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Research Article

Shape Optimization of Rotor Blade for Pulp Pressure Screen Based on FLUENT

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Abstract: The study got two modified blades by changing the structure and shape of the rotor blade of the pressure screen. Pulp flow field in the same condition is numerically simulated by the fluid dynamics software FLUENT. The pressure distribution is showed especially in the location of the sieve drum circle. The ideal blade structure is obtained by the pressure field compared with conventional blades. It has strong cleaning ability and not easy to blockage sieve drum. The shape of the rotor blade is optimized. The blade shape is analyzed to the influence law of energy consumption. It is proved that the new rotor has energy-saving advantages. It is significant to improve the performance of pulp screening equipment. The theoretical support for select of blade shape of bars is provided by analysis of flow field.

Keywords: Analysis of flow field, CFD, FLUENT, influx sieve, rotor, sieve drum

INTRODUCTION

Pressure screen is a kind of pulp screening equipment. The rotor (Chen, 2006) is an important part of the pressure screen and plays a key role in the pulp screening process, the front of the rotor blades not only promote the pulp producing tangential velocity, but also put pressure on the sieve drum, increasing the pressure difference of the sieve drum's internal and external. But excessive pressure difference may let excessive pulp fiber flow through the sieve at the same time and then the sieve is blocked easily. By using the optimized shape of the rotor blade to prevent the sieve clogging, keep the sieve smooth, has a very positive sense in improving the continuity of production and production efficiency.

The early analysis data of fluid flowing phenomena mainly obtained through experimental study. But many flow problems are quite complex, involving many external environment factors, so the experimental results have large errors. And experimental analysis will spend a lot of financials, materials and humans sometimes, the cost of experiments is quite high.

CFD (Computational Fluid Dynamics) (Shi *et al*., 2005; Guo and Okamoto, 2003) is using the computer's numerical calculation of the physical phenomena such as gas flowing, liquid flowing and heat moving, visually display the results by using the images and then analyze the flow laws (Sun and Wang, 2008), Currently, the software of FLUENT is one of the most using software of CFD domestic and in the United States. Compared with other software, it has more comprehensive features, stronger applicability and widely used in a variety of fluid flowing, heat moving, burning and other issues (Zhou *et al*., 2010).

In this study, according to local transient characteristics of the flow field to establish the analysis of a simplified model of the flow field of the rotor blades, the pulp flow field was analyzed by using FLUENT (Qingwen *et al*., 2011). By changing the blade's shape, different flow field distribution can be got. Through analysis and comparison, an improved shade of the wing can be obtained. At the same time, the law of the impact of the blade's shape on energy consumption is studied, the advantages of the new rotor's energy saving is proved, the theoretical study of the screening equipment is deepened.

THE WORKING PRINCIPLE AND SIMULATION MODEL

The pressure screen's working principle and its basic structure: Pulp tangent into the cavity between the cylinder and sieve drum, rely on the of both sides of the sieve drum's pressure difference, qualified fiber of the pulp can flow into the sieve drum through the sieve seam (or sieve hole), discharged from the pulp out port of the lower part, the pulp residue staying in the outside of the sieve drum is discharged out from the tailings mouth under the pulp pressure and rotor's driving force. The high-speed rotation of the rotor have the effect of self-cleaning on the sieve drum.

The structure of pressure screen is vertical. It's mainly made up of base, sieve body, sieve cover, rotor components, drum sieve and other transmission-equipments, etc. Rotor and sieve drum components are

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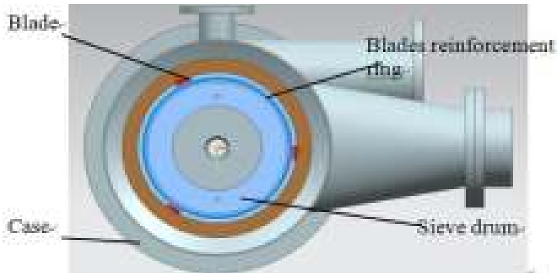

