ABSTRACT

Paper reports a numerical study on vaneless diffuser flow instability performed for the purpose of better understanding of rotating stall mechanism in radial vaneless diffusers. This analysis is restricted to the two-dimensional flow where effect of wall boundary layers is neglected. Numerical results reveal that a two-dimensional rotating flow instability similar to rotating stall occurs when critical flow angle is exceeded. They also show that the stability limit and the structure of a two-dimensional rotating instability are influenced by the configuration geometry and inlet and outlet flow conditions. Good agreement with data from the literature is found for the stability limit and number and speed of propagating cells. Number of cells and their speed is somewhat higher than observed in experiments from literature. This might imply that inception point is caused by the core flow instability and that wall boundary layers are more determinative for the structure of rotating instability.

Keywords: Centrifugal compressor, Vaneless diffuser, Rotating stall

INTRODUCTION

The performance of compressors at low mass flows is characterized by the occurrence of unsteady flow phenomena surge and rotating stall. Both instabilities cause critical operating conditions with strong dynamical loading on the blades and can therefore not be tolerated during compressor operation. To avoid the occurrence of rotating stall and surge the compressor is operated at reduced pressure ratio to keep a safety margin to the stability limit. This action is paid with the loss of high-pressure ratios. Main effort of this research is concentrated on the development of stall and surge control systems. The understanding of the basic effects that can lead to the breakdown of the flow is important for successfully delaying or controlling it.

This paper deals with the study on rotating stall mechanism within the vaneless diffuser of centrifugal compressor. To increase the region of operation the flow dynamics of rotating stall in vaneless diffusers must be investigated. In the literature different analytical and experimental approaches have been used to investigate the rotating stall phenomenon and several theories that explain the vaneless diffuser rotating stall mechanism are developed. Jansen [1], Senoo [2], Frigne [3] and Dou [4] have used the wall boundary layer theory to investigate rotating stall. They generally hold the effect of the three-dimensional boundary layers near the walls responsible for the occurrence of rotating stall in vaneless diffuser. On the other hand a two-dimensional diffuser flow approach, where the effect of wall boundary layers is excluded, is applied by Abdelhamid [5] and Tsujimoto [6]. These studies suggest the existence of a two-dimensional core flow instability at the onset of rotating stall in vaneless diffusers. Additionally, measurements of rotating stall in vaneless diffusers are performed by Abdelhamid [7,8], Frigne [9], Dou [10], You Hwan [11], Ferrara [12,13] and Cellai [14,15]. Experimental work shows significant influence of the diffuser geometry on the vaneless diffuser performance and structure of the rotating stall pattern. Abdelhamid [7], Dou [10] and You Hwan [11] found that the performance of the vaneless diffuser is different for narrow and wide diffusers and suggested that different flow mechanisms might exist that can lead to the occurrence of rotating stall. In the more recent work also numerical studies on
rotating stall can be found although studies on rotating stall in vaneless diffusers are still rare.

Previous studies have indicated that rotating stall mechanism is still obscure and that further research is needed to discover its flow dynamics. Since some literature suggests that the core flow instability might be one of the mechanisms causing the rotating stall in vaneless diffusers, rotating stall inception in vaneless diffuser is investigated from the point of view that it can be a two-dimensional flow instability. In this paper an instability analysis of the two-dimensional vaneless diffuser flow is performed using CFD. The results of this analysis are applicable to wide diffusers where the core flow dominates and the influence of the wall boundary layers can be neglected. This analysis involves the influence of the geometry parameters and diffuser inlet flow conditions on the two-dimensional vaneless diffuser flow instability. To study the effect of diffuser inlet flow conditions, the impeller tip speed, mass flow rate and Reynolds number at diffuser inlet are varied and to investigate the influence of geometry, the diffuser radius ratio and the number of impeller blades are varied. The effect of these parameters on the stability limit of a two-dimensional vaneless diffuser flow and on the structure of the two-dimensional rotating flow instability, i.e. the number, radial and circumferential extent and speed of propagating cells, is studied and presented in this paper.

The paper consists of a number of sections. In the first section the numerical model is explained. The second and third section contain the model results which are compared with the data from literature in the fourth section. In the final section of the paper the main conclusions are summarized. The numerical results are split into two sections, one about the stability limit and the other about the structure and characteristics of the rotating instability, where the influence of the varied parameters on a two-dimensional rotating flow instability is studied and discussed. Each time only one parameter is varied while the other parameters remain unchanged.

