Design and simulation analysis of vacuum fish suction pump

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Abstract: Most of Chinese aquacultural products rely on artificial nets to catch in 2020. Fish suction pump can replace artificial net, is an important mechanical equipment of fish breeding industry. The development of fish suction pump is relatively backward and the level of automation is still to be improved, which is not conducive to the large-scale and rapid development of aquaculture in various countries. This paper designs a single tank vacuum suction fish pump, the suction fish pump mainly uses the tank and the air pressure difference, through the automatic control system on the suction fish pump and each stage of the control, relying on the gravity of the mixture of fish and water to release fish. In this paper, fluent was used to conduct simulation analysis on the flow diagram of fish-water mixture inhaled at work, and the flow diagram and velocity vector diagram of the internal flow field were obtained. The results show that the vacuum fish suction pump can effectively reduce the fish collision damage. The vacuum fish suction pump designed in this paper can effectively complete the fishing work of cultured fish, with the characteristics of high efficiency and low damage, which can provide theoretical reference for the design of vacuum fish suction pump in the future.

1. Introduction
In 2020, China's aquaculture area was 703,611 hectares, and the total output of aquaculture products was 65.4902 million tons, an increase of 1.06 percent over the previous year. And fish suction pump can replace artificial net, is an important mechanical equipment of fish breeding industry. With the continuous development of modern fishery, the market demand for fishing by deep-sea fishing boats and the production and quality of fish raised in cage has been sharply increased. Therefore, it has become an important topic for fishery researchers at home and abroad to realize the mechanization and automation of fish sucking and transportation, reduce the labor intensity of fishermen and improve the survival rate of fish [1]. The present application of net technology and high mechanization of abroad is in stark contrast. Purse Seine, trawl, inefficient and injury mortality rate is high, the comprehensive benefit is relatively low [2]. With the continuous development of manufacturing industry, the structure of domestic fish suction pump has changed a lot, its working principle is more perfect, and its application field is also expanding [3]. Existing equipment is mainly aimed at deep-sea fishing and fish suction and capture in ocean cage farming, while there are relatively few studies on fish suction pump in pond farming [4-5]. Therefore, it is necessary to analyze the foreign fish suction machine and design the fish suction machine suitable for our country.

With the continuous development of China's manufacturing industry, the structure of the fish pump has been improved, the working principle is more perfect, and the field can be used is also expanding.
Such as hyS-60 vacuum fish suction pump, vacuum live fish catching machine, etc.\cite{3}. Hydraulic motor driven submersible centrifugal pump suction fish, every 100 minutes can pump ice 35 t large yellow croaker, also may transport length 10 to 50 cm of live grass carp fish, etc. Foreign fish suction pump mainly depends on the high-speed rotation of the impeller to carry out the fish suction. ETI’s TRANSVAC fish pump has a pumping capacity of 300 to 360 tons per hour\cite{6}. Denmark IRAS company’s fish pump absorption, by Norway, France, Iceland, Ireland, Japan and other countries\cite{7}.

At present, the research of fish suction pump is gradually transferred from centrifugal type to vacuum type. Vacuum type fish suction pump can effectively reduce labor intensity and improve work efficiency. Therefore the design and use of type vacuum pump fish fluent on the analysis of the internal flow field in pump suction fish is very meaningful. This paper carries on the corresponding design to the vacuum type fish suction pump, and carries on the corresponding internal flow field analysis to the vacuum type fish suction pump suction tank fish water mixture in the fish collection tank, so as to obtain some performance parameters of the internal flow field, to provide some reference for the future design of fish suction machine. In order to promote the application and development of fish suction equipment in China and improve the modernization level of fishery machinery.

2. Calculation Model

2.1 Physical Model

According to the current use of vacuum drum fish machine set fish shape are analyzed. The model of the whole container is drawn in the scale of 1:1 using SOLIDWORK software.

The main physical parameters of the model are determined as follows:

(1) The volume of the fish collecting tank is determined according to the suction pipe and suction speed per second. According to the determination of the expected workload $Q = \frac{W + W_{\text{tube}}}{\rho T}$, the corresponding working flow can be obtained as $Q = 1.65 \text{m}^3/\text{min}$. Then, the volume of fish collection tank can be obtained as $0.69 \text{m}^3$.

(2) Considering the overall coordination of the volume of the fish collecting tank, the diameter of the fish collecting tank is $0.7 \text{m}$. On the premise that the diameter has been determined, the length of the fish collecting tank is $1.5 \text{m}$ according to the volume formula of the cylinder and the calculation formula of the circular area.

