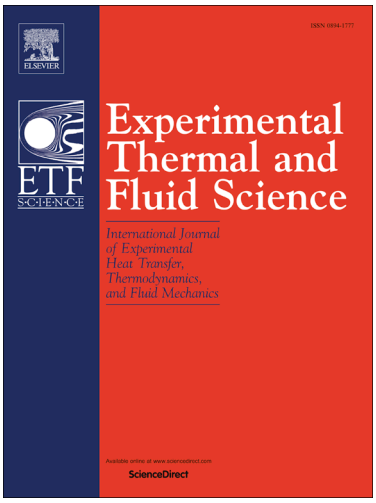

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Unsteady flow structure and its evolution in a low specific speed centrifugal pump measured by PIV

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Abstract: The intense fluid-dynamic interaction associated with the complex flow structure in the centrifugal pump is detrimental to the stable operation of the pump. Based on the particle image velocimetry (PIV) measuring technique, flow structures in a low specific speed centrifugal pump are measured and presented in detail. Emphasis is laid upon the complex flow structures around the volute tongue region, where intense rotor-stator interaction appears. Results show that the typical jet-wake flow pattern at the blade outlet is observed for flow rates lower than the nominal working condition, and the inflection point of the jet-wake region is found to be at the center of the blade channel. At high flow rate, the jet-wake flow pattern is not apparent due to the high momentum fluid concentrating on the blade suction side. Within the pump, several typical vorticity sheets (both positive and negative) are captured on the blade pressure and suction sides at high flow rates, while at low flow rates, the negative vorticity sheets on the blade suction side disappear due to the separated and reverse flow structures occurring. When the vorticity sheet sheds from the blade trailing edge, it would impinge on the volute tongue with subsequent cutting and distortion. Three typical interacting modes are observed at different flow rates, and the cutting effect of the volute tongue on the vorticity sheet is dependent strongly on the local absolute velocity distribution. At high flow rates, the cutting effect is more significant, and the entire vorticity sheets (positive and negative) would be cut and torn by the volute tongue.

Keywords: centrifugal pump, flow structure, vorticity distribution, PIV measurements

Nomenclature

Q_d	Nominal flow rate,m^3/h
H_d	Nominal head, m
n_d	Nominal rotating speed, r/min
n_s	Specific speed, $(rad\cdot m^{3/4})/s^{3/2}$
Z	Blade number
D_1	Impeller inlet diameter, mm
D_2	Impeller outlet diameter, mm
b_2	Impeller outlet width, mm
D_3	Volute inlet diameter, mm
D_4	Volute outlet diameter, mm
b_3	Volute inlet width, mm
β_2	Blade outlet angle, °
ϕ	Wrap angle, °
θ	Angle of volute tongue, °
U	Tangential velocity at the blade outlet，m/s
Ω	Vorticity magnitude, 1/s
x	Horizontal axis, mm
y	Vertical axis, mm
v	Absolute velocity, m/s
u	Tangential velocity, m/s
w	Relative velocity, m/s
r_0	Impeller radius at typical position, mm
L	Relative distance ratio to the blade pressure side
v_a	Time average absolute velocity, m/s
w_a	Time average relative velocity, m/s
u_a	Time average tangential velocity, m/s
v_a^*	Non-dimensional absolute velocity
w_a^*	Non-dimensional relative velocity
u_r^*	Non-dimensional radial velocity
Ω^*	Non-dimensional vorticity magnitude
Δt	Time interval, s

Introduction

For centrifugal pumps, the energy transport process and the excited response characteristics, such as vibration and pressure pulsation are closely associated with the internal unsteady flow structures[1,2]. Resulted from fluid-dynamic phenomenon, rotor-stator interaction between the rotating impeller and the stationary volute is detrimental to the stable operation of pumps[3]. Intense pressure pulsations characterized by the discrete blade passing frequency and the harmonics are finally generated[4]. For centrifugal pumps, the low noise and vibration requirements are becoming more strictly in some fields. With regard to that, it is really essential to clarify the unsteady flow structures and the induced excitation characteristics to effectively control the noise level of the pumps.

The internal flow structures in centrifugal pumps are really complex, because flow separation, vortex shedding, backflow and jet-wake flow pattern would easily occur at part flow rates[5]. When the fluid sheds from the blade trailing edge, it would interact intensely with the volute tongue and the volute casing wall[6]. So it is considered that the unsteady shedding flow structures from the blade trailing edge and the corresponding striking effect are crucial to the induced pressure pulsations of the pump.

With regard to flow structures in centrifugal pumps,

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