**NOMENCLATURE**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$D$</td>
<td>diffuser width ratio $= h/r_2$</td>
</tr>
<tr>
<td>$H$</td>
<td>high rotating speed pattern</td>
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<tr>
<td>$h$</td>
<td>diffuser width [m]</td>
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<tr>
<td>$L$</td>
<td>low rotating speed pattern</td>
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<td>$m$</td>
<td>number of stall cells</td>
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<td>$N$</td>
<td>number of impeller blades</td>
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<tr>
<td>$r$</td>
<td>diffuser radius [m]</td>
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<tr>
<td>$Re$</td>
<td>Reynolds number</td>
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<tr>
<td>$t$</td>
<td>time [s]</td>
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<tr>
<td>$u$</td>
<td>radial velocity [m s$^{-1}$]</td>
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<tr>
<td>$V$</td>
<td>absolute velocity [m s$^{-1}$]</td>
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<tr>
<td>$v$</td>
<td>tangential velocity [m s$^{-1}$]</td>
</tr>
<tr>
<td>$v_{tip}$</td>
<td>impeller tip speed [m s$^{-1}$]</td>
</tr>
</tbody>
</table>

**Greek letters**

- $\alpha$: flow angle [$^\circ$]
- $\nu$: kinematic viscosity [m$^2$ s$^{-1}$]
- $\theta$: circumferential position
- $\omega$: angular velocity [rad s$^{-1}$]

**Subscripts**

- $c$: critical value
- $i$: impeller
- $m$: mean value
- $s$: stall
- $i$: diffuser inlet
- $o$: diffuser outlet

**NUMERICAL MODEL**

To study the core flow or the jet-wake instability in a vaneless diffuser a two-dimensional flow in the plane parallel to diffuser walls is modeled. The influence of the wall boundary layers is excluded.

For the numerical analysis a commercial software package, the Fluent6 code from Fluent Inc., is used. The governing integral equations for the conservation of mass and momentum are solved using the finite-volume approach. For the time dependent terms the second-order implicit unsteady formulation and for discretization of the convection terms the QUICK scheme as proposed by Leonard [16] is used. Although the studied fluid flow is turbulent, the incompressible laminar viscous flow solver is applied. Since the turbulence models capture the diffusion-like character of turbulent mixing associated with many small eddy structures it is not known if they will give the same results as the laminar model, but to avoid excessive numerical dissipation laminar viscous model is chosen for this analysis. It is assumed that the two-dimensional core flow instability is the instability of large structures that probably would be damped out if a turbulence model were used and would result in delay of instability inception. It is not known which model will better approach the real flow situation until some experiments are performed for model validation.

A two-dimensional numerical model is destined for the investigation of the core flow in the parallel wall vaneless diffuser. The reference geometry of the modeled vaneless diffuser has the inlet and outlet radius at $0.03225$ [m] and $0.04908$ [m] respectively, which gives the diffuser radius ratio of $r_2/r_1 = 1.52$ [-]. In this model the diffuser width ratio equals zero. At the reference flow condition the tangential and the mean radial velocity component at the diffuser inlet equal $v = 2.4282$ [m/s] and $u_{avg} = 0.2905$ [m/s] respectively, which corresponds to the Reynolds number of $Re = 78868$ [-] as $Re = V \cdot r_2 / \nu$. A simple two-dimensional quadrilateral grid consisting of 750 by 62 elements is applied to this geometry. The convergence criterion of $10^{-3}$ is applied to the continuity, $x$-velocity and $y$-velocity residual. At diffuser inlet the jet-wake flow pattern rotating in the clockwise direction is prescribed. The tangential velocity component is kept constant while the radial velocity component is prescribed as a square hyperbolic tangent function, generally $\tanh(N \cdot \theta + \omega_1 \cdot t)$. The rotational velocity of the jet-wake $\nu_{tip}$ is coupled to the tangential velocity component by the slip factor that is assumed to be constant, $\nu = \sigma \cdot \nu_{tip}$. The jet-wake pattern existing of 17 jet-wake lengths around the circumference, $N = 17$, and with equal circumferential length of the jet and the wake between the impeller blades is prescribed. The ratio of the jet-to-wake intensity equals 5.5. At the diffuser outlet constant static pressure is assumed.