Fig. 1: Assembly relationship between the rotor and sieve drum, shell

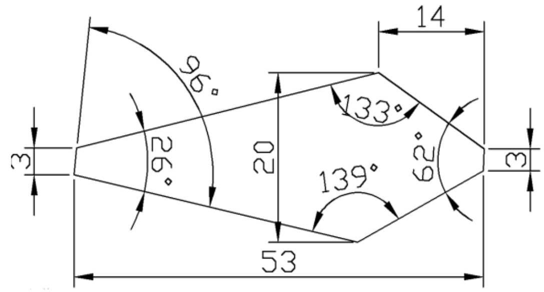

Fig. 2: Geometry of conventional rotor blade

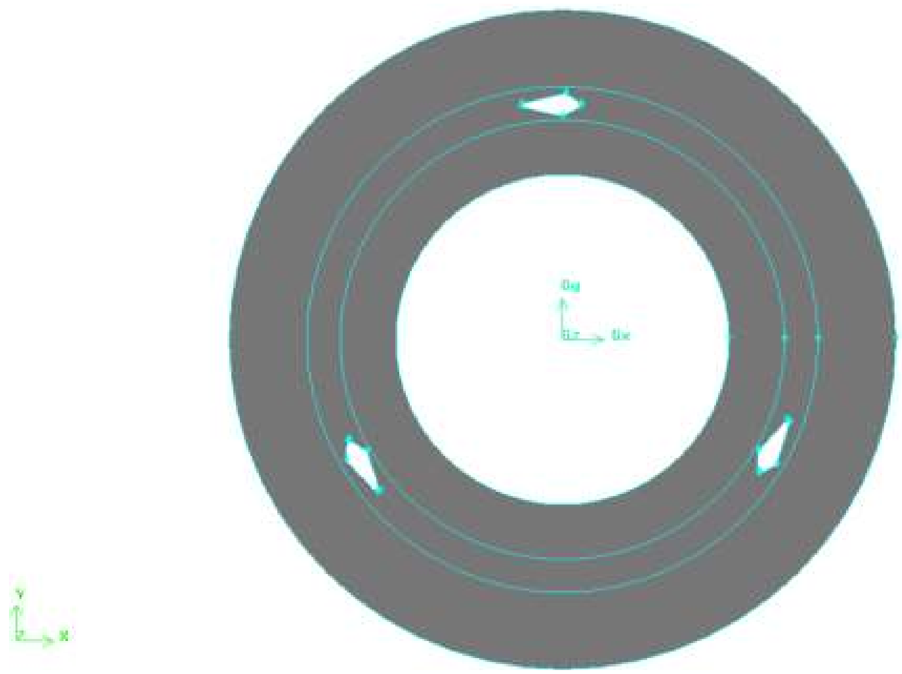

Fig. 3: GAMBIT model of the rotor

the main part of the screening system among them. Rotor is made up of the blade wheel, the blade holder, the blade, the reinforcing ring, etc. The positional relationship between the rotor, the sieve drum and the housing, is shown in Fig. 1.

Blades are located between the sieve drum and case. The fields between the sieve drum and case as well as between the sieve drum and inner case are filled with pulp, the pulp between the sieve drum and case is puree and the pulp located between the sieve drum and the inner case is the good pulp. Puree can be made into good pulp through the sieve slit into good pulp room under the action of the pressure difference between the import and export.

Analysis model of the flow field of the rotor blades: To HB1 screen as the research object, due to the geometry shade of the rotor on the entire rotor height unchanged, speed remains the same, the pressure difference inside and outside of the sieve drum is substantially unchanged and the density of the pulp is only from 0.4 to 1.2%, its density, viscosity, fluidity are approximated with water, the water will be used to simulate the calculation of the flow field, so the entire height of the pulp is the same. And the positional relationship between the pulp and the sieve drum. The case in the entire height of the rotor remain unchanged, the sieve drum and the case keep consistent in the vertical direction and does not consider the impact of the pulp's gravity, so the effect that the entire rotor to flow field can be reflected by two-dimensional model. Therefore, the cross-section of the horizontal position is taken to establish the physical model of the flow field analysis.

The size of the known structure of the conventional rotor blade is shown in Fig. 2. Import the AutoCAD model to the pre-processing software of FLUENT: GAMBIT, the imported model is shown in Fig. 3. The model totally forms three torus, the middle of the torus is a motion region constituted by the rotating together of pulp and blades under the function of the rotor, the other two torus are static areas.

