DESIGN AND TEST OF NORMAL MILK PROCESSING AND SUPPLY SYSTEM FOR CALF FEEDING

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To realize fine feeding of calf, it is necessary to enable normal calf feeding milk being automatically processed and supplied. In this article, on basis of an analysis on the processing flow of normal calf feeding milk, an isometric double-head normal milk processing and supply system for calf feeding was designed. Then Solidworks software was used to conduct 3D modeling to the equipment, and Fluent fluid simulation software was utilized to simulate the mixing effect of normal processing system. In addition, feed stability and accuracy was tested and studied under different pulsed quantity in order to fit a systematic feeding model and carry out feeding test. The testing results showed that, under a rotate speed of 500r/min, the system had obtained feeding accuracy no less than 99%, maximum feed time of 37.1s and feed speed of 134.6kg/s, all which can meet the requirements of normal milk processing and supply for fine calf feeding.

Keywords: Calf; Normal feeding milk; accurate feed; Isometric double-head; Test

1. Introduction

For calves in normal milk feeding stage, their normal feeding milk is primarily pasteurized milk. To process normal feeding milk, there are two main methods. The first method is to heat the milk up to 60-65℃, then preserve for 30min and finally become cool; the second one is to heat the milk up to 75-90℃, then preserve for 15-16s and finally become cool.

Currently, the normal calf feeding milk is primarily processed by manpower. In the course of feeding, the milk is firstly heated by manpower to 78-85℃ and pasteurized, then naturally cools down to 38℃, and finally put into feeder, rundlet or basin to feed the calves. Though the work of feeding calves with normal milk could be completed by artificial feeding, it still has prominent problems, such as high labor intensity, low feeding efficiency, serious effect from manpower, etc [1-3]; regarding normal calf feeding milk processing equipment and methods, some research have been developed in Urban (Germany), DeLaval(Sweden), Kastenschmidt KM, Karel Van den Berg, Bergeron, J.A.Pempek, J.C.Bernal-Rigoli, etc [4-9] .

In the course of fine calf feeding, the feed accuracy, efficiency and stability of normal

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feeding milk are important factors to influence calf feeding effect. For this purpose, in this article, on basis of earlier research on fine breeding technology and equipment [10-14], a normal milk processing and supply system for fine calf feeding with double isometric heads was designed. To guarantee feeding efficiency, in processing flow, after the milk is heated to 75-90℃, preserved for 15-16s and cooled down to 39℃, finally it could be fed to calves. The designed and completed normal feeding milk processing and supply system could realize automatic processing and accurate supply of normal feeding milk and establish solid foundation for health development of calf breeding.

2. System Compositions and Working Principle

2.1 System Composition

The system is primarily composed of two parts: normal milk processing system and accurate supply system. Out of these, the normal milk processing system mainly includes external bucket (water heating bucket), mixing bucket, stirrer, mixing motor, reducer, temperature sensor and water pump; the normal milk accurate supply system mainly includes peristaltic pump, cleaning nozzle and milk cup, as presented in the structure diagram from Fig. 1.

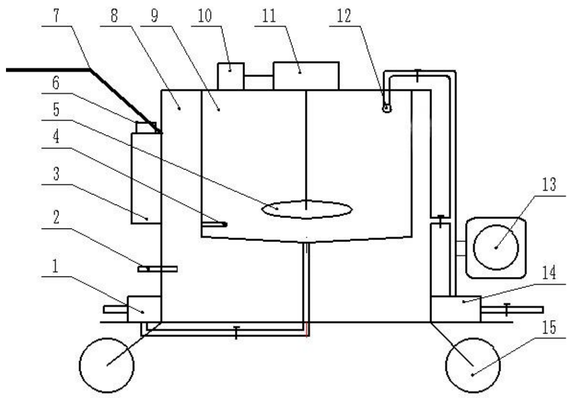

Fig.1 Structure Diagram of Accurate Calf Feeding Machine
1.Peristaltic pump; 2.Heating rod; 3.Control casing; 4.Temperature sensor; 5.Stirrer; 6.Touch screen; 7.Handle; 8.External bucket; 9.Mixing bucket; 10.Mixing motor; 11.Reducer; 12.Cleaning nozzle; 13.Identifier; 14.Water pump; 15.Caster