By alternately varying the tangential and mean radial velocity component the stability of a two-dimensional vaneless diffuser flow is studied for different flow angles at the diffuser outlet.
inlet. The two-dimensional rotating flow instability, similar to rotating stall, is found to occur when the critical flow angle at the diffuser inlet is reached. The mean flow angle $\alpha_m$ at diffuser inlet is defined as $\alpha_m = \tan^{-1} (u_m/v)$. For the reference diffuser geometry it is found that if $\alpha_m < \alpha_{cr} = 6.8^\circ$, the rotating flow instability occurs. The instability is considered to occur as soon as the periodicity of the steady stable diffuser flow is disturbed. The rotating instability develops within few impeller revolutions and consists of a number of rotating cells, which propagate with approximately 35% of the impeller speed around the circumference. Because of the found similarity and a good agreement with the measurements in literature authors believe that this instability might contribute to the vaneless diffuser rotating stall.

In the following sections, the critical flow angle $\alpha_{cr}$ at the diffuser inlet and the ratio between the instability propagating speed and impeller speed $\omega_s/\omega_i$ are monitored. The estimated uncertainty in the critical flow angle and the propagation speed ratio is ± 0.1 [°] and ± 0.01 [-] respectively.

**STABILITY LIMIT**

In this section influence of the diffuser geometry and diffuser inlet flow conditions on the stability limit of the core flow is investigated. Each time only one parameter is varied with respect to the reference diffuser geometry and flow conditions that are described in previous section.

**Diffuser radius ratio:** To investigate the influence of the diffuser radius ratio on the critical flow angle the diffuser outlet radius is varied while the inlet radius remains unchanged. The critical flow angle is found to depend on the diffuser radius ratio according to figure 1. As the diffuser radius ratio decreases critical flow angle also decreases and the core flow stability of the vaneless diffuser improves. For large diffuser radius ratios such as $r_3/r_2 = 2.5$ and $r_3/r_2 = 3.0$ diffuser flow is found to be unstable or stalled for all flow angles.

For $N = 23$ and 25 diffuser flow is found to be stalled for all flow angles at the diffuser inlet. Figure 2 shows that the number of impeller blades influences the stability limit of the vaneless diffuser, but no particular trend of the critical flow angle versus the number of impeller blades can be noticed.

**Inlet Reynolds number:** Subsequently, the influence of the Reynolds number at the diffuser inlet, $Re = V \cdot r / \nu$, is varied. Figure 3 shows the obtained relation between the critical flow angle and the Reynolds number. The critical flow angle increases with increasing Reynolds number, but compared to the influence of the diffuser radius ratio on the stability limit this influence is quite slight.

For the Reynolds numbers below $2 \cdot 10^4$ no instability occurred but the solution of the stable steady diffuser flow is obtained. Since the viscosity rate increases with decreasing Reynolds number this could imply that for $Re < 2 \cdot 10^4$ the high rate of viscosity does not allow the occurrence of instability and might confirm the earlier suspicion.

The Reynolds number, based on the impeller outlet radius, at which the calculations are made is much lower than what is of interest for practical application, but in absence of wall friction the Reynolds number influences only the mixing between jet and wake and is thus almost irrelevant. Since decrease of the Reynolds number has stabilizing effect on the vaneless diffuser core flow it is expected that the obtained two-dimensional rotating instability still exists at even higher Reynolds numbers. According to figure 3 the critical angle might be somewhat higher at Reynolds numbers higher than $10^5$.

**2D ROTATING INSTABILITY**

The influence of the geometry parameters as well as diffuser inlet flow conditions on the structure of two-
dimensional rotating instability is investigated. Obtained relations between different geometry or flow parameters and instability characteristics, such as the number of propagating cells \( m \) and their rotational speed \( \omega_s \) are presented and discussed in this section. Varied geometry parameters are the diffuser radius ratio and number of impeller blades and varied inlet flow conditions are the impeller speed and the Reynolds number at diffuser inlet. Each time only one parameter is varied with respect to the reference diffuser geometry and flow conditions that are described previously.

**Diffuser radius ratio:** The influence of the diffuser radius ratio on the two-dimensional rotating instability is given in figure 4. The number of rotating cells and their propagation speed decrease as the radius ratio increases. Corresponding solutions to the three investigated radius ratios are given in figure 5, which show the structure of the two-dimensional rotating instability around the circumference. In figure 5 velocity field colored by the velocity magnitude is shown. Once a certain number of rotating cells is obtained for a given diffuser radius ratio it does not change when the mass flow is being reduced down to zero. Only the extent and the distance of the cells to the impeller reduce with decreasing mass flow.

