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Research on driving force in dredging system

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Abstract. This paper presents a drag device which can provide driving force for sludge cleaning scraper in rainwater storage tank without any external energy. Based on its structure and principle, the design formula for the device is deduced. The working condition is analysed, the results of analysis show that the drag device can offer a large range of two-way pulling force for scraper device automatically and it has a great work environment adaptability.

1. Introduction

Rainwater storage tank is an important facilitate for rainwater management, scholars have made many researches on it [1-4]. Dredging is the key problem for managing storm rainwater in rainwater storage tank, especially in underwater storage tank, the environment of the storage tank is difficult for workers to clean the sludge in the tank, it has a great work intensity and high working risk. Many non-artificial dredging methods have been proposed [5-8], they rely on electronic control system, and the electronic control system is completely dependent on the supply of electricity, long time standby of the system is not conducive to energy conservation and environmental protection, and also shorten the service life of the equipment. Aging of the electrical components increases the risk of the system failure and reduces the working reliability of the equipment, furthermore, it needs to add investment costs in equipment maintenance and supervision. Especially in remote areas, the lack of electricity supplies and difficulties of laying electrical facilities are also the constraints of the rainwater utilization. So it is necessary to propose feasible ways to solve the above problems. To this purpose, introduced the composition of the dredging system, mainly studied the structure and principle of the driving device, the results prove that using the driving device can make the dredging system work reliability and safety.

2. Rainwater storage tank and its cleaning system

Rainwater storage tank is a rain facility, which is used to cache and regulate runoff rainwater, it is mainly built underground, so as to save the land surface area, keep the rainwater quality for longer time, reduce evaporation of the rainwater. During the rainfall the rainwater storage tank collects the rainwater from ground quickly, prevents waterlogging occurring, and reduces surface garbage flow into the river. In the dry season, the stored rainwater will be pumped out for reasonable using, so as to ease water shortage. However, in the process of rainwater harvesting, the garbage such as leaves, branches and other rubbish flow into the storage tank with the runoff rainwater. In the storage tank the garbage will precipitate to the bottom, and then changes to be sludge. After a long time, the sludge will pile thicker and thicker. So sludge discharge is an important aspect for rainwater harvesting



project. Sludge cleaning equipment is a very important facility for the system. Sludge cleaning system for rainwater storage tank is shown in Figure 1.

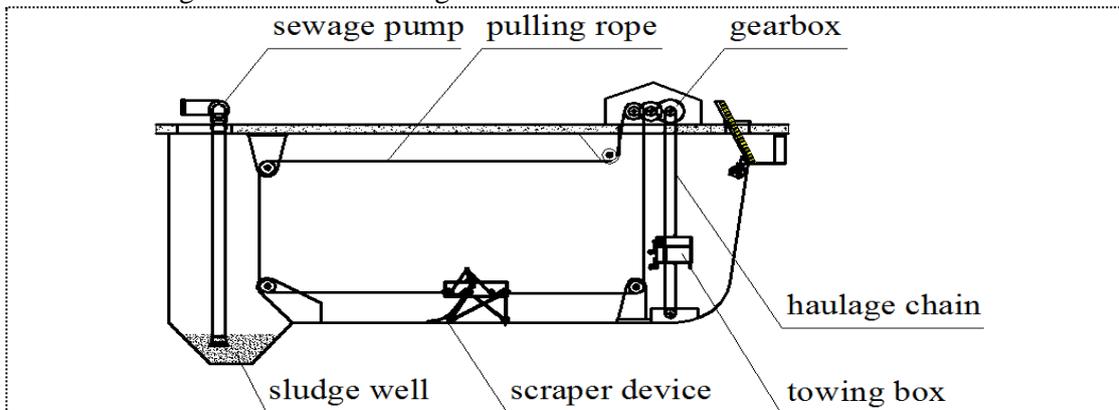


Figure 1. Schematic of rainwater storage tank sludge cleaning system

The system includes sewage pump, pulling rope, gearbox, haulage chain, towing box, scraper device and sludge well.