2.2 Working Principle

During the course of normal milk processing, the equipment control system will control heating unit to heat the water in external bucket in order to heat milk through thermal transmission. When heating to the setting temperature of 75-90℃, it is necessary to stop heating and preserve heat for 15-16s, and then inject cold water into external bucket so as to cool the heated milk through circulation of cold water in external bucket. After the milk is cooled down to a setting temperature of

39℃, the processing of normal feeding milk is completed. During the courses of heating and cooling, the milk should be unceasingly stirred by mixing motor and stirrer. When feeding the calves, peristaltic pump and instrumenta suctoria should be used for accurate supply of normal feeding milk.

3. Design of Normal Milk Processing System

The normal milk processing system is primarily composed of mixing system, water heating and cooling system, and mainly used for pasteurization of milk in order to process normal calf feeding milk with uniformly mixed texture, suitable temperature and good palatability.

3.1 Design of Mixing System

The mixing system is mainly composed of mixing bucket, mixing fan, mixing motor, etc.

The optimal calf feeding quantity generally equals to normal feeding milk that is equivalent to 10% of calf weight. Calculated from that the equipment could feed 40 calves with average weight of 35kg at a time. The volume of normal milk mixing bucket should be no less than 150L. The designed mixing bucket is a cylindrical bucket of dia. 500cm x 400cm height on the top with a conical part of dia. 25cm x 23 cm heights at the bottom. The final volume of this mixing bucket is 157L.

In accordance with material characteristics of milk and requirements of processing flow, the axial-flow double-fan tilt paddle stirrer is applied and installed in the center of top surface, as shown in Fig. 2. In the mixing system, the stirrer is driven by a three-phase asynchronous motor through gear reducer. The stirrer is connected with mixing axis by bolts.

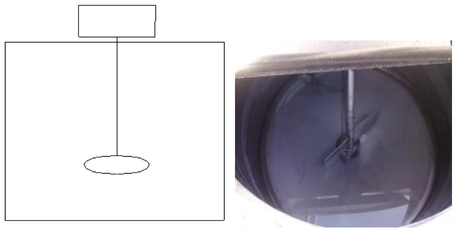

Fig. 2 The Installation Position of Mixing Paddle

3.2 Design of Heating System

The heating system is primarily used to heat milk before feeding and preserve heat of milk during feeding. It mainly includes external bucket, heating rod and temperature sensor. The heating rod is installed in external bucket to heat the water, and the temperature sensor is installed in mixing bucket to measure real-time temperature of milk. In operation, it is required to set heating temperature value of milk in mixing bucket firstly. When temperature of milk rises to set value (generally 75℃), it is necessary to stop heating and preserve heat for 15-16s. In our system, the sensor is WZP-187 SS water-proof temperature sensor produced by Shanghai Songdao Heating Sensor Co., Ltd.

3.3 Design of Cooling System

In cooling system, the water cooling circulation method is used to cool the milk in the mixing bucket. The system pumps the cool water into external bucket and utilizes heat transmission between cool water and milk to cool the milk. After external bucket is filled with cool water, such cool water could flow into storage tank from outlet through pipeline. This system uses heat transmission between water and milk to implement non-contact heating and cooling, which largely simplifies the structure of equipment cleaning system and enables the used water to be recycled.

4. Design of Normal Milk Accurate Supply System

The normal milk accurate supply system is primarily composed of peristaltic pump, instrumenta suctoria and pipes. Its main function is to feed calves with normal milk processed by normal milk processing system and implement accurate feeding. When feeding, after a radio frequency identification system indentifies a calf, the peristaltic pump will complete accurate supply of normal feeding milk under the requirements of control system. Accurate quantity of normal milk will be pumped out and flow into the mouth of calf through pipes and anti-leak instrumenta suctoria.

