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Scale-resolving simulations and investigations of the flow in a hydraulic retarder considering cavitation

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Key words:

Scale-resolving simulation, hydraulic retarder, cavitation, unsteady flow

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Research Background

- Cavitation has a significant influence on the accurate control of the liquid filling rate and braking performance of a hydraulic retarder.
- Up to now, scholars have been devoted to the simulation of the flow field inside a hydraulic retarder, laying the foundation for our research to investigate the flow field considering cavitation.
- Previous studies of the flow field in hydraulic retarders have provided insufficient information in terms of considering cavitation.
- Hence, in this study, the volume of fluid method and a scale-resolving simulation were employed to numerically calculate and analyze the flow field in a retarder considering the cavitation phenomenon.

Computations method

Volume of Fluid method + Turbulence method with cavitation model

- **Cavitation model**

The first of this study is properly accounting for the bubble growth and collapse. The bubble dynamics equation can be derived from the Rayleigh-Plesset equation.

$$R_b \frac{d^2 R_b}{dt^2} + \frac{3}{2}\left(\frac{dR_b}{dt}\right)^2 = \frac{p_b - p}{\rho_l} - \frac{4\nu_l}{R_b}\frac{dR_b}{dt} - \frac{2\sigma}{\rho_l R_b} \quad (1)$$

The p and p_b in equation (1) are the internal and external pressures of the bubble. R_b is the radius of a bubble, v_l is the kinematic viscosity of the oil phase, ρ_l is the density of the oil phase, and σ is the tension coefficient of the oil-air surface.

Simulation results and discussion

☐ Model verification

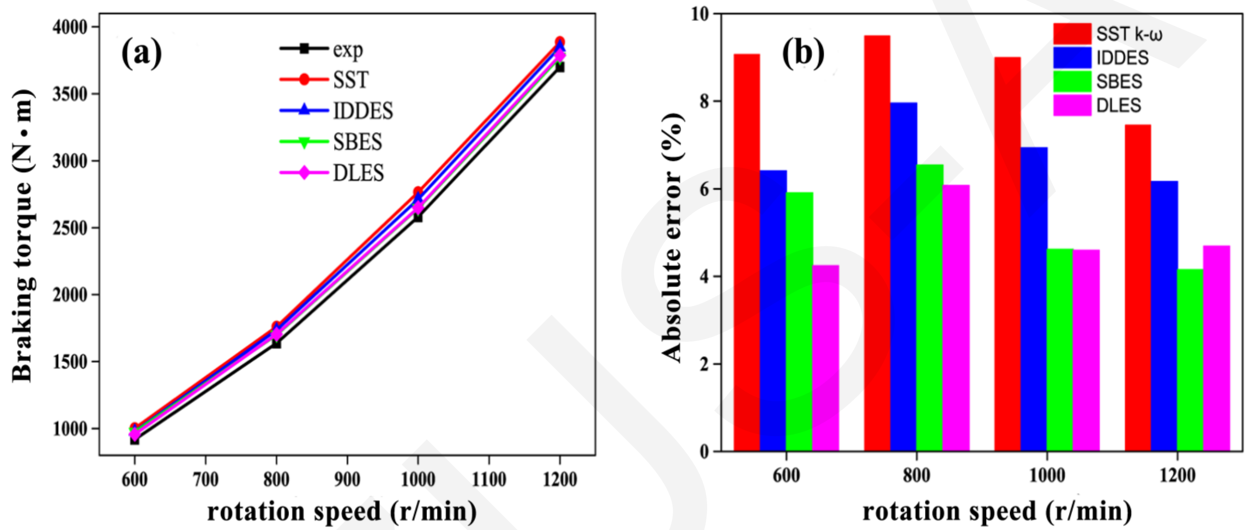

Fig. 1 Comparison studies between the simulation and experimental data for different models. (a) is the braking torque values and (b) is the errors between different models.

- Firstly, the error values of all models are within 10 % indicating that four turbulence models have good application prospects in engineering.
- Furthermore, the error values of the SST and IDDES models are larger than those of the SBES and DLES models. The DLES model is the most accurate model.

Simulation results and discussion

Analysis of cavitation flow

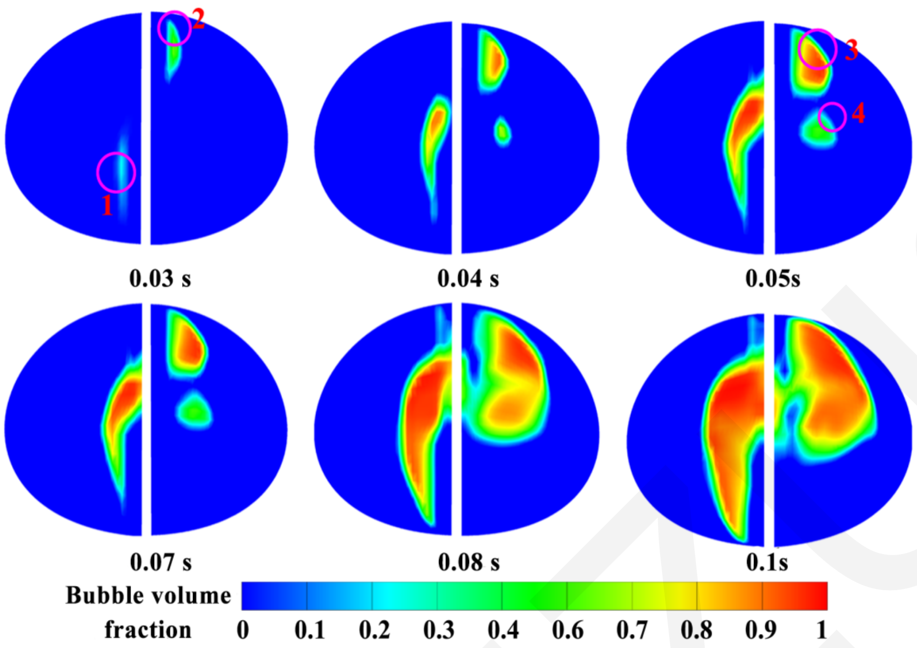

Fig. 2 Bubble volume fraction evolution cloud over time on the flow surface.

