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Internal hydraulic analysis of impeller rounding in centrifugal pumps as turbines

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ABSTRACT

The use of pumps as turbines in different applications has been gaining importance in the recent years, but the subject of hydraulic optimization still remains an open research problem. One of these optimization techniques that include rounding of the sharp edges at the impeller periphery (or turbine inlet) has shown tendencies of performance enhancement.

In order to understand the effect of this hydraulic optimization, the paper introduces an analytical model in the pump as turbine control volume and brings out the functionalities of the internal variables classified under control variables consisting of the system loss coefficient and exit relative flow direction and under dependent variables consisting of net tangential flow velocity, net head and efficiency.

The paper studies the effects of impeller rounding on a combination of radial flow and mixed flow pumps as turbines using experimental data. The impeller rounding is seen to have positive impact on the overall efficiency in different operating regions with an improvement in the range of 1–3%. The behaviour of the two control variables have been elaborately studied in which it is found that the system loss coefficient has reduced drastically due to rounding effects, while the extent of changes to the exit relative flow direction seems to be limited in comparison. The reasons for changes to these control variables have been physically interpreted and attributed to the behaviour of the wake zone at the turbine inlet and circulation within the impeller control volume.

The larger picture of impeller rounding has been discussed in comparison with performance prediction models in pumps as turbines. The possible limitations of the analytical model as well as the test setup are also presented. The paper concludes that the impeller rounding technique is very important for performance optimization and recommends its application on all pump as turbine projects. It also recommends the standardization of the rounding effects over wide range of pump shapes including axial pumps.

1. Introduction

1.1. Background

Pumps as turbines have come a long way since its accidental discovery by Thoma [1] for both energy recovery and decentralized power generation. The focus of the pump companies as well as the scientists has been to develop accurate prediction models for the turbine operation of different designs of centrifugal pumps. Despite there being considerable work by various scientists as reported by Williams [2], Amelio et al. [3] and Derakhshan and Nourbakhsh [4], the accuracy of these models has remained a question mark. Recently, Singh and Nestmann in [5] presented an optimization model with accuracies within ±3% for pump specific speeds 20–80 rpm. However, even this model requires continuous verification and optimization.

While the prediction model for pumps as turbines will undergo further development, there are other important issues that have to be dealt with. Singh [6] demonstrated various possibilities of modifying the pump geometry to improve the performance of a given pump in turbine mode. The topic of hydraulic optimization is the next stage of research activity in PATs and should be treated on par with the topic of prediction model. The issue of hydraulic performance optimization comes only after a convincing pump selection has been made for a given turbine application. Singh [6] showed that off the different geometric modifications attempted, the modification at the periphery of the impeller blades known as impeller rounding was the most beneficial. This type of modification was first carried out by Lueneberg and Nelson [7] and Cohrs [8] on individual pumps and both reported an efficiency improvement in the range of 1.5–2%. Singh [6] carried out inlet rounding on eight different centrifugal pumps and presented a qualitative understanding of impeller rounding effects with respect to the

Abbreviations: PAT, pump as turbine; BEP, best efficiency point.

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Nomenclature

Full scripts

A	flow area, m^2
c	absolute velocity, m/s
D	outer impeller diameter, m
g	acceleration due to gravity, m/s^2
H	head parameter, m
k	loss coefficient, $1/m^4$
$\dot{m}$	mass flow rate, kg/s
N	speed, rpm
N_q	specific speed, $NQ^{1/2}/H^{3/4}$ (N in rpm, H in m, Q in m^3/s)
P	power, kW
Q	discharge, m^3/s
r	radius vector, m
T	torque, N m
u	tangential blade velocity, m/s
w	relative velocity, m/s

Greek symbols

η	efficiency, %
α	absolute flow angle, °
β	relative flow angle, °

Superscripts

$*$	blade condition

Subscripts

1	impeller inlet (turbine mode)
2	impeller exit (turbine mode)
L	losses
p	pump mode
r	radial direction
u	tangential component

internal hydraulics. Derakhshan et al. [9] used a computer model to study the effects of impeller rounding on a low specific speed pump, but did not discuss the internal hydraulic effects.

The internal flow phenomena resulting from impeller rounding is not clear despite the fact that it is pretty evident that this modification improves performance in the turbine mode. Further, accurate understanding of these phenomena in a wide range of pump shapes remains a bigger challenge, which involves the characterization of turbomachinery parameters like the Euler momentum, impeller losses and different velocity vectors involved in the energy transfer. In addition, the relevance of inlet rounding should also be studied in comparison with prediction errors of the PAT operating line to give a holistic perspective to this modification technique. The contemporary study of impeller rounding only reports the change in performance in few pumps but falls short of bringing out the accurate internal hydraulic behaviour and its relevance to system issues like pump selection and performance prediction.

1.2. Objectives and problem outline

The background of the stated problem leads to the following objectives of the study.

(a) To develop a theoretical model based on turbomachine fundamentals with help of a zonal approach in a PAT control volume and to identify the internal variables and their behaviour.
(b) To experimentally study impeller rounding effects in a wide range of PAT shapes and to accurately characterize these effects with respect to internal hydraulic variables over the complete operating region of the PAT (part-load, BEP and overload).
(c) To study the relevance of impeller rounding compared to system issues in pumps as turbines like selection and performance prediction.

2. The pump as turbine control volume

In order to develop a meaningful model for understanding the internal hydraulic behaviour, the pump as turbine system can be treated as control volume. Beginning from the spiral volute to the draft tube entry, it is divided into five different zones as represented in Figs. 1 and 2. The hydraulics within these zones (both stationary and rotary) is function of fluid flow condition, geometry and frictional effects at the solid boundaries. But, there are more complex mechanisms involved in these zones.

The hydraulics of the zones that could be subjected to change due to impeller rounding are zone iii, zone iv and zone v. While zone iii and zone v are transition zones, zone iv is the rotary zone within the impeller. Hydraulic changes can take place with respect to flow lines at zone iii and zone iv, particularly in the inlet flow space of the zone iv. The changes in the transition zone iii and zone v are associated with relative flow direction. The flow conditions in these three zones due to impeller rounding would have to be investigated using experimental studies.

3. Theoretical model for optimization studies

The theoretical model (mentioned in Section 1.2) involves the development of a link between the external operating variables on the PAT and the internal variables using fundamental hydraulic and turbomachine laws. The model will be objected to identify the internal variables that control the entire performance and how

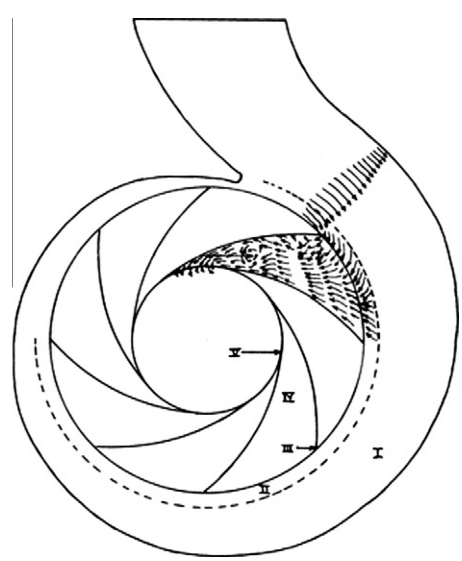

Fig. 1. Flow zones in a radial flow PAT control volume-view 1.