4.1 Design of Peristaltic Pump

When peristaltic pump works, normal milk is supplied by the driving pump of stepping motor. The pump head is mainly composed of shell, upper holder block, wrench and rotor. The pump head of the accurate supply unit is designed as three round rotors of same dia. 20mm with 50mm distance between the centers of the two rotors. Relative parameters of accurate supply unit could be calculated according to the following equations.

$$V = V_r G \tag{1}$$

$$V_r = V_s / 3 \tag{2}$$

$$G = \pi r^2 h \rho \tag{3}$$

Where,

V-Feeding speed calculated with minimum feeding quantity and time under double pump head working methods, which should be no less than 60g/s;

*V*r-Speed of rotor, in rpm;

*V*s-Speed of stepping motor, which is set to be 500 rpm;

G-Weight of normal milk between sections, in gram;

r-Radius of hose, in cm;

h-Distance between the two rotors, in cm;

ρ-Density of milk, which is set to be 1.1-1.2g/cm^3.

Acquired from equation (1), (2) and (3), the inner diameter of hose shall be 9.6mm. Therefore, 36# hose with wall thickness of 2.4mm is selected. The selected pump head is KZ25 SS pump head with PC shell. The relative technical parameters of double pump head normal feeding milk unit are shown in Table 1.

Table 1

Technology Parameters

Item	Technical parameter
Working voltage	36V
Working current	5.6A
Feeding efficiency	12L/min
Feeding error	≤5ml
Pulse frequency	14KHz under 100rpm

4.2 Feeding Error Analysis

In the course of feeding by the accurate feeding unit, the stepping motor will drive the rotor to extrude hose in order to realize the supply of normal milk. Therefore, calculating under equation (3), if the weight of milk is 3.9g, and its feed scope should be 3kg-5kg according to requirements of accurate calf feeding, we can obtain a theoretical maximum feed error of double pump head feeding unit σ=3.9x 2/3000=2.6%, which meets the need for accurate calf feeding.

4.3 Design of Cleaning System

Cleaning system is mainly composed of cleaning nozzle, water pump and pipe, which is responsible to clean and disinfect the equipment mixing bucket and pipeline. In operation, water pump is used to pump relative cleaning solution into cleaning pipeline, and cleaning nozzle is used to wash inner wall of mixing bucket (as shown in Fig. 3). In the course of cleaning, the cleaning solution should be added according to certain order: clean water-alkaline aqueous solution-clean water-acid aqueous solution. At the end of the cleaning process, peristaltic pump should be started to pump water out and simultaneously complete the cleaning of inner wall of pipeline.

Fig. 3 Cleaning nozzle

5. Simulation of Normal Milk Processing Flow

5.1 Establish Mixing Model

Physical models of mixing bucket and mixing fan are shown in Fig. 4. In the course of modeling, we assume that the mixing speed of stirrer is uniform, the mixing fluid is water with isotropous viscosity coefficient, and the water flow in the mixing space is turbulent.

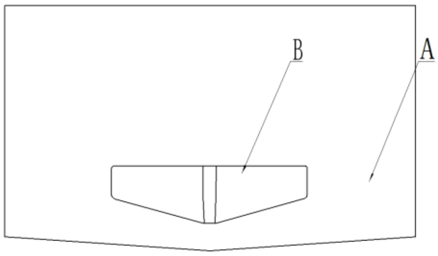

Fig. 4 The Physical Model
A. Mixing bucket; B. Stirrer

Continuity equation, momentum equation and turbulence energy equation are used to describe the flow state of water in mixing flow field.