(3) According to the formula for calculating the wall thickness of the cylinder under the external pressure of the vacuum tank: $\delta \geq D^{0.6} \times \left(\frac{MPL}{2.59E}\right)^{0.4} + C_0$, wall thickness $\delta = 2.64 \times 10^{-2} \text{m}$ can be obtained by corresponding calculation. According to the working environment of the fish pump, the material of the fish tank in the fish pump is 314 stainless steel, and then the corresponding material strength should
be checked. Because the fish suction pump works through the internal and external pressure difference, when the wall thickness of the fish collection tank is insufficient, the phenomenon of deflating the fish collection tank may occur, and the wall thickness is too large will lead to the fish suction pump is too bulky, large consumables. The appropriate wall thickness is particularly important. According to the calculation of the wall thickness also need to carry on the corresponding stress checking, only after checking the right to finish the expected work smoothly. According to the judgment condition of thin-walled cylinder, fish collecting tank can be regarded as thin-walled cylinder, and then the stress analysis of fish collecting tank is carried out. The state of stress on the wall of fish collecting cylinder is in two directions. One direction is atmospheric pressure applied to the outer surface of the vacuum fish collecting cylinder, and the other direction is pressure applied to the inner surface of the fish collecting cylinder after air is pumped from the inside. According to the cylinder section stress calculation formula:
\[ \sigma' = \frac{PD}{4\delta}, \quad \sigma'' = \frac{PD}{2\delta} \]
The stress can be obtained \( \sigma' = 6.9 \times 10^4 \text{N}, \quad \sigma'' = 3.45 \times 10^4 \text{N} \). According to the fourth strength theory \( \sigma_s = 7.1 \times 10^5 \text{N} \), Refer to the material strength limit table to see that is less than 314 stainless steel stress limit.

(4) Fish suction pump in the fish tank also need to design the corresponding fish inlet and outlet, to complete the complete workflow. Fish inlet and outlet are channels for fish in and out of fish tank, in order to reduce damage to fish and smooth fish in and out of work. The diameter should be as far as possible to ensure that a single successively or accumulative equivalent cross-sectional area of the fish body passes through in an orderly manner, that is, the maximum cross-sectional area of the fish body should be as far as possible to ensure that the maximum cross-sectional area of the fish body takes up half of the suction pipe,

\[ \frac{D_{\text{fish}}}{D_{\text{lube}}} = \sqrt{2}. \]

According to the corresponding design, the diameter of the fish collecting tank in the fish suction pump is 0.7m, the length is 1.5 m, the wall thickness is 8×10⁻³m, and the diameter of the fish inlet is 0.2m.

2.2 Flow field model

Sports, as a result of the analysis after the fish into the only consider putting fish movement, so in the ANSYS model is not designed to put the fish in the mouth, as shown in figure 1. Figure 2 is shown in figure 1 is divided by the ANSYS fluent grid model, the mesh with 15943 nodes and 74626 elements, the model after meshing the model of average quality reached 0.82, and can better complete the numerical calculation. Before the fluid analysis of the grid model, it is necessary to check the results of the grid division. Only when there is no unqualified grid, can the corresponding fluid analysis of the grid model be carried out. Because the fish suction machine is the fish from the aquaculture pond through the negative pressure suction into the fish tank, mainly on the fish from the suction mouth into the fish tank, fish in the tank movement track analysis. The standard K-Epsilon (2 EQN) model was selected as the calculation model. The turbulence model is accurate and easy to converge, and has been widely used in fluent fluid simulation.

2.3 Boundary constraint

The suction process of fish suction machine is analyzed to determine the corresponding boundary constraints. Through the analysis of the swimming speed of fish in the water, the inlet speed of fish suction machine was selected as 1.2m/s. After the fish entered the fish collecting tank, the fish fell along the Y-axis direction, and the gravity acceleration was set as 9.8m/s². Name the working face inside the model in Face and the rest of the non-working face other. After all the parameters are set, the calculation is carried out. After the settlement, the results are saved and analyzed accordingly.
3. Results and Analysis