![Figure 4: Influence of the radius ratio on rotating stall](image)

Figure 4: Influence of the radius ratio on rotating stall

Figure 5 shows that not only the number of rotating cells but also their radial and circumferential extent and distance from the impeller change as the radius ratio is varied. All of these characteristics might have influence on the propagation speed of the rotating instability. In the next section the propagation speed of the rotating instability will be extensively discussed.

![Figure 5: Solutions for different radius ratios](image)

Figure 5: Solutions for different radius ratios

The number of rotating cells decreases as the radius ratio increases while the radial as well as circumferential extent of the cells increase. Larger diffuser space allows the cells to be larger in radial extent. It seems that the circumferential and radial extent of the cells must be proportional to each other to obtain an on itself stable pattern of rotating cells. This extent proportionality is probably together with the mass flow rate determinative for the occurring number of rotating cells.

If the cell center is defined by the highest velocity point that is located in the middle of the cell then the distance of the cell center from the impeller is also observed to increase with increasing diffuser radius ratio.

**Number of impeller blades:** The number of propagating cells of the two-dimensional rotating instability that is obtained for different number of impeller blades is given in figure 6, which shows that the number of impeller blades influences the number of cells. Similar trends as shown in figure 2 are obtained, which might indicate the existence of some coupling between the critical flow angle and the structure of the two-dimensional rotating instability. It is shown that the distance between the jet and wake patterns, i.e. the density of the jet-wake patterns around the circumference, also plays role in the core flow instability and structure of the two-dimensional rotating instability within the vaneless diffusers.

![Figure 6: Number of impeller blades versus number of cells](image)

Figure 6: Number of impeller blades versus number of cells

**Impeller speed:** The influence of the impeller speed on the propagation velocity of the rotating cells is also investigated. The results show that the impeller tip speed does not influence the number of rotating cells, but also, as shown in figure 7, does not influence the propagation speed of the two-dimensional rotating instability. In figure 7 the ratio between the rotational speed of the two-dimensional rotating instability and impeller speed is plotted versus the impeller tip velocity. The flow angle at the diffuser inlet remains unchanged along the lines of constant radius ratio.

![Figure 7: Impeller tip velocity versus cell propagation speed](image)

Figure 7: Impeller tip velocity versus cell propagation speed

**Inlet Reynolds number:** Here, the influence of the inlet Reynolds number on the number of propagating cells of the two-dimensional rotating instability is studied. The obtained
number of rotating cells for different Reynolds numbers at the
diffuser inlet is plotted in figure 8. It shows that the number of
propagating cells increases from six to seven as the Reynolds
number at the diffuser inlet increases.

![Figure 8: Influence of Re on number of propagating cells](image)

Decrease in the Reynolds number at diffuser inlet results in a
slight decrease of the critical flow angle as well as the number
of propagating cells of the two-dimensional rotating instability.
This could indicate that the increasing viscosity rate stabilizes
the diffuser flow and even delays the occurrence of rotating
instability when the critical value is reached, as obtained for
$Re < 2 \cdot 10^4$.

**Comparison with Data from Literature**

To check the validity of the two-dimensional vaneless
diffuser flow model obtained results are compared with the
measurements found in literature. Experimentally most
monitored parameters are the critical flow angle at which the
instability occurs, number of stall cells and the rotational speed
of stall cells. The most varied parameters are the geometry
parameters such as the diffuser radius ratio and diffuser width.
Since this analysis is restricted to a two-dimensional vaneless
diffuser flow where the influence of the diffuser width is not
taken into account, only the measurements studying the
influence of the diffuser radius ratio are included in this section.

**Critical flow angle:** With the two-dimensional diffuser
flow model it is obtained that the critical flow angle decreases
with decreasing radius ratio improving the vaneless diffuser
core flow stability. This result is shown once again in figure 9
where the critical flow angle is plotted versus the diffuser
radius ratio. The same trend is found by Tsujimoto [6] who also
performed a two-dimensional inviscid flow analysis and found
a flow instability similar to vaneless diffuser rotating stall.
Since he prescribed a vanishing velocity fluctuation at the
diffuser inlet consisting of one, two or three stall cells, three
relations for the critical flow angle are found. Measurements of
Abdelhamid [8] showed the successive occurrence of two
rotating pressure patterns, which are in figures 9 and 11
indicated with $H$ when high rotating speed patterns and $L$ when
low rotating speed patterns are observed. The critical flow
angle at diffuser inlet at which each pattern was first observed
also increased with the diffuser radius ratio. The symbol $D$
in the legend of figures 9 and 10 indicates the diffuser width ratio,
$h/r_2$, of tested vaneless diffusers. You Hwan [11] has
measured the critical flow angle only for one radius ratio and
his measurements show the same order of magnitude of the
critical flow angle at the diffuser inlet.