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

Momentum equation:

$$\frac{\partial u_i}{\partial t}+\frac{\partial(u_i u_j)}{\partial x_i}=F_i-\frac{1}{\rho}\frac{\partial \rho}{\partial x_i}+v\frac{\partial^2 u_i}{\partial x_i \partial x_j}$$

Turbulence energy equation:

$$\frac{\partial u_i k}{\partial x_i}-\frac{\partial}{\partial x_i}\left[\left(v+\frac{v_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right]=P_r-\varepsilon$$

5.2 Gambit Pretreatment

Solid Works 3D cartographic software is used to make 3D physical modeling on mixing bucket and stirrer. In Gambit pretreatment, it is required to conduct mixing area treatment, mesh division of mixing bucket and stirrer and boundary condition setting, the definition of mixing area division is shown in Fig. 5.

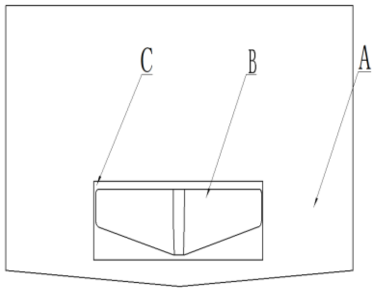

Fig. 5 Schematic Diagram of Multiple Reference Frame
A. Static area; B. Stirrer; C. Live area

5.3 Calculation for Solution

The velocity contour and vector diagram of vertical section and cross section are shown in Fig. 6.

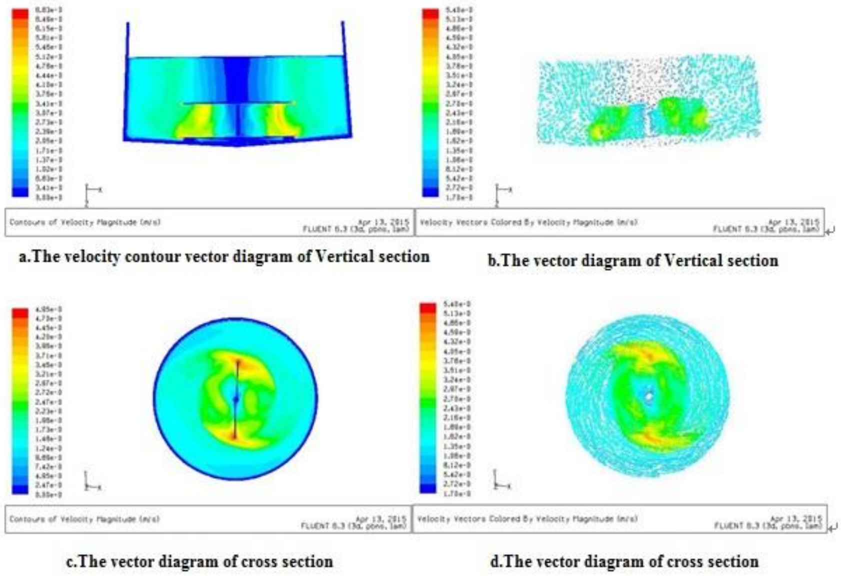

Fig. 6 The Velocity Contour and The Vector Diagram of Vertical Section and Cross Section

As shown in the above picture, the speeds of both ends of stirrer paddles are the highest, and both speeds of upper and lower ends of stirrer are lower. After striking the wall of mixing bucket, water around stirrer is divided into two parts: one part moves upward along bucket wall and goes back to stirrer paddle until it reaches a certain height; the other part moves downwards along bucket wall and goes back to stirrer paddle until it reaches the bottom, so as to avoid particle material stacking at the bottom of the bucket.

5.4 Stirrer Paddle Simulation

The factors that influence the mixing effect of the mixing bucket mainly include three aspects: stirrer paddles, distance from stirrer to bottom and rotate speed of stirrer. The simulation results of six groups of paddles (220mm, 270mm, 320mm, 370mm, 420mm and 470mm) under same rotate speeds are shown in Fig. 7.