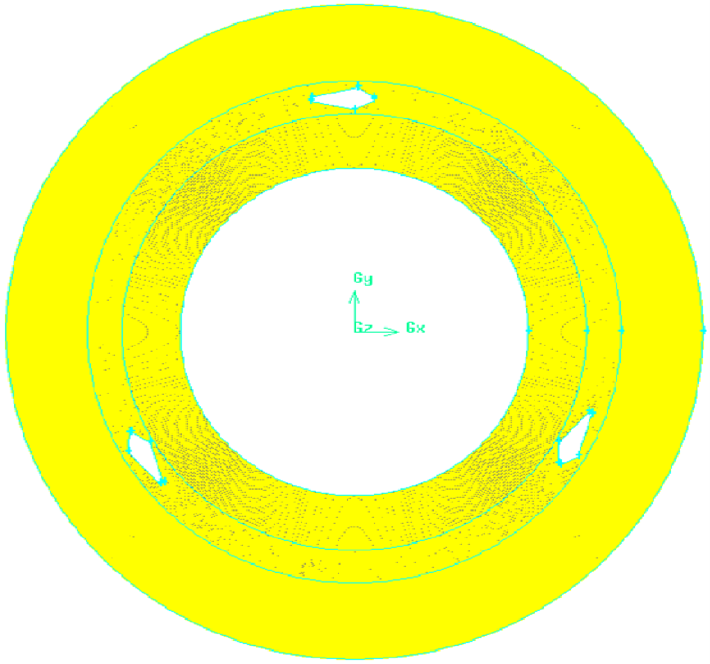

Fig. 4: Surface grid

GAMBIT is the preprocessing module of the software package, used to create geometric structures and generate the networks. Since the pulp has viscosity, taking the effect of near-wall viscosity into account, boundary layer mesh should be divided. And the region of the boundary layer mesh where has a large gradient change in flow parameters should be divided. Mesh is divided into two kinds of structures: structural and non-structural, in which the non-structural mesh's internal point contains the adjacent units, which make up for the defects of the structural mesh cannot solve the complex areas. Its outstanding advantage is the strong adaptability when face the irregular regions. Therefore, the non-structural mesh is used in the area where contains complex blades, the structural mesh is used in the other area. The mesh of the model is divided (Ammala *et al*., 2001; Fredriksson, 2004; Ju, 2004; Pescantin and Edwards, 2000) as shown in Fig. 4.

RESULTS, OPTIMIZATION AND DISCUSSION

The results and analysis: Through the calculation of the software FLUENT6.3.26, the situation in that the flow field is formed in the pulp in a certain speed is imitated in computer. The pressure distribution formed by the whole rotor, pressure field and velocity field distribution around the local single blade are included in the results of the simulations, the specific impact of the blade geometry to the flow field can be studied better. The distribution of the flow field as follows.

It can be seen that the distribution of the pressure surrounding the three blades are substantially consistent in Fig. 5. Generally speaking, the pressure of the pulp in the sieve drum is lower than the pulp outside sieve drum and then the different pressure of internal and external drum sieve is formed. Under the pressure, the puree becomes good pulp after flowing into the good pulp chamber through the sieve drum gap, that's the process of HB screen.

The pressure situation formed by a single blade is shown in Fig. 6. It can be seen from the nephogram that the maximum pressure is 8.93×104 Pa, the minimum pressure is -7.01×104 Pa. It is shown in the Fig. 6 that positive pressures indicated by red and green areas are mainly concentrated in the head of the blade. The largest positive pressure is in the top of the blade head and the positive pressure under the head is smaller, it's mainly in the range between 2.55×104~4.15×104 Pa. It is indicated that the front of the blade not only promote the pulp to produce a tangential velocity, but also add pressure on the sieve drum, which increased the pressure inside and outside of the sieve drum. But excessive pulp fibers flowing through the sieve at the same time can be caused by excessive pressure difference and then the sieve is easily to be clogged. So increasing the pressure excessively in front of the blade is unnecessary or even harmful.

It is shown in Fig. 7 that the curve of pressure value formed by three rotor blade in the circumferential direction of the sieve drum. The perimeter of the circumference is D = 1.3 m, the pressure formed in the position of each rotor is substantially consistent. All the values of minimum pressure are -2.0×104 Pa, the value