Rainwater storage tank is a rainwater reservoir which is built by concrete wall in the underground space. The bottom of the tank is built into a certain slope so as to clean the silt easily, the sludge well is built in the lowest end of the slope, and pulling rope is laid along the slope. The pulling rope tows the scraper device move along the slope, and the sludge will be collected to the sludge well by moving the scraper device. In the sludge well the sludge will be pumped out of the tank by the sewage pump. The gearbox is mounted above the storage tank. The output wheel of the gearbox is connected to the scraper device by pulling rope. The input wheel of the gearbox is connected to the towing box by haulage chain. The towing box suspends in the water, goes up and down by following the water level, thereby it pulls the scraper device to move along the slope back and forth, and then the sludge can be automatically cleaned up.

3. Structure of the towing box and its working principle

The structure of the towing box is shown in Figure 2, it consists of vent tube, sealed chamber, water chamber, stand, drain float, outlet valve, inlet valve, ratchet and ratchet float.

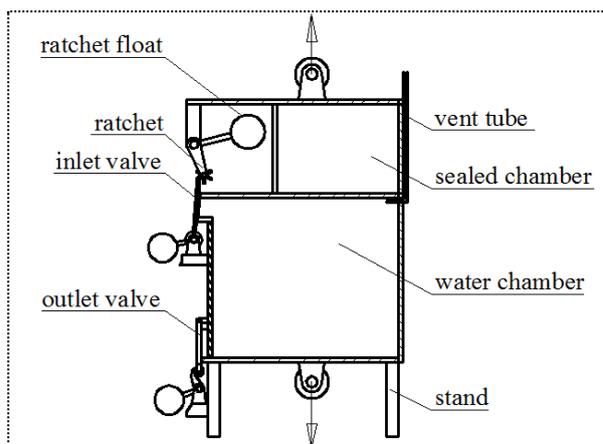


Figure 2. Structure of the towing box.

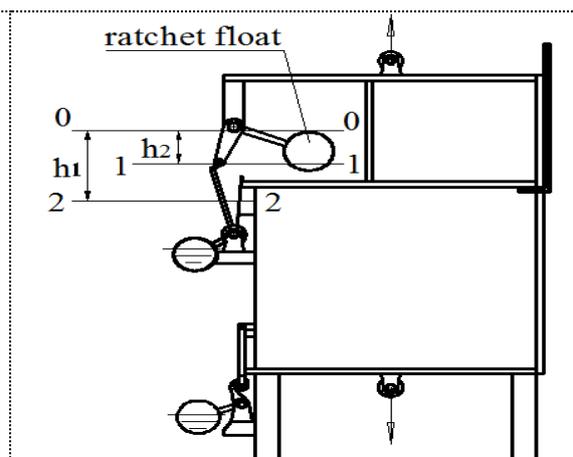


Figure 3. Structure of inlet valve.

The towing box consists of upper and lower parts. The upper part is the safety float, it ensures that when the towing box is filled with water in the water chamber, it can rise up freely to the surface of water. The lower part is the water regulating tank which consists of vent tube, water chamber, stand, drain float, outlet valve, influent float, inlet valve, ratchet and ratchet float. The vent tube connects the water chamber to the atmosphere, so as to discharge the air which is in the water chamber. The stand is mounted on the bottom of the towing box, and it should be high enough to ensure that the outlet valve can be opened reliably. The drain float is mounted on the low part of the water chamber, the link of the drain float connects to the outlet valve fixedly, and rotates around the joint freely, when the drain float goes up, the outlet valve will close, when the drain float goes down, the outlet valve will open. The hinge seat of the influent float is mounted at the entrance below of the water chamber, the link of the influent float connects to the inlet valve fixedly, and rotates freely with the water floating up and down. When the influent float goes up, the inlet valve will close, when the influent float goes down, the inlet valve will open. The hinge seat of the ratchet float is mounted above the entrance of the water chamber, the link of the ratchet float connects to the ratchet rack fixedly, and rotates freely with the water rise and fall. When the ratchet float goes up, the ratchet revolves with the ratchet rack, on the other side, the ratchet rotates in one direction. It rotates cross the inlet valve. When the ratchet float goes down, the ratchet revolves with the ratchet rack. In this direction, the ratchet cannot rotate, it pushes the inlet valve open. The water flows into the water chamber. In the rainwater storage tank, when the water level drops below the outlet valve, the drain float goes down, the outlet valve opens, the water will flow out from the water chamber. When the device needs to be pulled downward, the towing box should be in a hollow state, so as to increase buoyancy. When the device needs to be pulled upward, the towing box should be in full of water, so as to increase gravity.