3.1 Streamline trajectory diagram

In the actual experiment, the working process of fish suction pump is fast, so it is difficult to measure the fluid trajectory inside the fish collecting tank. After calculation by Fluent, the streamline trajectory inside the fish collecting tank can be observed intuitively and simply. As shown in Figure 3, when the fish-water mixture enters from the entrance of the fish collecting tank, it falls towards the bottom of the fish collecting tank under the action of gravity and initial velocity. After a period of curve movement, it slides to the bottom of the fish collecting tank. It can be seen from the figure that when the fish-water mixture reaches the bottom of the fish collecting tank, the speed is 0.005 m/s. The lower speed can reduce the damage caused by the collision between fish and tank wall when they fall into the bottom of the tank, improve the integrity of fish during transportation, reduce the damage caused by the collision between fish and tank wall because of too fast speed, and thus improve the survival rate of fish. In addition, it can be intuitively observed from Figure 3 that the lines of the flow field inside the fish collecting tank are smooth and there is no obvious backflow phenomenon. Therefore, the flow field inside the fish collecting tank is reasonable.

3.2 Velocity vector

It can be clearly observed from Figure 4 that when fish and water mix into the fish collecting tank, there is a period of acceleration due to the acceleration of gravity. The velocity of fish-water mixture reaches the maximum value when it first contacts the upper right section of the fish-water tank, and the higher speed is conducive to promoting the fish-water mixture to flow to the arc at the bottom of the bow of
the fish-water tank to prevent the blockage in the fish-water tank. Then the velocity gradually decreases to 0.005 m/s and becomes stable at the bottom of the fish-water tank. It can effectively avoid the damage caused by collision between fish and bottom of fish collecting tank caused by high speed.

4. Conclusion
This paper designs a vacuum fish suction pump, and uses SOLIDWORK to model the arc-shaped fish collecting tank at the bottom of the bow. Fluent is used to simulate the streamline track and velocity of the liquid inside the fish collecting tank when it works, and the corresponding analysis of the simulation results is made, and the simulation results are as follows:

(1) When the fish-water mixture enters from the entrance of the fish collecting tank, it falls towards the bottom of the fish collecting tank under the action of gravity and initial velocity. After a period of curve movement, it will slide to the bottom of the fish collecting tank. The internal streamline of the fish collecting tank is smooth and stable, and there is no direct collision with the inner wall of the fish collecting tank. The bottom of the arc can better reduce the speed of fish and water mixture and reduce fish damage.

(2) The speed at the inlet of fish collecting tank can absorb fish and water mixture better. Then, after a period of acceleration under the force of gravity, the fish-water mixture flows at a faster rate towards the bottom of the bow of the tank. It can effectively prevent the blockage of fish collecting tank caused by too slow speed, which is conducive to the subsequent entry of fish and water mixture. And when reaching the bottom, the speed is almost zero, which can effectively reduce the damage caused by the collision between fish and fish collecting tank.

In this paper, the vacuum fish suction pump is designed accordingly, and the fluent software is used to analyze the internal flow field of the fish water mixture sucked into the fish collecting tank of the vacuum fish suction pump, so as to obtain some performance parameters of the internal flow field, which provides some reference for the design of the fish suction machine in the future. In order to promote the application and development of fish suction equipment in China and improve the modernization level of fishery machinery.

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Reference
[1] Ye X M, Xu J Z. Status of Fish Pump Research at Home and Abroad [J]. Modern Fisheries Information, 2005, 20; 7-8.
[2] Lu J, Qian R C, Huang H L, Li L Z, Feng C L, Liu Z D, Chen S, Wu Y, Xu B. Research Progress of Fish Pump at Home and Abroad [J]. Fishery Information & Strategy, 2013, 40; 57-62.
[3] Lu P. Flow Analysis of Fish Pump Base on ANSYS CFX [J]. Fluid Machinery, 2014, 42; 43-46.
[4] Gehrke P C. Diel Abundance, Migration and Feeding of Fish Larvae (Eleotridae) in a Floodplain Billabong [J]. Journal of Fish Biology, 1992, 40; 695,707.
[5] Menabbed C D, Liston C R, Borthwicksm S M. Passage of Juvenile Chinook Salmon and other Fish Species Through Archimedes Lifts and a Hidrostal Pump at Red Bluff [J]. Trans--actions of the American Fisheries Society, 2003, 132; 326-334.
[6] Davis K B, Newson J, Simco B A. Physiological Stress in Channel Catfish, Ictalurus Punctatus, Harvested by Lift Net, Vacuum Pump, or Turbine Pump [J]. Journal of Aquacult--ure, 1994, 3; 297-310.
[7] Summerfelt S T, Davidson J, Wilson G, Waldrop T. Advances in Fish Harvest Technologies for Circular Tanks [J]. Aquacultural Engineering, 2009, 40; 62-71.