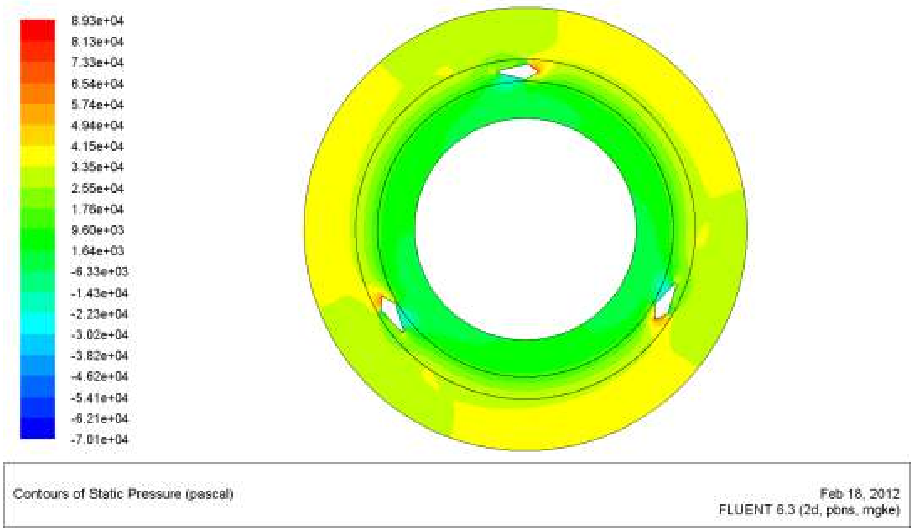

Fig. 5: Overall pressure distribution cloud

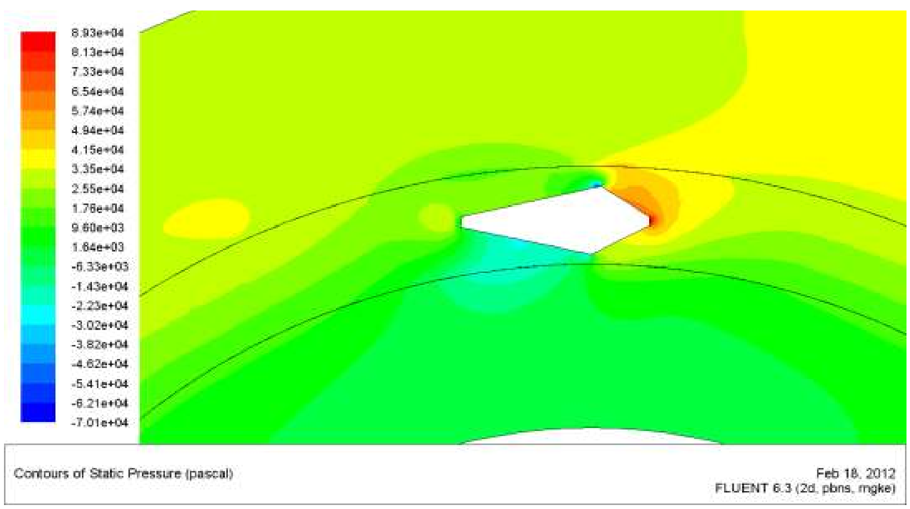

Fig. 6: Pressure distribution of a single blade

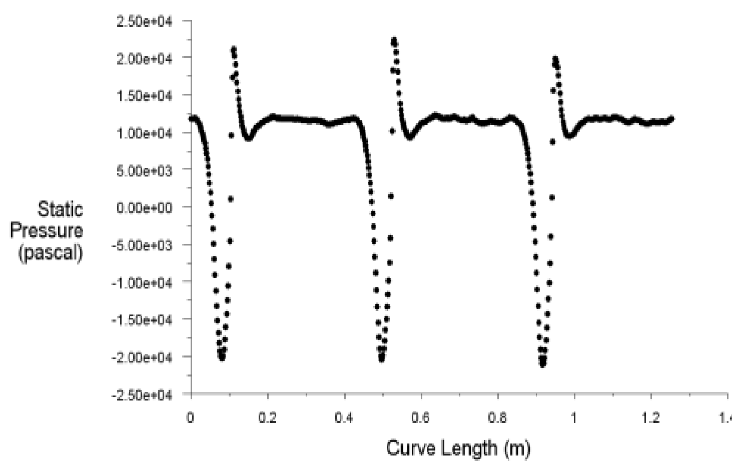

Fig. 7: Value of static pressure of the circumferential direction

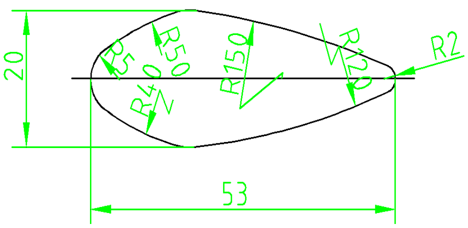

Fig. 8: The shape of the blade's structure in program 1

is the vacuum force of the sieve drum's surface cleaning, cleaning ability of the rotor is characterized by it.