3.1. Design of the sealed chamber

To ensure that when the water chamber is filled with water, the towing box can rise to the surface from water by itself, design of the sealed chamber should meet the following condition (1).

$$(V_m + V_c)\rho_w g > \rho_m g V_m \quad (1)$$

Where, V_m is the volume of the towing box material, $k_1=1.2$, ρ_m is the density of the towing box material, V_c is the volume of the sealed chamber, g is the acceleration of gravity, we can design the sealed chamber by the following formula (2).

$$V_c = \frac{k_1(\rho_m - \rho_w)}{\rho_w} V_m \quad (2)$$

Where, k_1 is the coefficient of reliability, so the formula (2) is the design basis by which the volume of the sealed chamber.

3.2. Design of the water chamber

Assume that the towing box provides the maximum tractive force. F_s is the maximum tractive force upwards, F_x is the maximum tractive force downwards, then the towing box should meet the following requirements,

$$(V_w + V_m + V_c)\rho_w g - \rho_m g V_m > F_s \quad (3)$$

$$\rho_w g V_w + \rho_m g V_m > F_x \quad (4)$$

Where, V_w is the volume of the water chamber, by the formula (3) we obtain

$$V_w = \frac{k_2}{\rho_w g} [F_s - (k_1 - 1)(\rho_m - \rho_w)gV_m] \quad (5)$$

Where, k_2 is the coefficient of reliability, in engineering project, $k_2=1.2$, $\rho_w=1000\text{kg/m}^3$, $g=9.8\text{m/s}^2$, $F_s=10\sim 980\text{N}$, $k_2=1.2$, $\rho_m=8930\text{kg/m}^3$, by the formula (4) we obtain

$$V'_w = \frac{k_3}{\rho_w g} (F_x - \rho_m g V_m) \quad (6)$$

Where, K_3 is coefficient of reliability, in this paper, $K_3=1.2$, $F_x=10\sim 980\text{N}$, $\rho_m=8930\text{kg/m}^3$, Compare the results which are calculated from formula (5) and (6), choose the larger value as the design volume of the water chamber.

To ensure that when the water level drops, the water chamber should be filled more water. From this point of view, the opening of the inlet valve of the water chamber should be smaller, but the smaller the opening is, the slower the flow rate will be. For a limited time, the water chamber should be finished of diversion, when the opening is too small, the water chamber cannot be filled full.

Assume that the drainage flow of the rainwater storage tank is Q_w , the surface area of the rainwater storage tank is S_w , then we get the descent velocity of the water level v_w ,

$$v_w = \frac{Q_w}{S_w} \quad (7)$$

In the beginning process of influent, the towing box remains stationary, see Figure 3, the structure of water chamber, the effective volume of the water chamber is V_w . Design the opening height, when the water level drops to 0-0, the inlet valve starts to open. When the water level drops to 1-1, the inlet valve opens to the largest size. At this time, once the water level continues to decline, the inlet valve will close quickly, the mark 0-0 in the Figure 4 represents the starting position of the water level, 1-1 represents the limit position of the water level, 2-2 represents the centerline of the inlet valve. The flow rate of which flows into the water chamber can be calculated by the following formula [9].

$$Q = KA\Delta P^m \quad (8)$$

Where, A is the stream section area of which flows into the water chamber,

$$A = \int_{h_2}^{h_1} dA(h) \quad (9)$$

K is the throttling coefficient,

$$K = C_d \sqrt{\frac{2}{\rho_w}} \quad (10)$$

According to the experimental data, $C_d=0.6\sim 0.8$, let $C_d=0.6$, m is the structure index of the inlet, $m=0.5$.