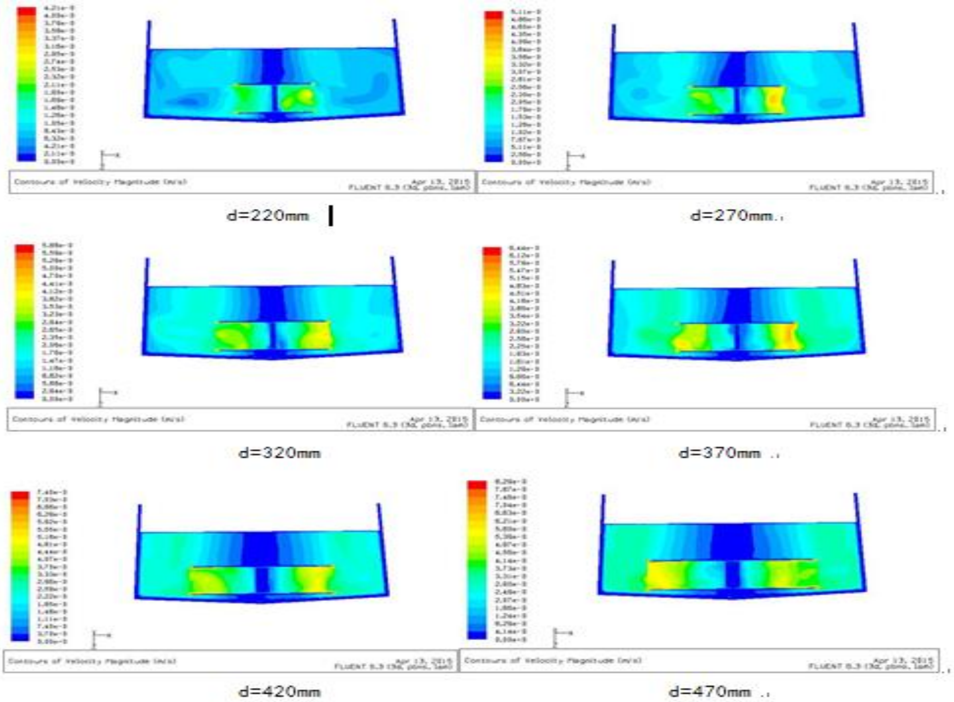

Fig. 7 The Mixing Flow Field of Different Impeller Diameters

Fig.7 illustrates that, when paddle d≤320mm, the velocity distribution of water in the mixing bucket is so low that it shows non-uniform mixing; when paddle d≥420mm, though there is a large velocity distribution, the water slowly flows and forms a recirculation zone to create a dead flowing angle, which results in a bad mixing effect; when paddle d = 370mm, none of the above problems appears and it shows a good mixing effect.

Under the same paddle diameter and rotate speed, the simulation results of different distances between stirrer and bottom (20mm, 25m, 30mm, 35mm, 40mm and 45mm) are shown in Fig. 8.

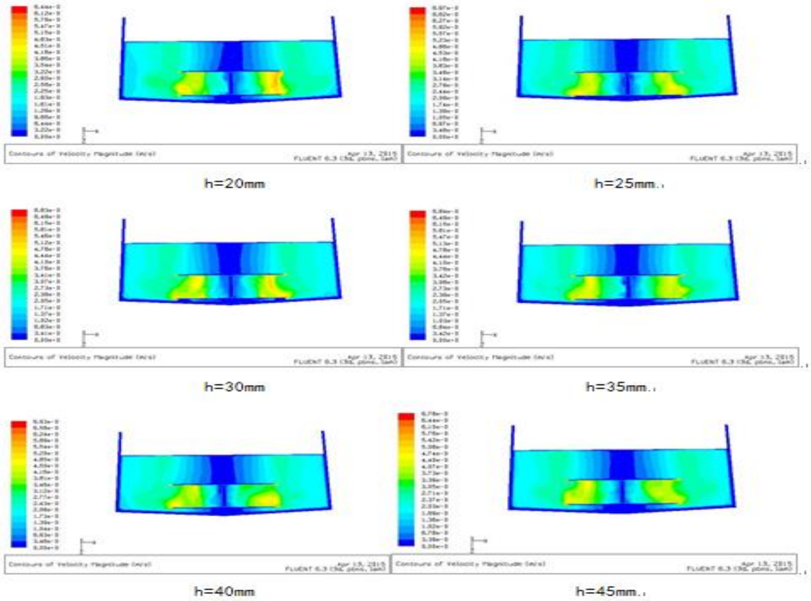

Fig. 8 The Mixing Flow Field under Different Distance between Stirrer and Bottom of Barrel

