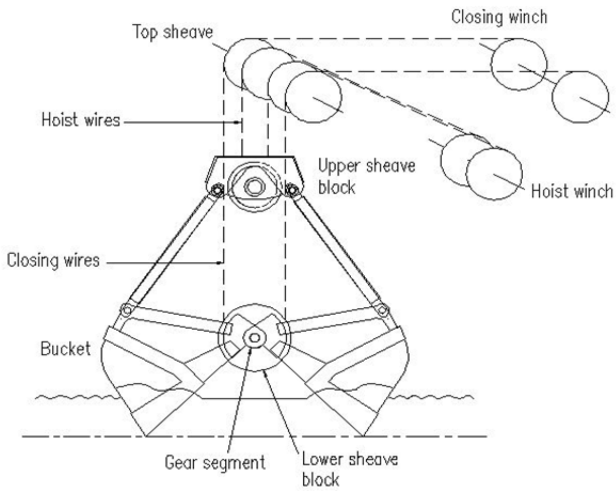

Fig. 1. Structure of clamshell grab.

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2.2 The concept of flat digging of grab

Figure 2 provides a digging curve of the grab in the conventional excavation and flat digging working state, where the blue is the conventional section of the excavated soil, and the red is the flat digging curve of the excavated soil. It can be seen from the figure, the thick red line for the maximum allowable depth, fine red line for the ideal cross-section curve.

In order to achieve the effect of flat digging, control the trajectory of the grab is needed. Through the automatic control device, the grab in the closing process for the length of two wires is controlled [8], so the grab trajectory is a straight line, as shown in Figure 3.

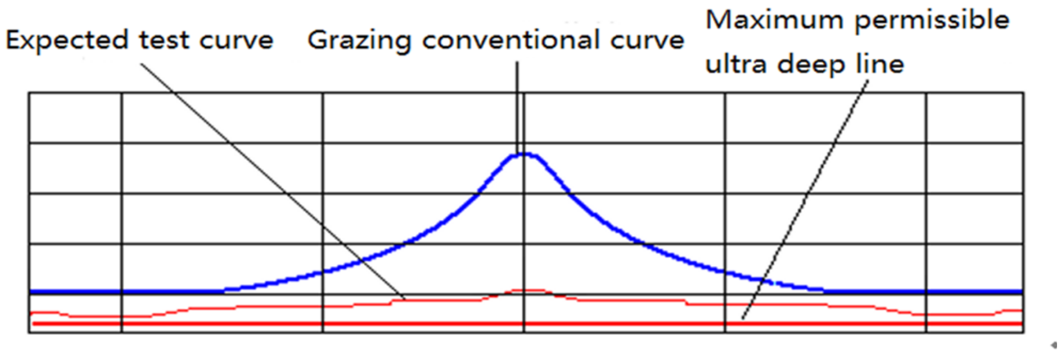


Fig. 2. Graph of grab's closed track.

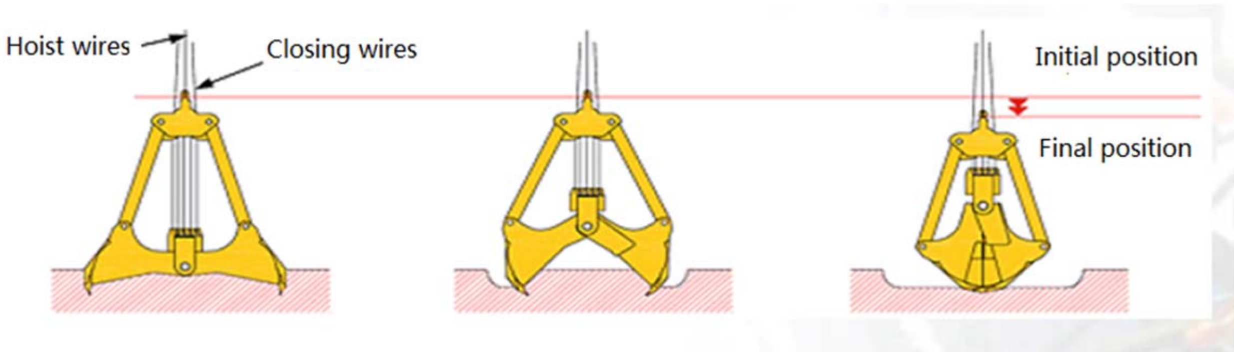
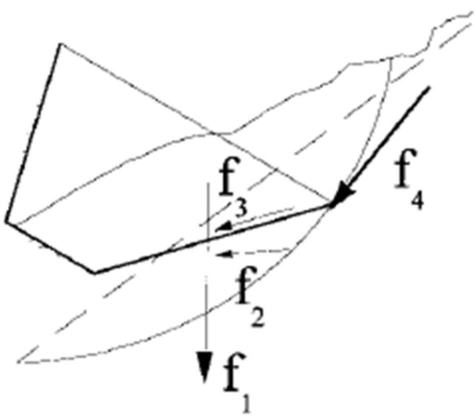