ΔP is the differential pressure of the intake,

$$\Delta P = \rho_w g (h_1 - h_2) \quad (11)$$

Where, h_1 is the water level at which the water begins to flow into the water chamber, h_2 is the water level at which the water terminates inflow to the water chamber, then,

$$Q = 0.6 \sqrt{2g(h_1 - h_2)} \int_{h_2}^{h_1} dA(h) \quad (12)$$

The elapsed time of which the water declines from level h_1 to h_2 can be calculated by the following formula

$$t = \frac{h_1 - h_2}{v_w} \quad (13)$$

After t time the water chamber should be filled full of water.

The volume of water is

$$V_w = 0.6\sqrt{2g(h_1 - h_2)} \int_{h_2}^{h_1} dA(h) \frac{(h_1 - h_2)}{v_w} \quad (14)$$

The section area of the water intake port is

$$A = \int_{h_2}^{h_1} dA(h) = \frac{V_w v_w}{0.6\sqrt{2g}(h_1 - h_2)^{\frac{3}{2}}} \quad (15)$$

In engineering application, $V_w=0.001\sim 0.010 \text{ m}^3$, $h_1=0.27 \text{ m}$, $h_2=0.21 \text{ m}$, $A=2.56\times 10^{-05}\sim 2.56\times 10^{-04} \text{ m}^2$, $v_w=0.001 \text{ m/s}$. In this paper, $V_w=0.0029 \text{ m}^3$, $h_1=0.27 \text{ m}$, $h_2=0.21 \text{ m}$, $v_w=0.001 \text{ m/s}$, $A=7.43\times 10^{-05} \text{ m}^2$.

4. Experiment

For the research, a physical model is made, show as in Figure 4, the towing box is made of iron plate, its size length \times width \times height is $170\times 100\times 320 \text{ mm}$. The height of the inlet port is 185 mm , the diameter of the inlet port is $\text{Ø}24 \text{ mm}$, the gravity of the towing box is 0.715 kg , the volume of the water tank is $2.90\times 10^{-3} \text{ m}^3$; the volume of the sealed chamber is $1.11\times 10^{-3} \text{ m}^3$.



Figure 4. Towing force test process.

Table 1. The test filling time.

No.	Time(s)
1	32.50
2	27.27
3	26.99
4	28.17
5	25.68
6	26.74
7	27.26
8	25.38
9	27.16
10	26.33

The test was carried out in river under bridge. Pull the towing box downwards, when the towing box submerges into the water, see the Figure 4, the towing force will reach to 34.1 N . Hang the towing

box upwards, when the water tank leaves the water level, and the drain float is still in the water, the towing box has the maximum towing force downwards. By the testing, it reaches to 33.5N. Perfusion time testing: by the test, the height of the water from the water level to the underline of the inlet port is 10 mm. During the test, the water level is fluctuating slightly. Test ten times and record the test time. The test perfusion time is show in table 1. The average tine is 27.35s.

In normal applications, water level descending speed is less than 5.5×10^{-4} m/s, in 27.35s, the water level will drop 0.0152m. In this paper, the water level difference is 0.005m. It has enough time for the water to fill the water chamber.

5. Conclusions

The research of the sealed chamber shows that the towing box can be made always in the upper water, so as not to be buried by mud.

When the water level rises in the rainwater storage tank, the inlet valve of the towing box will close, the water cannot flow into the water chamber, it will provide great buoyancy.

When the water drops in the rainwater storage tank, the ratchet float goes down due to gravity, the ratchet mechanism revolves and pushes the inlet valve open. The water flows into the water chamber to make the towing box heavier, so that the towing box can provide great gravity.

In the rainwater storage tank, the towing box offers a large range of two-way drag force for scraper device, the scraper device can perform the scraper task without any external energy, and realize sludge dredging automatically, it is conducive to energy saving and environmental protection.

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