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# The effects of blade stacking lean angle to 1400 MW canned nuclear coolant pump hydraulic performance☆

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ABSTRACT

Canned nuclear coolant pump is used in the advanced third generation pressurized water reactor and is key equipment and unique rotating equipment in the first loop of a nuclear power plant. High efficiency, low power consumption, low axial force and low pressure pulsation are the significant hydraulic performance demanding to hydraulic components. Impeller is a key component of canned nuclear coolant pump. The blade stacking lean angle is one of the main geometric parameters in impeller design. Therefore, an investigation into the stacking lean angle to the canned nuclear coolant pump can be useful. In order to understand effects of stacking lean angle to canned nuclear coolant pump, this paper numerically investigated three different stacking lean angles. The validity of numerical simulation was confirmed through a comparison between numerical and experimental results. The performance change of canned nuclear coolant pump with the stacking lean angle was acquired. Hydraulic performance curve, axial force curve, static pressure distribution at impeller outlet and static pressure pulsation were performed to investigate the performance changes caused by the stacking lean angle. The results show that the stacking lean angle has important influence on the performance of canned nuclear coolant pump and should be paid attention to in the impeller design. Positive stacking lean angle is good for efficiency and reducing pressure pulsation in impeller. Negative stacking lean angle is good for increasing the head and reducing the axial force, while reducing pressure pulsation in static components.

## 1. Introduction

Reactor coolant pump used to circulate the coolant between the reactor and the steam generator, is key equipment and unique rotating equipment in the first loop of a nuclear power plant. Reactor coolant pump used in the advanced third generation pressurized water reactor is canned pump, called canned nuclear coolant pump. The hydraulic components located on the canned motor, which are composed of suction adapter, impeller, radial diffuser and annular discharge case. The structure sketch is shown in Fig. 1. The canned nuclear coolant pump for a currently planned 1400 MW power station unit (CAP1400) needs hydraulic components to produce the following data at rated operating point: $Q = 21642\,m^3/h$, $H = 111\,m$, $n = 1485\,rpm$. The impeller type is closed mixed flow impeller and specific speed $n_q$ is approximately 105 in Europe, $n_s$ is approximately 385 in china.

The flow rate is big, so the power consumption of canned motor is high. Canned motor efficiency is very low, so in order to reduce the motor power, the efficiency of prototype hydraulic components must be greater than 85%. Use water lubricating graphite bearings which in canned motor to balance the axial force of rotor, the axial force must be reduced to satisfy bearing capacity. Hydraulic axial force is the main source of the axial force of rotor, hydraulic axial force of prototype required to be less than 230000 N. Due to structural constraints, it can not use the external balance device for axial force balance which used in the ordinary centrifugal pump, and balance hole is forbidden too; so can only use the reasonable design of the impeller to balance. Under the condition of structure limited size, the design should to meet the requirements of both high efficiency and low axial force. At the same time, the hydraulic components should be run safety, so it is necessary to study pressure pulsation. High efficiency, low power consumption, low axial force and low pressure pulsation are the significant hydraulic performance demanding to hydraulic components. So it was decided to build a hydraulic model(Knierim et al., 2005) (on a scale 1:2.5) to make study, and the model pump rated operating data: $Q = 1385\,m^3/h$, $H = 18\,m$, $n = 1485\,rpm$.

The impeller design is the key to the canned nuclear coolant pump performance. Usually, the design of impeller comprises the following steps: (Lobanoff and Ross, 1985; Gülich, 2008) (1) Calculating the main

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**Nomenclature**

| | |
|---|---|
| Q | Flow rate $m^3/h$ |
| H | Head (m) |
| n | Rotation speed (rpm) |
| SLA | Stacking lean angle |
| ω | Angular velocity |
| Qr | Rated operating point |
| η | Pump efficiency (%) |
| P | Power (W) |
| Fa | Axial force (N) |
| $U_2$ | Impeller outlet circumferential velocity(m/s) |
| Fr | Axial force acted on rear shroud(N) |
| Ff | Axial force acted on front shroud(N) |
| Fi | Axial force of momentum (N) |
| Ft | Total axial force (N) |
| p | Static pressure (Pa) |
| $h^*$ | Static pressure coefficient |
| ρ | Density ($kg/m^3$) |
| fr | Rotating frequency(Hz) |

geometric parameters based on similarity coefficient and statistical data, then draws the meridian section of the impeller. (2) Selecting number of blades. (3) Calculating blade thickness based on structural strength requirements. (4) Design blade central profile. The blade central profile is formed by: (a) a number of streamlines at different span, which controlled by blade installation angle changing from leading edge to trailing edge; then the streamline wrap angle formed; (b) the streamlines array in the circumferential direction, which controlled by stacking. Usually different streamlines stacking starting angles are coincidence at trailing edge along span, so the blade shaping is decided by streamlines. Most of studies focused on design of streamlines (Fan et al., 2002; Goto et al., 2002; Varchola and Hlbocan, 2012; Bing and Cao, 2013), while less discussion the different stacking in circumference direction. The impeller is made of NC machining. And the blade profile is significant difference with different stacking. In order to meet both performance and processing, the 3D shape of the blade must be studied. So except study the streamline angle and wrap angle of blade, the blade stacking is must to study too.