The first program of the optimization: After the rotor's rotating in the pulp liquid is considered, the shape of the rotor blade is changed into streamline, then the resistance of the head-flow can be reduced and the energy can be saved. The sectional shape of the blade of the first program is shown in Fig. 8. It is shown in the that the blade's size of the structure does not change basically, the angular of the blade are changed into the transition of circular arc.

Through the calculation of the software FLUENT 6.3.26, the distribution of pressure formed by the whole rotor is shown in Fig. 9.

It is shown in Fig. 10 that two regions are also formed by the rotation of the improved blade rotor in the pulp: the positive pressure area of the blade's head and the negative pressure area of the tail. The maximum positive pressure is 7.39×104 Pa, the minimum negative pressure is -2.82×104 Pa. Compared to the previous

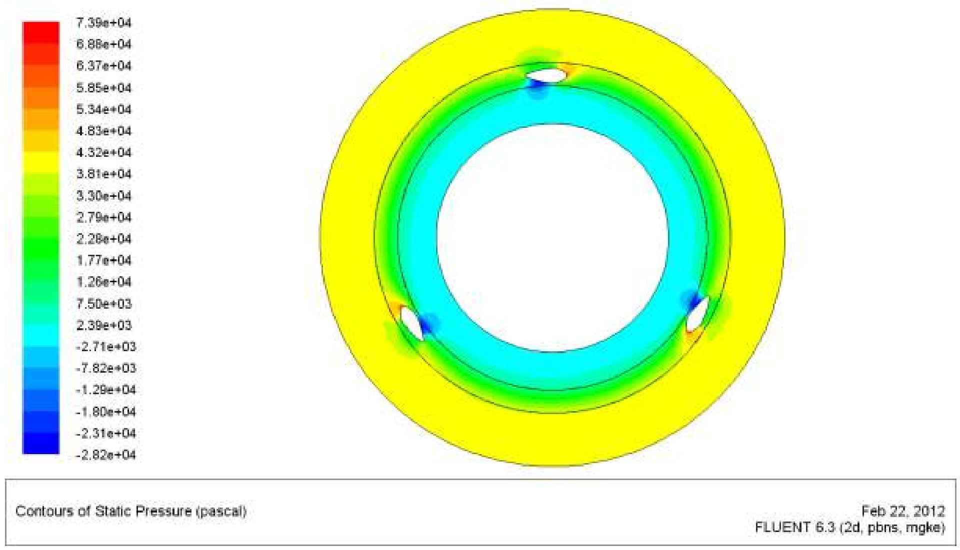

Fig. 9: Whole distribution cloud of pressure of the optimized rotor 1

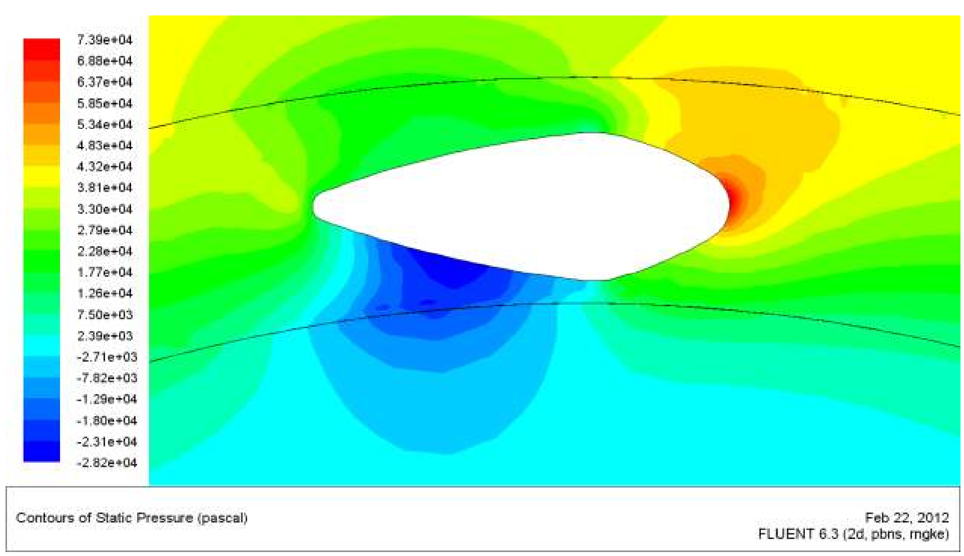

Fig. 10: Single blade's distribution diagram of pressure of the optimized rotor 1