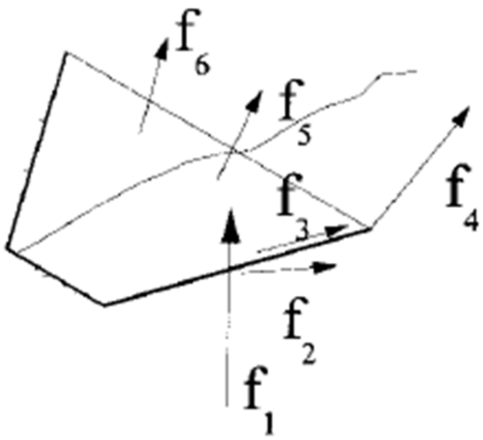
Fig. 3. Closed track of grab flat digging.

2.3 Cutting forces analysis of a grab

Balovnev[9] developed an analytical expression by extending passive pressure theory for large retaining walls to a bucket. Balovnev proceeded by dividing the bucket into its constitutive parts (blade, sides, etc.) and afterwards adding their individual influence,as shown in Figure 4.



(a)



(b)

Fig. 4. Force Components during Loading Task.

The accumulating bucket regolith weight is f1, f2 is the compacting material resistance, f3 are the wall friction forces acting along the bucket, f4 is the resistance to penetration, f5 is inertial force required to accelerate the regolith in the bucket to the velocity of the scoop, and f6 is inertial force needed to create empty bucket motion.

$$f_{4x} = P_1 + P_2 + P_3 \quad \text{and} \quad f_{3x} = P_4 \tag{1}$$

where P1 is the cutting and surface friction resistance of a flat trenching blade with a sharp edge; P2 is the additional cutting resistance due to resistance from a blunt edge; P3 is the resistance offered by cutting from the two confining sides of the bucket; and P4 is the resistance due to friction on those sides. Interestingly f1, f2, f5, f6 are not included in this picture. The Russian literature considers these secondary and small [10, 11].

The horizontal component of the total force is now written as

$$\begin{aligned} H &= f_{4x} + f_{3x} = (P_1 + P_2 + P_3) + P_4 \\ &= wd(1+\cot\beta\cot\delta)A_1 \\ &* (\frac{dg\gamma}{2} + c\cot\phi + gq + BURIED*(d - l\sin\beta)(g\gamma\frac{1-\sin\phi}{1+\sin\phi})) + \\ &we_b(1+\tan\delta\cot\alpha_b)A_2(\frac{e_b g\gamma}{2} + c\cot\phi + gq + dg\gamma(\frac{1-\sin\phi}{1+\sin\phi})) + \\ &2sdA_3(\frac{dg\gamma}{2} + c\cot\phi + gq + BURIED*(d - l_s\sin\beta)(g\gamma\frac{1-\sin\phi}{1+\sin\phi})) + \\ &4\tan\delta A_4 l_s d(\frac{dg\gamma}{2} + c\cot\phi + gq + BURIED*(d - l_s\sin\beta)(g\gamma\frac{1-\sin\phi}{1+\sin\phi})) \end{aligned} \tag{2}$$

