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Failure analysis of cavitation in a hydraulic loader

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ABSTRACT

Cavitation is one of the major failure modes in hydraulic loaders. The failure mechanism is related to damage induced by cavitation at the working surface. Moreover, the vibrations caused by cavitation reduce the efficiency of the unit and lead to irregular output. To further explore the cavitation-induced failure mechanism in hydraulic loaders, a vapor/liquid two-phase flow numerical calculation method was used to obtain the radial distribution of water vapor volume fraction in the internal flow field with different structural parameters of a prototype hydraulic loader. This method was also used to predict the intensity of cavitation under different conditions. It was found that with an increase of the stator and rotor blade angle, blade number and blade thickness, the water vapor volume fraction and intensity of cavitation reduced; however, with an increase of the stator and rotor vortex pit depth, water vapor volume fraction and cavitation intensity increased. Moreover, the clearance of the assembly had little effect on cavitation. The results of the numerical simulation are in good agreement with the experimental observations, which verifies the reliability of the calculation method for cavitation failure analysis of a hydraulic loader and provides a good basis for structure optimization.

1. Introduction

The mechanism of cavitation-induced damage on surfaces is highly complex. Most work in this field has focused on centrifugal pumps and turbines [1–3]. Ji and co-workers [4–7] studied the cavitation evolution around a propeller under unstable conditions by experiment and simulation, and obtained a relationship between the blade installation angle and the intensity of cavitation. They also assessed the pressure fluctuations and vibrations caused by cavitation, and found that when the blade installation angle was 18° and 35°, the pressure fluctuated sharply. Cavitation creates a vortex in the flow field. By increasing the depth of the boundary, the stability of the flow field can be improved. Pouffary [8] adopted a cavitation flow theory to study the effect of cavitation on the pressure distribution of the internal flow field and head of a pump. The experimental results verified the accuracy of the simulation and revealed a trend between the number of cavitation bubbles and the failure of the pump. Liu [9] used two-phase flow cavitation theory to simulate the effect of cavitation on the pump performance and compared experimental and simulated results. Liu demonstrated that the diameter of the bubble affects the volume fraction of the vacuole phase. Coutier-Delgosha [2], Rossetti and co-workers [10–14] investigated cavitation on a curved blade and the effect of flow rate and cavitation coefficient on the pump performance. Chou and co-workers [15–17] reported for wind and hydro-power turbines, that the major failure types of the machinery in contact with the liquid phase were cavitation, corrosion, and fatigue.

The hydraulic loader is a key piece of equipment in heat-recovery-type liquid nitrogen pump trucks. It is mostly used to load the engine to provide constant heat to the system. The conventional approach to study hydraulic coupling machinery relies on estimations

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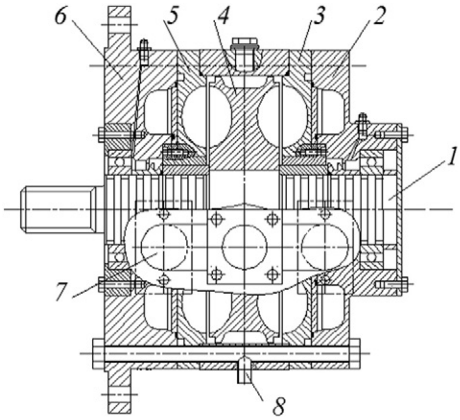

Fig. 1. A 2D diagram of the hydraulic loader used in the simulations. 1. Principal axis; 2. right bearing shell; 3. right stator; 4. rotor; 5. left stator; 6. left bearing shell; 7. inlet; 8. outlet.

based on empirical measurements. This method cannot solve all problems that occur during operation such as the fracture of the stator of rotor blades, or vibration of the unit. Therefore, a new and more effective method is urgently needed to improve the cavitation performance of hydraulic loaders.

2. Numerical model

This paper studies on cavitation. The result of cavitation is to produce a lot of bubbles in the liquid. When the local pressure is lower than the water vaporization pressure, bubbles are produced in the water. Within a very short time, air bubbles are formed (which contain water vapor) and subsequently implode rapidly (i.e., transient cavitation). A higher fraction of water vapor indicates a greater number of air bubbles and more severe cavitation. Therefore, the water vapor volume fraction is used to reflect the occurrence of cavitation and cavitation intensity [19].

Cavitation process is unsteady in theory, but the unsteady calculation needs larger memory and takes more time. Steady calculation can also reflect the status of cavitation. So the mixture model for steady vapor/liquid two-phase turbulent flow is used to analyze.

The internal flow field in hydraulic loader is three dimensional incompressible. Because the internal structure of hydraulic loader is complex and easy to cause separation, the internal flow is turbulent for processing. This article uses the SST (Shear Stress Transport) turbulence model which is applicable to revolver. The advantage is that taking into account the turbulent shear stress, which will not cause excessive prediction to eddy viscosity. Its transport behavior can be obtained by eddy viscosity equation includes limited number. The turbulent eddy viscosity is defined as follows [20]:

$$\upsilon_t = \alpha_1 k / \max(\alpha_1 \omega, SF_2) \tag{1}$$

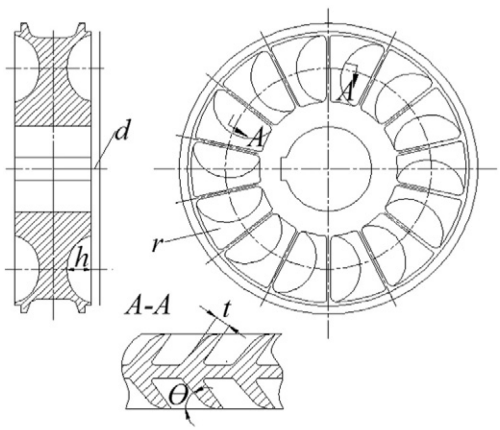

Fig. 2. Rotor structure. r, Rotor blade number; s, stator blade number; θ; blade angle; t, blade thickness; d, assembly clearance between rotor and stator; h, vortex pit depth.