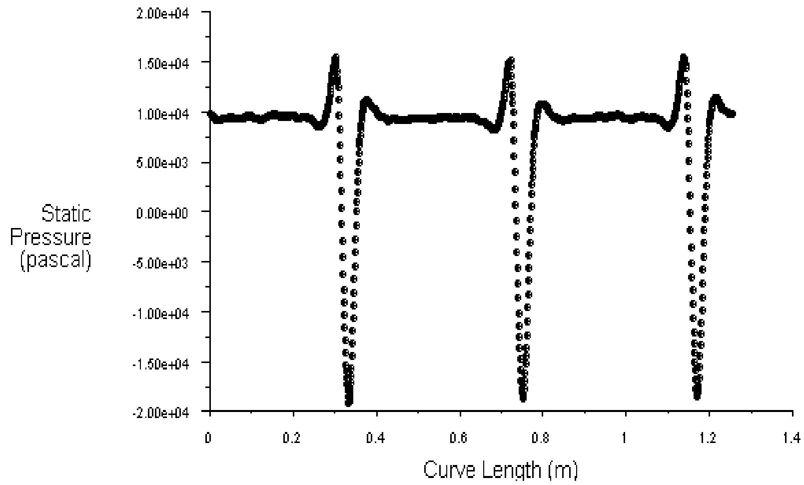

Fig. 11: Value of static pressure of the improved rotor 1 along the circumferential direction of the surface of the sieve drum

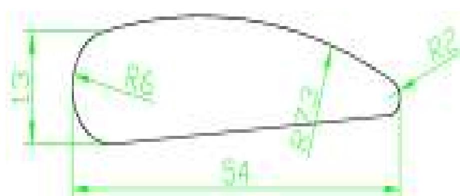

Fig. 12: Program 2's shape of the structure of the blade

rotor, in the improved rotor 1, the positive pressure area in the head are decreased, while the negative pressure area is increased. It reduces the resistance of head-flow and achieves the purpose of energy-saving. At the same time, the vacuum force of cleaning the surface of the sieve drum has also been enhanced.

But the value of pressure formed by the rotor in the whole surface of the sieve drum on the circumference is shown in Fig. 11. It can be seen that the minimum value of pressure is -2.0×104 Pa. It can also been indicated that the cleaning ability of the rotor has no change. It can be explained that by changing the shape, more negative pressure zone can be got, but it changes a little when applied to the surface of the sieve drum. So it is necessary to improve the shape of the structure of the blade further, the tail of blade should be closer to the surface of the screen drum.

The second program of the optimization: The circular arc transition of linear flow is retained, the size of the rotor's head is thinner, the positive pressure formed by the blade head reduced further. Due to more negative zone can be formed by improving the tail of the rotor in program 1, but its effect to the surface of the sieve drum is nearly the same as the unmodified, so it's better to make the tail became slim and closer to the surface of the drum sieve. The shape of the structure of the blade improved is shown in Fig. 12.

The whole distribution of the pressure formed by the entire rotor is shown in Fig. 13. The figure of partial enlarged pressure formed by a single rotor is shown in Fig. 14.

The pressure-distribution formed by rotor improved further is shown in the Fig. 14, in which the maximum value of positive pressure is 6.96×104 Pa, the minimum value of negative pressure is -2.98×104 Pa. And the zone of positive pressure narrows further, the zone of negative pressure increases further, which will be conducive to improve the effect of screening. The curve of the vacuum pressure-value formed by the surface of the sieve drum is shown in Fig. 15.

In Fig. 15, the minimum value of pressure representatives of the cleaning ability is -2.5×104 Pa, it shows that the cleaning ability of the rotor has been improved further. So the rotor has a better effect of screening compared to the previous two kinds drum sieves, the drum sieve is difficult to plug, the ability of continuous production is stronger and can save the energy.

The effect of blade's shape to energy consumption: When the rotor whirls in pulp, it must overcome the resistance of the head-liquid first and do work, overcome the frictional force of viscosity of the liquid and do work at the same time. How much work is done corresponds to the level of energy consumption of the rotor, while the energy consumption is a very important indicator of the rotor's performance. It is particularly important that reducing the energy consumption and pursuing the better economic benefits, especially in the increasingly fierce competition in the economic, the energy costs gradually increased.