with *BURIED = TRUE* or *FALSE* being 1 or 0 based on whether or not the entire bucket is submerged into the regolith. Geometric factors that consider the srace angle relative to the plane of reference are $A_1 = A(\beta)$, $A_2 = A(\alpha_b)$, $A_3 = A_4 = A(\frac{\pi}{2})$. For A_i, β and α_b the following equation can be used:

$$A(\beta) = \frac{1-\sin\phi\cos 2\beta}{1-\sin\phi} \quad \text{if } \beta < 0.5\left[\sin^{-1}\left(\frac{\sin\delta}{\sin\phi}\right) - \delta\right] \tag{3}$$

$$A(\beta) = \frac{\cos\delta(\cos\delta + \sqrt{\sin^2\phi - \sin^2\delta}}{1-\sin\phi} e^{[2\beta - \pi + \delta + \sin^{-1}(\frac{\sin\delta}{\sin\phi})]\tan\phi} \quad \text{if } \beta \geq 0.5\left[\sin^{-1}\left(\frac{\sin\delta}{\sin\phi}\right) - \delta\right] \tag{4}$$

The total and vertical components of this force[12] are

$$T = H\csc(\beta + \delta) \quad V = H\cot(\beta + \delta) \tag{5}$$

When the depth of the grabbed flat digging is constant, the grabbing horizontal excavation resistance and the vertical excavation resistance are a function of the grab opening and time. Taking the 0.3 square grab as an example, when the depth of flat digging of grab is 10cm, 20cm, the horizontal excavation resistance and the vertical mining resistance of the force function are shown in Figure 5, 6. (S1- horizontal mining resistance, S2- vertical mining resistance)

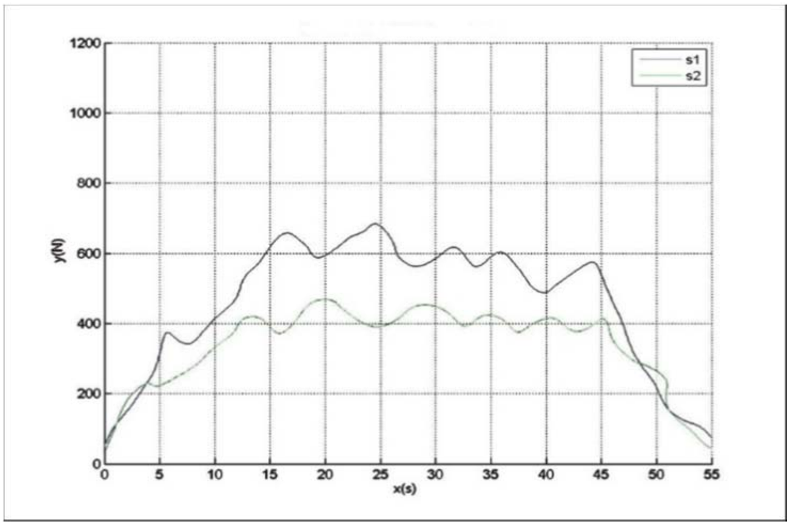


Fig. 5. Depth of flat digging of grab is 10cm, the horizontal mining resistance and the vertical mining resistance.