Fig. 8 illustrates that, when the distance is less 25mm, the speed around stirrer is low and non-uniformly distributed; when the distance equal than 35mm, there are weak mixing flow areas to influence the effect of mixing; however, when the distance is exactly 30mm, there is a good mixing effect.

Mixing speeds of 1.5rad/s, 2.5rad/s, 3.5rad/s, 4.5rad/s, 5.5rad/s and 6.5rad/s are selected to make simulation analysis, the simulation results being shown in Fig. 9.

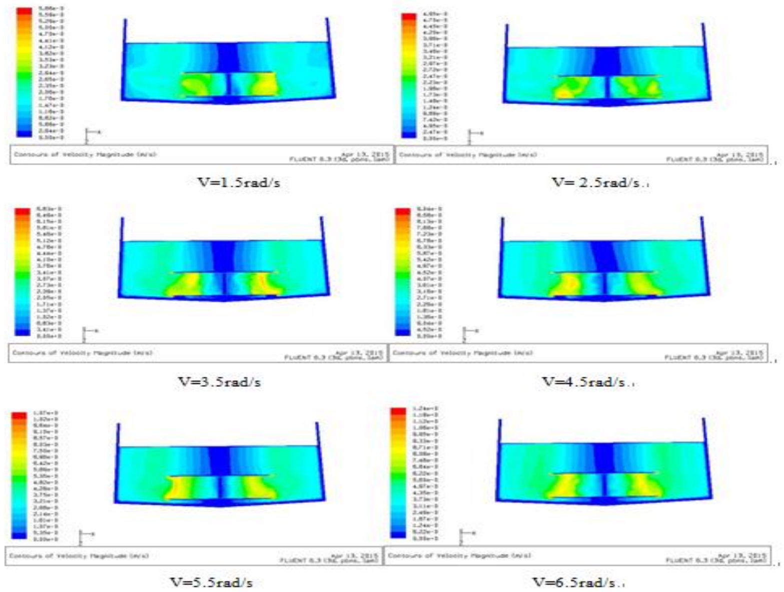

Fig. 9 The Mixing Flow Field of Different Mixing Speed

As shown in the above picture, with increasing mixing speed, the distribution speed of each point of liquid in mixing bucket also rises, however, there is no large effect on flow style of the mixing flow field. As the increasing rotate speed will increase mixing power, so in this article, we choose mixing speed of 3.5rad/s.

6. Performance Test

6.1 Material and Method

6.1.1 Test material and equipment

Milk, Accurate calf feed machine, notebook computer, stopwatch, ear tag, electronic balance (produced by Shanghai Southeast Weighing Apparatus Co., Ltd with maximum value of 30kg and division value of 10g).

6.1.2 Evaluation indicator

Feed stability is described with coefficient of variation that could be calculated with equation (4).

$$\mathrm{CV} = \mathrm{S}/V \tag{4}$$

Where,

CV-Coefficient of variation;

S-Standard deviation of sample;

V-Mean value of sample.

Feed accuracy indicator is described with relative error that could be counted out with equation (5).

$$\delta = (M - M_0) \times 100\% / M_0 \tag{5}$$

Where,

δ-Relative error, in percentage (%);

M-Practical feed weight, in kilogram (kg);

M_0-Target feed weight, in kilogram (kg).

6.1.3 Test arrangement

Firstly, the feed quantity of peristaltic pump at rotate speed of 500r/min under various pulses should be measured to fit a feed model. Then we could use this feed model to measure practical laying-off and further figure out the feed accuracy under this model. The feed accuracy can be calculated from practical and target laying-off. The feed efficiency could be worked out from setting different feed quantity and time.