- The bubble volume fraction in the flow field is small at 0.03 s and the bubbles mainly exist in entrance area 1 of the rotor and entrance area 2 of the stator.
- Since the stator blades are stationary, the flowing fluid has a large pressure loss when the fluid impacts the entrance of the stator blade, the fluid also exhibits a decrease in pressure when flowing out of the stator passage to the rotor passage.
- The area 3 and 4 is the obvious bubble accumulating area, and two aggregating regions gradually expand over time.

Simulation results and discussion

Temperature variation of pressure blade

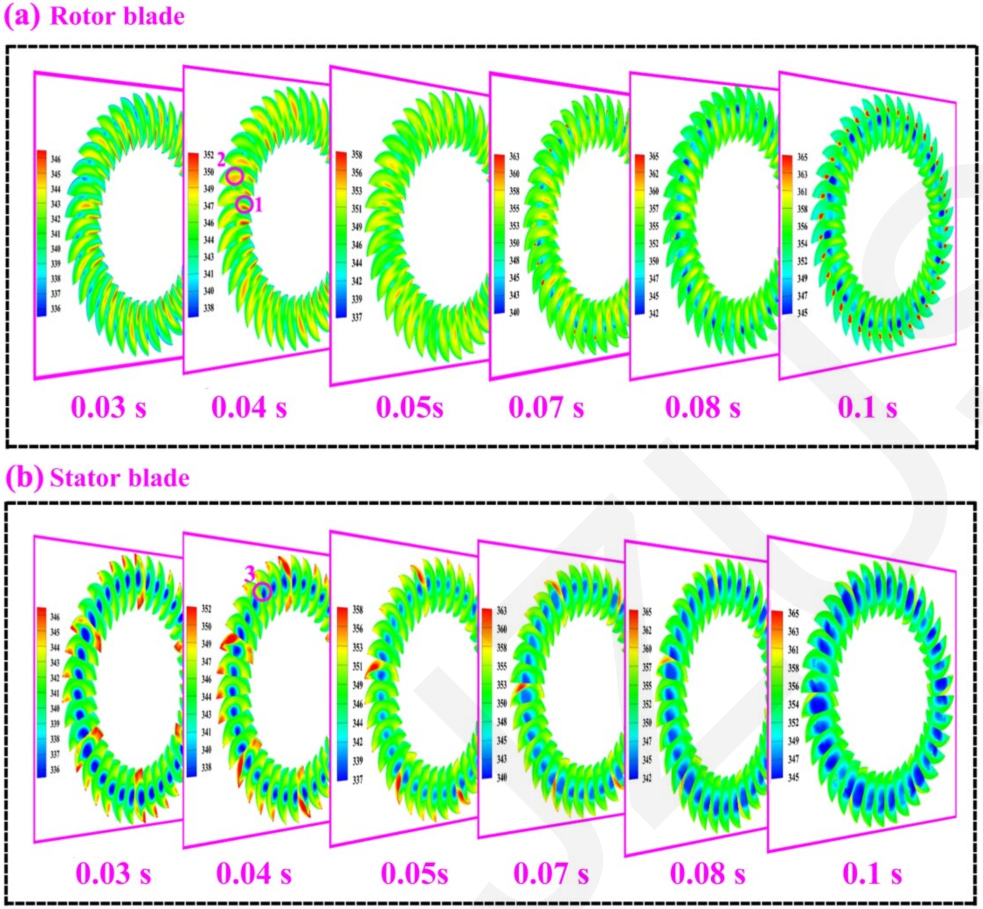

Fig. 3 Temperature evolution cloud over time on the pressure blades.

- Compared to the temperature changes at 0.03 s, the temperature changes at 0.1 s are more obvious.
- the highest temperature is in the rotor inner diameter entrance area 1, where there is a large amount of heat due to the fluid impact.
- The lowest temperature is located in the center of the flow surface, as shown in area 3. This area is the bubble accumulation area, and thus the temperature is the lowest.

Conclusions

- In the present study, the IDDES, SBES, DLES models in an SRS and the SST model in an RANS simulation were employed to simulate the flow field of a hydraulic retarder considering cavitation.
- In the model verification, The simulation errors of the SBES model and DLES model were within 4 % under all conditions, which shows the most accurate ability.
- From an analysis of the bubble volume fraction distribution, the center area of the flow surface, which was a low-pressure region, was the region where the bubbles precipitated. The bubble volume fraction increased over time, gradually affecting the steady of retarder.
- An analysis of the temperature variation of the pressure blades showed that the temperature in the central region of the blade was lower than that in the inner and outer ring regions.
- This study analyzed the flow field of a hydraulic retarder considering the cavitation phenomenon and laid a theoretical foundation for future optimizations of the retarder structure to improve the performance during operation.