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Study of a Bionic Paddy Impeller Inspired by Buffalo Hoof

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Abstract

Based on the particular geometric characteristics of buffalo hoof, which is capable to walk on the soft soil of paddy-field with low resistance, a bionic blade for paddy field impeller was designed. The test results in soil bin show that the traction ability of the bionic blade for paddy wheel is improved. Compared with the conventional plate blade, the maximum pull force of the bionic blade is increased by 37.8% and the maximum impeller efficiency is 38.3% higher. Computational simulation analysis shows that bionic shape can improve the driving force of the impeller by resisting and reducing the impacts resulted from the sharp velocity change of the discontinuous surface water flow, and the driving torque of the bionic blade may increase as well.

Keywords: buffalo hoof, bionic blade, paddy impeller, computational simulation, orthogonal test

1 Introduction

Paddy impeller is the most important driver type and the main driving component in paddy cultivation operating. The impeller blade is the basic driving component whose working surface directly contacts the paddy soil to get driving force and carrying capacity, therefore its working surface parameters strongly influence the impeller traction capability. The main types of paddy impeller blade in China are straight plate, involute and hyperbolic teeth-surface shape, *etc*. However, the traditional design method can't greatly improve the capability of paddy impeller[1].

In nature, several animals are very capable to walk on soft soil, such as buffalo, which have attracted the attentions of researchers and inspired engineers to design machines that are capable to walk on soft soils, such as paddy-field impeller[2,3]. The buffalo hoof has developed special shapes during million years. Yang *et al*. studied the performance of a tractor with walking wheel by imitating the animals walking posture. The bionic walking wheel may improve the traction efficiency of the tractor by 17%[4]. Lu investigated the buffalo gait and the movement parameters by high-speed camera, which may provide the guidance for ambulate machinery design[5]. Using reverse engineering technology, Li *et al*. conducted a study of three-dimensional geometrical modeling of the exterior configuration of a cattle hoof[6].

In this research we developed a bionic blade for paddy impeller which is inspired by the special shape of buffalo hoof. Experiments were conducted in a soil bin and computer simulation was carried out. Both experiment and simulation results show that the performance of the designed bionic blade is much better than that of commonly used plated blade.

2 Extraction of bionic analog information

After many years of evolution, buffalo hoof has developed a geometric shape suitable for walking on the paddy field and other soft soil. Tests found out that buffalo walks in the paddy field using symmetrical gait, and the four hoofs hit the ground separately. High-speed photography found that the hoofs usually hold support

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and swing in each motion cycle. The paddy-field impeller's operating manner and the walking action of buffalo hoof have some comparability. The reasons why buffalo hoofs are suitable for walking on the paddy field are not only due to its reasonable gait but also the geometric characteristics at the bottom and in the front of buffalo hoof, which makes buffalo achieve bigger driving force and less walking resistance.

The authors acquired 3D surface point group data of a buffalo hoof by using a 3D scanner laser instrument and reconstructed the 3D geometric curve model of buffalo hoof. The profile of the front part of the buffalo hoof is extracted as the first bionic information; and the bottom surface, which is similar to the paraboloid features, is the second bionic information. The blade was designed in respect to the bionic information. Two pictures of buffalo hoof are shown in Fig. 1, from which we can see the shape of the out edge. The hoofs' geometric shape is illustrated in Fig. 2, which is helpful in reconstruction of the outline of the bionic blades. We can also see the curvature changing point, which is the most important factor affecting the driving force and walking resistance.

Fig. 1 Profile of the cattle hoof geometrical surface.

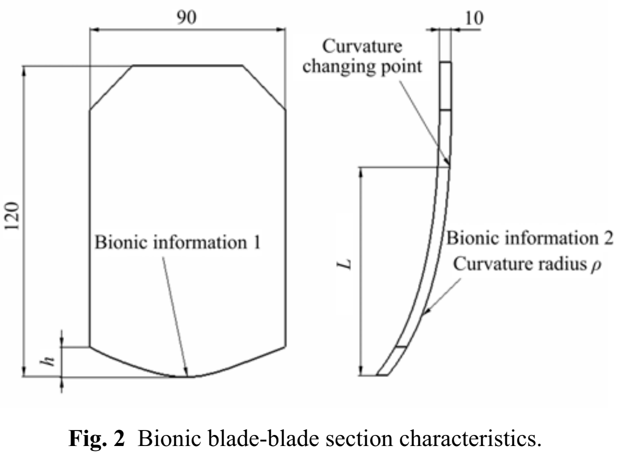

Fig. 2 Bionic blade-blade section characteristics.

3 Bionic impeller in a model soil bin test

3.1 Test systems design and conditions

The Test-Bed of Paddy Field Impeller (TBPFI) includes a set of Small Soil Bins (SSB) and a measuring system. The dimension of the Model Soil Bin (MSB) is 1800 mm × 350 mm × 400 mm, and is made up of high strength plexiglass for facilitating to observe the interaction between soil and impeller.

The impeller is set on the upper part of the MSB by a stand. As shown in Fig. 3, the impeller shaft is driven by a step motor through the reducer. In order to get the blade into different depths in soil, the lifter is set on the stent to make the MSB fluctuate sideways. The different impeller slip rates are gotten by setting the horizontal movement. A octagonal ring transducer is laid out on the upper side of the blade for measuring the tangential and normal forces of the blade, then the wheel axle is pasted on the strain gauge due to rotating[7,8]. The blade receives soil reaction forces (tangential force and normal force signal) and the torque signal of wheel axle which are transferred and processed by Virtual Instrument (VI) system and stored in relevant format, then the pulling force (P), the lift force (L), the impeller efficiency value are obtained through Eqs. (1), (2) and (3).

$$P = F_n \sin(\theta - \beta) - F_t \cos(\theta - \beta)\,, \tag{1}$$

$$L = F_n \cos(\theta - \beta) + F_t \sin(\theta - \beta)\,, \tag{2}$$

$$\eta = \frac{P \cdot V}{M_E \cdot \omega} = \frac{P \cdot \omega \cdot R_0 (1-i)}{M_E \cdot \omega} = \frac{P \cdot R_0 (1-i)}{M_E}\;. \tag{3}$$

F_n is the blade's normal force (N), F_t is the tangential force (N), θ is the impeller angle, β is the paddle's dip angle, R_0 is the radius of impeller addendum circle, i is track slip rate, ω is the wheel speed, M_E is the measuring wheel axle torque.

The test paddy field soil was taken from School of Changchun Academy of Agricultural Science and Research Institute. The physical properties and mechanical parameters of the paddy soil are shown in Table 1.