6.2 Results and Discussion

The feed quantity measured through test under various pulses is shown in Table 2, and the feed trend and average quantity variation trend is shown in Fig. 10 and Fig. 11.

Table 2

The Material Quantity under Different Pulse

Pulse	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	Avg. quantity
2465	2000	2005	2010	2015	2020	2015	2015	2015	2020	2010	2015	2015	2012.91
3081	2500	2500	2505	2505	2510	2510	2505	2500	2505	2500	2505	2505	2504.17
3697	3000	3005	3015	3005	3010	3005	3000	3005	3010	3015	3005	3010	3007.08
4313	3500	3510	3510	3510	3520	3515	3505	3500	3515	3510	3510	3500	3508.75
4929	4005	4005	4020	4015	4005	4020	4020	4000	4015	4005	4015	4005	4010.83
5546	4505	4505	4500	4510	4505	4515	4505	4500	4500	4505	4500	4500	4504.16
6162	5000	5005	5000	5000	4995	5015	5005	5000	5000	5000	5015	5010	5003.75
6778	5500	5500	5505	5505	5510	5505	5500	5505	5500	5500	5505	5505	5503.33

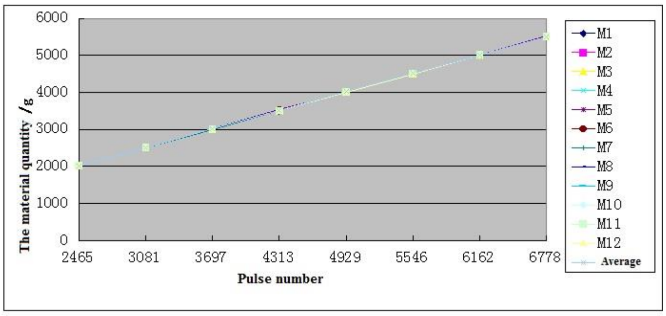

Fig. 10 The Trend Chart

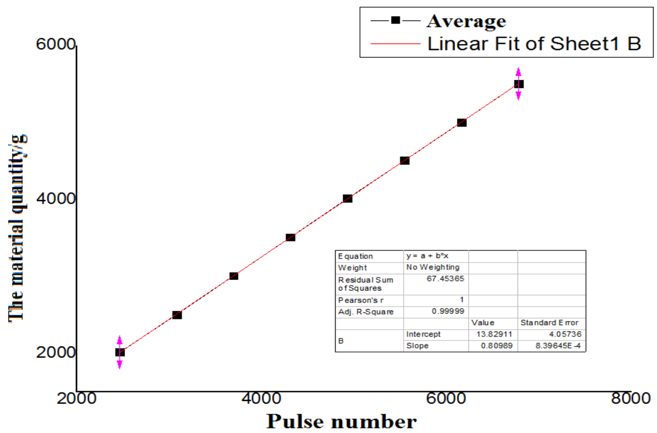

Fig. 11 The Trend Chart of Average Quantity

The above shows that there is linear relation between laying-off quantity and pulsed quantity variation. The Origin data analysis software is utilized to conduct curve fitting on such curve and get a unary linear regression equation:

$$Y=0.90989X+13.82911 \quad (6)$$

Where, X-Number of pulse; Y-Laying-off quantity, in gram.

According to physiological characteristics of calf, target feed quantity is set to be 3kg, 3.5kg, 4kg, 4.5kg, and 5kg. The laying-off quantity under various target values are measured as shown in Table 3, and the variation and error trends after repeated weighing for 10 times under various target values are shown in Fig. 12 and Fig. 13.