There are many factors affecting the energy consumption of the rotor, the effect of the shape of the rotor's blade to the energy consumption will be studied in this section. Leave the traditional rotor and

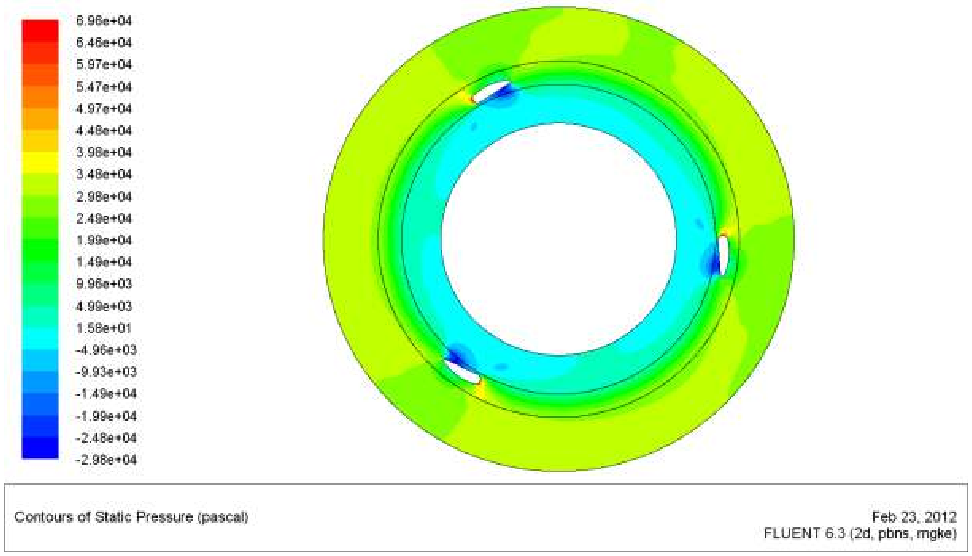

Fig. 13: Whole distribution cloud of pressure of the optimized rotor 2

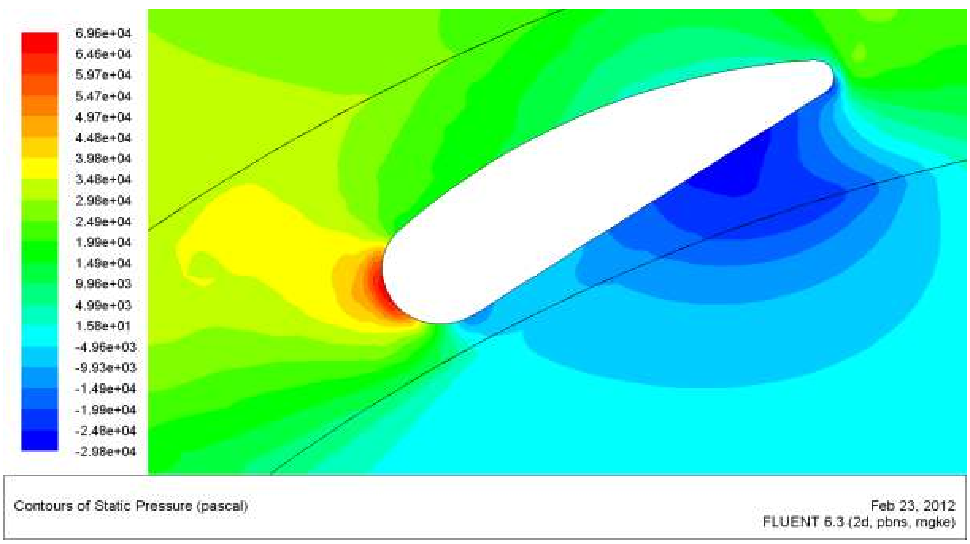

Fig. 14: Single blade's pressure distribution diagram of optimized rotor 2

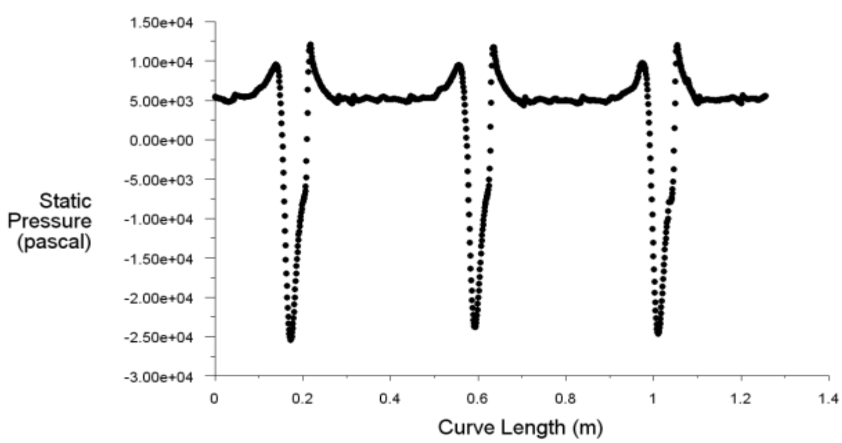

Fig. 15: Curve of the static pressure of the optimized rotor 2 along the circumferential direction of the sieve drum's surface

Table 1: Rotor's torque of a variety of blade's shape

The shape of the blade	Resistance torque (N*m)	The torque of viscosity (N*m)	The total torque (N*m)
The traditional rotor	388.0	20.5	408.5
The improved rotor 1	295.9	76.6	372.5
The improved rotor 2	262.0	81.9	343.9

the improved rotor as the objects of analysis and other parameters unchanged. By setting the same speed, you can see the moment of resistance formed by the pulp to the rotor at the same rotational speed.

The reference values of the movable region should be set first after the calculation of the FLUENT. The physical quantities which should be set are area, the density of the pulp, depth, length, line speed and viscosity, etc. The area is (□r22-r12) = 0.04 m^2; the density of the pulp is the density of water: 998.2001 kg/m^3; the depth is the height of the rotor: 0.5 m; the length is the circumference of the rotor: 1.4 m; the linear velocity is 20 m/s; the viscosity is 0.001003. And then view the rotating torque formed by the center of rotation. The torque which is needed to be overcome in the case of a certain speed of the three rotor-blades is shown in Table 1.

It can be seen from the table that how much the resistance torque, the viscosity torque and the total torque need to be overcome by the three kinds of rotor. And it can be seen from the table that the resistance torque reduced continuously. This is due to the improvement of the rotor, the thickness of the head of the blade decreases continuously. But the viscous torque is increasing continuously. This is because the linear flow of the blade is enhanced continuously by the improvement of the rotor. During the rotation, due to the surface area in contact of the pulp and the blade is increased continuously, the power needed to overcome the frictional force increased naturally. But the total torque decreases continuously with the improvements of the shape of the rotor's blade. It is indicated that the rotor has the effect of energy-saving with the improvements of the blade's shape.