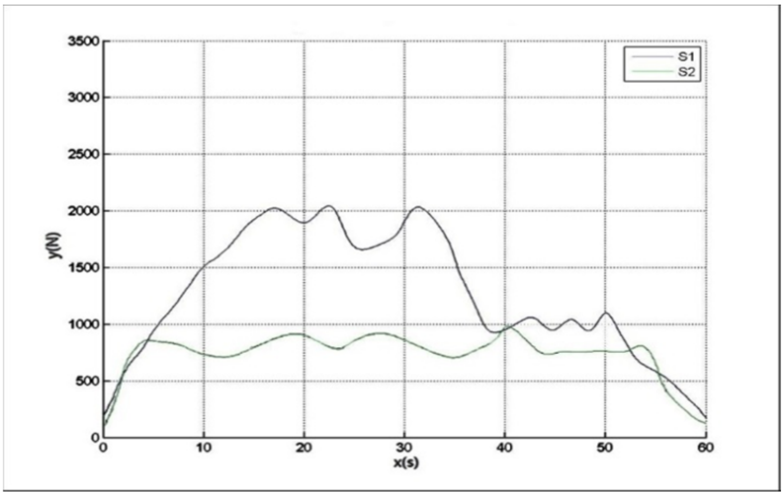


Fig. 6. Depth of flat digging of grab is 20cm, the horizontal mining resistance and the vertical mining resistance.

2.4 Mechanics analysis on flat digging of grab based on moment balance

In the study about grab, as shown in Figure 7.A half grab bucket body, which is △ABC ,is usually selected as the research object, the grasping force and grasping resistance on the center of the hinge point A moment, establish the torque balance equation of different digging depth (corresponding to each bucket opening)in digging progress, i.e. $M_1 = M_2$.

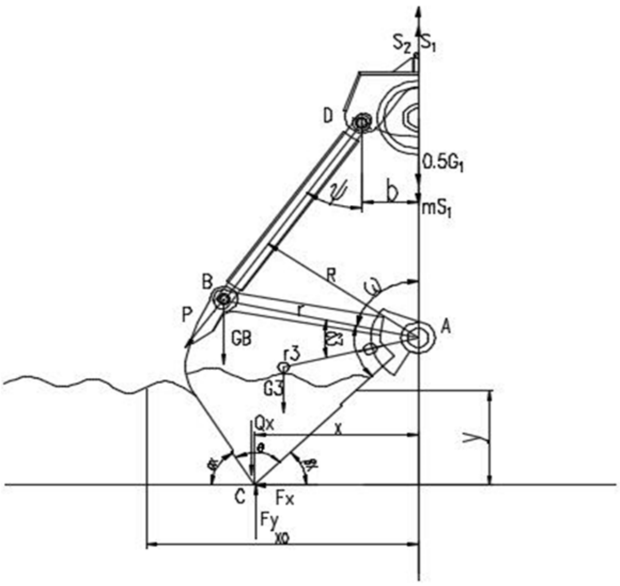


Fig. 7. Force diagram of grab digging.

Grab moment is the grab digging power, which is consist of force, strut on the bucket body and the bucket body weight and pressure into the weight of the material hopper bottom at the moment of the hinge point A.

$$M_1 = Q_x l_Q + PR + G_B r \sin\omega + \frac{G_3}{2} r_3 \sin(\omega + \delta_3) \quad (6)$$

In the formula: Q_x—the weight of the material Enter inside the hopper(N); l_Q —the length aimed at A(m); P —Support force of the hoist rod(N); R —the length of the hoist rod aimed at A(m); G_B—pressure which hoist rod stay on the bucket body(N); G_3—the weight of the bucket(N).

$$P = [S_1(m-1) + S_2 + \frac{1}{2} G_1 + G_B] / \cos\psi \quad (7)$$

In the formula, S_1—tension of the closing rope(N); S_2—tension of the hoist rope(N); G_1—weight of upper sheave block(N); G_B—pressure on the bucket body(N).

$$S_1 + S_2 = Q_x + \frac{1}{2} G_3 - F_y \quad (8)$$

In the formula, Q_x—the weight of the material enter inside the hopper(N); G_3—weight of bucket body(N); F_y —vertical mining resistance of grab(N).

Grab resistance is the material of grab force moment, including two reaction force F_x, F_y.

$$M_2 = F_x h_0 \sin\beta_x + F_y h_0 \cos\beta_x \quad (9)$$

In the formula, F_x—horizontal mining resistance of grab(N); F_y—vertical mining resistance of grab(N); h_0 —The length of the bucket body (m).