Table 3

The Feeding Quantity under Different Target Values

Target qty. (g)	Measurements（g）										Avg. feed qty. (g)
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	
3000	3005	3005	3010	3015	3010	3000	3005	3005	3015	3010	3007.27
3500	3510	3515	3520	3520	3515	3505	3500	3510	3510	3510	3510.45
4000	4025	4015	4005	4030	4020	4000	4005	4015	4015	4025	4014.09
4500	4505	4505	4500	4500	4505	4505	4505	4500	4500	4505	4502.72
5000	5000	4995	5015	5005	5000	5000	5000	5015	5010	5000	5003.63

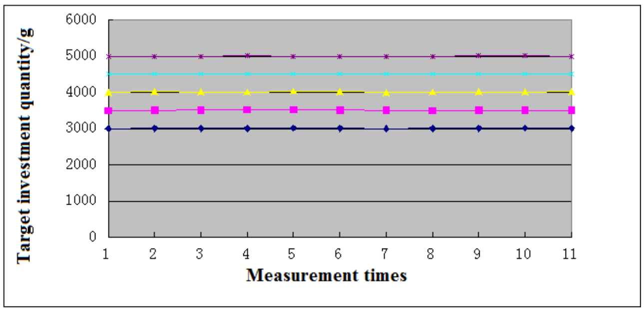

Fig. 12 The Chart of Variation Trend for Repeated Weighing for 10 Times under Various Target Values

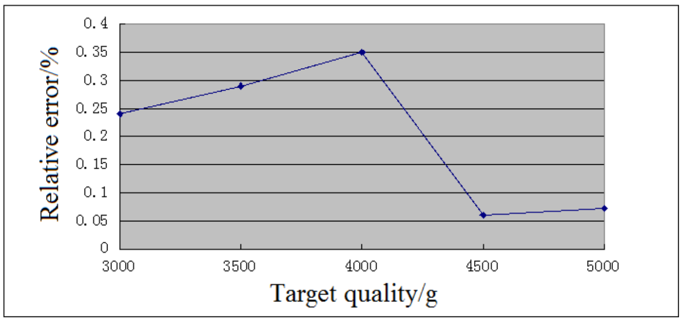

Fig. 13 The Error Trend Chart

The systematic feed coefficient of variation and average relative error is shown in Table 4.

Table 4

The Coefficient of Variation

Target qty.（g）	Coefficient of variation	Avg. relative error（%）
3000	0.0016	0.24
3500	0.0017	0.29
4000	0.0024	0.35
4500	0.0005	0.06
5000	0.0013	0.072

The feed time under various target value is measured as shown in Table 5.

Table 5

The Feed Time under Various Target Values

Target qty.（g）	Measurements (s)										Avg. feed speed（kg/s）
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	
3000	22.3	22.7	22.3	22.3	22.3	22.2	22.3	22.3	22.5	22.4	134.16
3500	26.0	25.9	25.8	26.0	25.9	25.8	25.8	26.0	26.0	25.8	135.14
4000	29.7	29.7	29.7	29.7	29.8	29.7	29.6	29.7	29.8	29.7	134.63
4500	33.4	33.4	33.6	33.5	33.6	33.6	33.4	33.4	33.6	33.6	134.29
5000	37.3	37.2	37.0	37.1	37.0	37.1	37.0	37.2	37.1	37.3	134.66

It could be concluded from above that, for feed under various target values, all feed relative errors are less than 1% which means feed accuracy no less than 99%，the maximum feed time is 37.1s and feed speed is 134.6kg/s. Both accuracy and efficiency could meet the requirements of accurate calf feeding.

7. Conclusions

(1) On basis of an analysis on processing flow of normal calf feeding milk, an isometric double pump head normal milk processing and supply system for accurate calf feeding was designed. The Solid Works software was used to conduct 3D modeling to the equipment, and Fluent fluid simulation software was utilized to simulate the mixing effect of normal milk processing system;

(2) The test results demonstrate that under rotate speed of 500r/min, the systematic feed accuracy is no less than 99%, the maximum feed time is 37.1s and feed speed is 134.6kg/s, which could meet requirements of normal milk processing and feed for fine calf feeding.

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Construction Corps(2015AB001), National fund program on commercialization of agricultural research findings(2010GB2G410603).

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