Besides data processed in figure 9 a few more observations
concerning the relation between the critical flow angle and
radius ratio are mentioned here. Abdelhamid [7] showed that
generation of rotating stall in the vaneless diffuser depends on
the diffuser radius ratio as well as the diffuser width ratio. For
diffuser width ratios greater than 0.076 they found that the
larger the radius ratio the higher the critical flow coefficient.
Also a two-dimensional vaneless diffuser flow analysis
performed by Abdelhamid [5] shows that the stability limit of
the vaneless diffuser strongly depends on the diffuser radius
ratio. The results included in figure 9 as well as the
observations of Abdelhamid [5,7] are in good agreement with
the results of the current two-dimensional diffuser flow model.

![Figure 9: Comparison of the critical flow angle](image)

**Number of stall cells:** According to the current two-
dimensional model the number of propagating cells decreases
as the radius ratio increases. Not much data for comparison is
found in the literature, but the one that is found is given in
figure 10.

![Figure 10: Comparison of the number of stall cells](image)
The measurements of Abdelhamid [7] show the same trend as that of the model. They have measured three or four stall cells for \( r_3/r_2 = 1.55 \) and two or three stall cells for \( r_3/r_2 = 1.83 \).

Figure 10 shows that the number of propagating cells predicted by the current model is up to two times larger than the measured number of stall cells by Abdelhamid [7]. Usually 1 to 5 stall cells are measured during the vaneless diffuser rotating stall, which is less than obtained with the two-dimensional vaneless diffuser flow model. This difference probably implies that three-dimensional effects, which are excluded in this model, are more determinative for the structure of rotating stall.

**Propagation speed of stall cells:** As the diffuser radius ratio increases the propagation speed of the cells decreases according to the two-dimensional model, which is in good agreement with the data from the literature as shown in figure 11.

The results of Abdelhamid [7] indicate that the rotational speed of Stall cells strongly depends on the diffuser radius ratio. They found as well as Abdelhamid [8] that the larger the diffuser radius ratio the smaller the propagation speed of the stall pattern.

As assumed earlier the number of rotating cells, their extent and distance from the impeller probably influence the rotational speed of the rotating instability. In figure 12 the impeller speed is kept constant as the mass flow is being reduced. Because the geometry remains unchanged the number of rotating cells does not vary with the mass flow. As the mass flow is being reduced only the distance to the impeller and the radial and circumferential extent of the rotating cells reduces. It is expected that the propagation speed of the two-dimensional rotating instability increases or remains unchanged as the distance from the impeller reduces and the extent of the cells decreases. But since the mass flow is gradually being reduced by decrease of radial velocity component, the imposed absolute velocity at diffuser inlet also decreases. This is probably the cause of the slightly decreasing trend of the propagation velocity versus the mass flow reduction as shown in figure 12. In practice the wall shear layers may be more determinative for the propagation speed of the stall pattern than the distance to the impeller and the extent of propagating cells. As the flow angle increases the extent of the stall cells will increase and the propagation speed of the stall pattern will decrease due to the larger wall shear layer surface on the hub and shroud side of the diffuser.

**Additional observations:** Using the two-dimensional, viscous and incompressible model of the vaneless diffuser flow a two-dimensional rotating flow instability similar to rotating stall is found to exist, which implies that the core flow instability can be responsible for the occurrence of vaneless diffuser rotating stall. Tsujimoto [6], who investigated vaneless diffuser rotating stall based on a two-dimensional inviscid flow analysis, also found that the flows in the vaneless diffuser have a two-dimensional, inviscid and rotational flow instability. Besides these models, the experimental results of Tsurusaki [17] also suggested that the instability of the main flow contributes to the onset of rotating stall in vaneless diffuser, which is in agreement with the two models.

It is found that the propagation speed of stall cells does not depend on the impeller speed as shown in figure 7. This agrees with the measurements of Abdelhamid [7] and Frigne [9] who made the same observation.

Two-dimensional analysis of Abdelhamid [5] has indicated that the propagation speed of stall pattern as well as generation of rotating stall are dependent on the coupling conditions between the impeller and the diffuser. The current model shows, in figures 2 and 6, that when the number of impeller blades is changed the stability limit as well as the number of stall cells shift to different values. This is in agreement with the observation of Abdelhamid [5]. Also the
measurements of Cellai [15] show that the diffuser stability limit changes when different impellers are used.