According to the formula, it can be seen that the grabbing horizontal mining resistance and vertical mining resistance are related to the size of hoist wires and closing wires. The specific function expression is:

$$\begin{aligned} F_x &= \{Q_x l_Q + [S_1(m-1) + S_2 + \frac{1}{2}G_1 + G_B] * R / \cos\psi + G_B r \sin\omega \\ &\quad + \frac{G_3}{2} r_3 \sin(\omega+\delta_3) - (S_1 + S_2 - Q_x - \frac{1}{2}G_3) * h_0 \cos\beta_x\} / h_0 \sin\beta_x \\ F_y &= S_1 + S_2 - Q_x - \frac{1}{2}G_3 \end{aligned} \quad (10)$$

3 Research on experiment of grab's flat digging resistance

3.1 Design of the flat digging experiment platform on grab

This experiment platform based on the 2t fixed cranes of the port machine lab in School of Logistics Engineering, Wuhan University of Technology,as shown in Figure 8.This four-link combined boom crane consist of hoisting mechanism, luffing mechanism, rotation mechanism, boom system, word frame, ,electrical control system and other auxiliary device. The capacity of the grab in the experiment is $0.3m^3$.

The load of the hoisting, opening and closing wire rope is tested by load sensor TLX-Z200, which with the core of microcomputer and displays the load of wire rope in real-time during the digging process, as shown in Figure 9. Combining the load of wire rope (hoisting, opening and closing) and mechanical analysis of flat digging based on moment Balance, the horizontal digging resistance and vertical digging resistance during the flat digging can be calculated.

3.2 Result analysis of experiment of grab's flat digging resistance

The proportion of the soil in the flat digging experiment is $1.6t/m^3$ and the digging depth are 10cm, 20cm, respectively, through the conversion of testing and load, the horizontal digging resistance and vertical digging resistance are shown in Figure 10 and Figure 11.

Figures 10 and 11 show the increasing of the horizontal digging resistance and vertical digging resistance with the progress of flat digging. The testing data is consistent with the theoretical calculation within a certain range of deviation by comparing them. The transfer of deviation depends on deviation properties and the measurement relationship between analysis results and testing data.

Transfer basic formula: $M = f(M_x, M_y, M_z)$.

So $dM = \frac{\partial f}{\partial M_x} dM_x + \frac{\partial f}{\partial M_y} dM_y + \frac{\partial f}{\partial M_z} dM_z$

Basic formula of absolute deviation:

$$\Delta M = \left|\frac{\partial f}{\partial M_x}\right| \Delta M_x + \left|\frac{\partial f}{\partial M_y}\right| \Delta M_y + \left|\frac{\partial f}{\partial M_z}\right| \Delta M_z$$

Compare the digging resistance measured in the dredging grab flat digging with theoretical calculation, the conclusion can be drawn that horizontal digging resistance and vertical digging resistance in flat digging are consistent with the theoretical calculation and the deviation of digging resistance of flat digging is about 4.15%.

Fig. 8. Appearance of grab dredger.

Fig. 9. Load sensor.