In this paper, it will be investigate three different stacking lean angles impellers to show the influence of stacking lean angle to hydraulic performance of canned nuclear coolant pump. Based on numerical calculation to model pump, the change and difference performances in hydraulic performance curve, axial force curve, static pressure distribution at impeller outlet and static pressure pulsation were investigated.

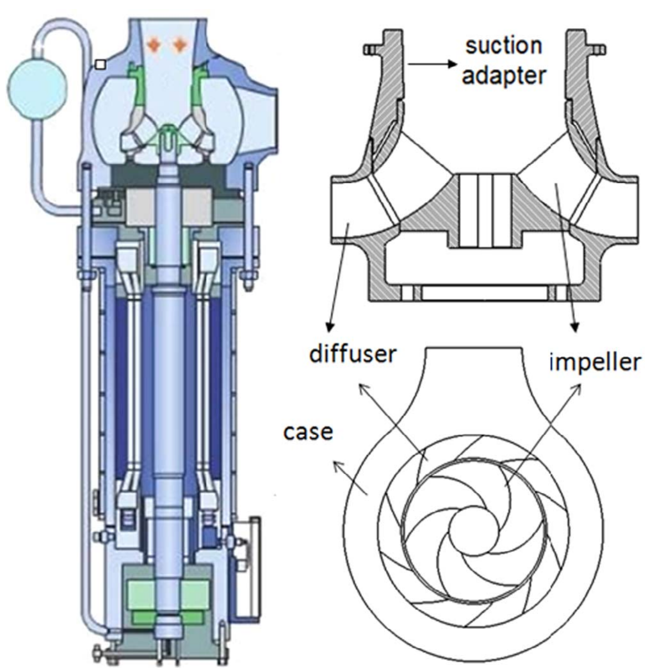


**Fig. 1.** Canned nuclear coolant pump hydraulic components.

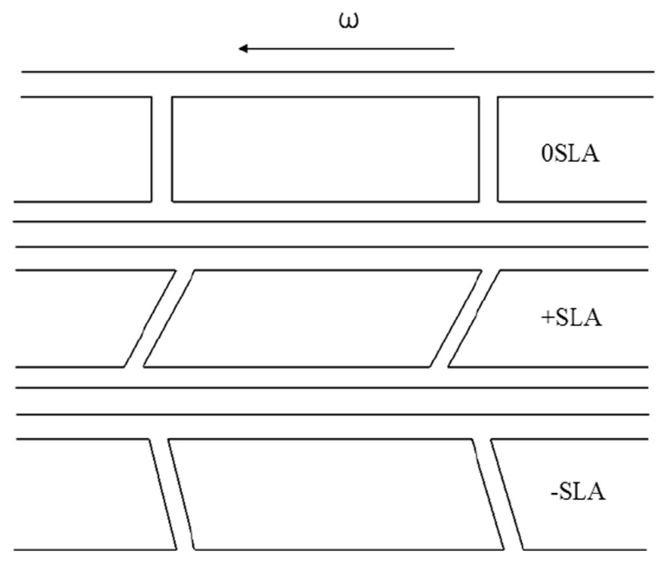


**Fig. 2.** Different stacking lean angle trail edge.

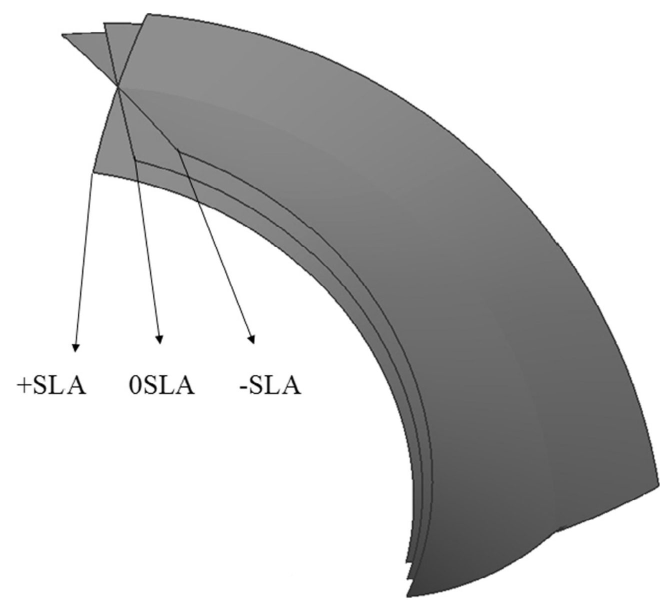


**Fig. 3.** Different stacking lean angle blade.

## 2. Geometry description

The different stacking starting angle along span in the circumferential direction produce different blade with same streamlines. We can do any stacking for every streamline, so different blade formed. But in