Since the power P = torque T × angular velocity ω, while the angular speed of the three kinds of the rotor are the same. The calculation of reduction rates of the energy consumption that improved rotor 2 compared to the traditional rotors are as follows:

$$\frac{\text{The torque of traditional rotor-The torque the improved rotor 2}}{\text{The torque of traditional rotor}} \times 100\% = 15.8\%$$

So the rotor 2 whose shade is improved can save the energy consumption about 15.8% compared to the traditional rotor. And the purpose of reducing energy consumption can be achieved by improving the shape of the blade. It is also showed that the improved rotor 2 is also better than the conventional rotors in terms of energy consumption.

CONCLUSION

In this study, the structural characteristics of the pulp pressure screen is analyzed, the geometric model of the rotor's blade is established. And the flow field's analysis model of the rotor's blade is constructed according to the flow characteristics of the pulp. The distribution of pressure formed by the traditional rotors in the pulp is simulated by FLUENT, the whole pressure cloud and the pressure-curve formed in the surface of the sieve drum are obtained. In order to improve the screening effect of the rotor, the cross-sectional shape of the rotor's blade are improved, two new rotors are obtained. After the calculation and simulation of FLUENT, two pressure fields of new rotors in the same conditions are obtained. A shape of the blade which has a good screening effect can be obtained after comparing to the traditional rotor. After the effect of the blade's shape to the energy consumption is analyzed, the new rotor has the advantages of reducing energy consumption and increasing production capacity is proved. An effective means and theoretical guidance provided for the optimal design of the pulp screening equipment by the flow field analysis, which have an important significance to improve the using performance of the pulp screening equipment.

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