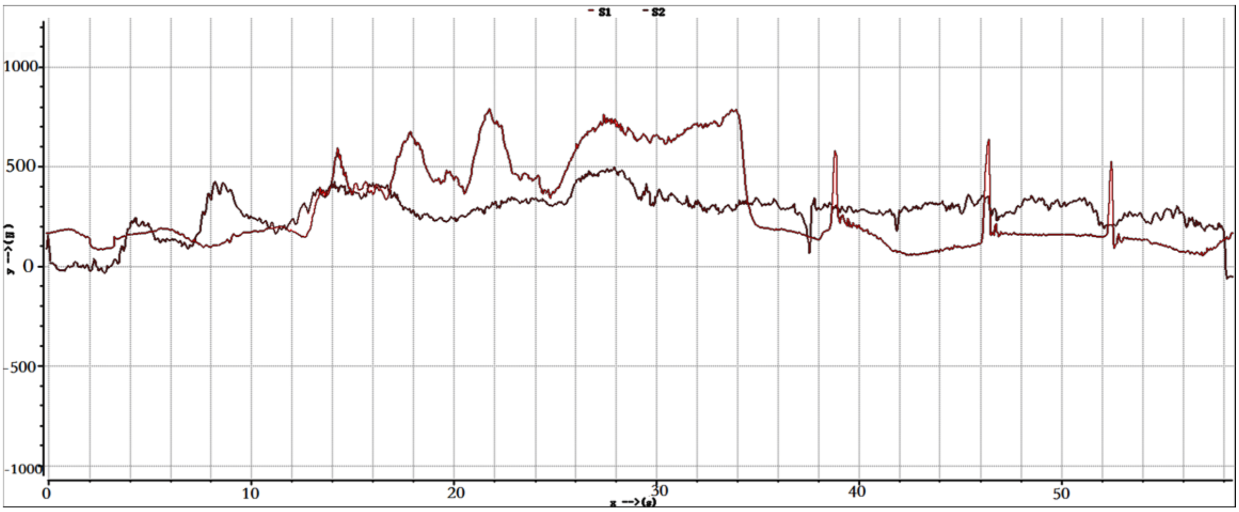


Fig.10. Testing depth of flat digging of grab is 10 cm, the horizontal mining, resistance and the vertical mining resistance (S1-horizontal mining resistance, S2- vertical mining resistance).

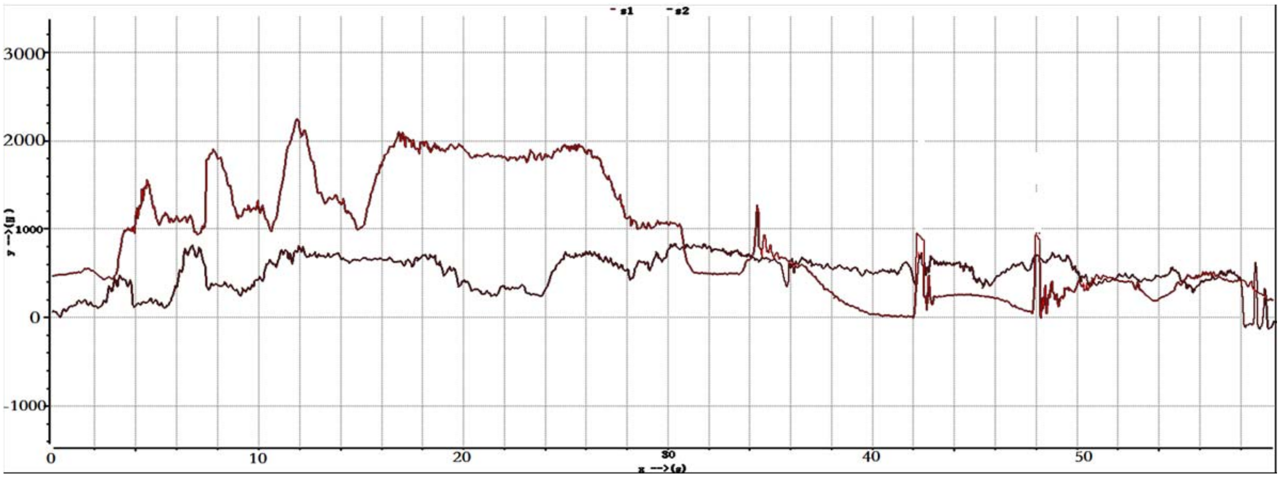


Fig. 11. Testing depth of flat digging of grab is 20 cm, the horizontal mining, resistance and the vertical mining resistance (S1- horizontal mining resistance, S2- vertical mining resistance).

4 Conclusion

This article aims to study the mechanical mechanism of grabbing materials. Based on the analysis of grab excavation process, a macroscopic mechanical model of the grab-material interaction is established. At the same time, the key technology of grabbing and digging is studied.

The simulation data provides theoretical support for experimental research.The reasonable experimental results, which get from the experiment on horizontal digging resistance and vertical digging resistance during the flat digging of the grab, are highly consistent with the theoretical calculation. So the research can provide technical support for the dredging grab flat digging.

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