In the early literature many investigators have shown that the vaneless diffuser rotating stall originates as a three-dimensional wall boundary layer instability but in the later years studies appeared showing that the two-dimensional core flow instability precedes the rotating stall instability. This points towards the possibility that two or more flow mechanisms might be responsible for the occurrence of rotating stall in vaneless diffusers. You Hwan [11] recognized two different mechanisms for the development of rotating stall in a vaneless diffuser, one dominated by the extension of the reentering flow from the diffuser exit and the other dominated by the growth of the local flow separation zone on the hub and shroud side. Measurements of Abdelhamid [7] and Ferrara [12,13] showed that wide vaneless diffusers behave different from narrow diffusers. This made them presume the existence of more than one set of flow conditions that could lead to the occurrence of rotating stall. This implies that distinction should be made between narrow and wide diffusers where two different flow mechanisms might lead to the occurrence of rotating stall. Generally, the core flow instability is suspected in wide diffusers and the three-dimensional wall boundary layer instability in the narrow diffusers.

CONCLUSIONS

A two-dimensional vaneless diffuser flow analysis is performed to investigate the core flow instability within the vaneless diffuser of centrifugal compressor. A two-dimensional, viscous and incompressible diffuser flow model is developed within Fluent where different geometry parameters and flow conditions are varied.

The two-dimensional rotating flow instability similar to rotating stall is found to exist. It develops within a few impeller revolutions and consists of a number of rotating cells that are propagating with a fraction of the impeller speed. This similarity and good agreement with experimental results from the literature might imply that this instability contributes to the vaneless diffuser rotating stall.

The stability limit can be expressed in terms of a critical flow angle, which is defined as the angle between the mean radial velocity and tangential velocity component.

A two-dimensional vaneless diffuser flow analysis shows that the diffuser radius ratio has significant influence on the critical flow angle, number of rotating cells and their propagation speed. As the diffuser radius ratio decreases critical flow angle also decreases and the core flow stability of the vaneless diffuser improves. The number of rotating cells and their propagation speed both decrease with increasing diffuser radius ratio. When the influence of the diffuser radius ratio on the vaneless diffuser flow instability is compared with the data found in literature generally a good agreement is found. The predicted number of rotating cells and their propagation speed are somewhat higher than the experimentally obtained values. This might imply that three-dimensional effects, which are excluded in this model, are more determinative for the final structure of rotating stall and that the two-dimensional flow instability is more decisive for the stability limit.

According to the current model the number of impeller blades influences the critical flow angle and the number of rotating cells. This implies that the structure of the stall pattern as well as the stability limit are dependent on the coupling conditions between the impeller and the diffuser. This is in good agreement with the observations found in literature. Since the inlet flow conditions seem to have significant influence on rotating stall, a two-dimensional vaneless diffuser flow analysis will be extended with simulations where the influence of the different jet-wake shapes and intensities on rotating stall is investigated.

By prescribing the fixed inlet conditions the interaction with the impeller is not taken into account in the current model. It is not known if the upstream impeller affects the vaneless diffuser stall or not. Abdelhamid [5] shows that stall pattern depends on the coupling conditions between the impeller and diffuser and Tsujimoto [6] shows that vaneless diffuser rotating stall is nearly unaffected by the upstream impeller.

The influence of the diffuser radius ratio on the stability limit and structure of the stall pattern suggests that not only the inlet but also the outlet flow conditions influence the vaneless diffuser rotating stall.

Investigation on the influence of the inlet Reynolds number has shown that the increase in Reynolds number at the diffuser inlet results in slight increase of the critical flow angle and the number of rotating cells. Since decreasing of the Reynolds number seems to have stabilizing effect on the diffuser flow a suspicion that the high amount of viscosity could delay the occurrence of instability might be confirmed.

For a given impeller-diffuser configuration the propagation velocity of rotating cells is probably a function of the distance of stall cells to the impeller, the number and extent of the cells and not a function of the impeller speed.

Current model points towards the possibility that the core flow instability might be one of the mechanisms responsible for the rotating stall in vaneless diffusers. To validate this model and to investigate the other flow mechanisms and investigate the difference between wide and narrow diffusers the numerical model will be extended to a three-dimensional vaneless diffuser flow analysis.

Besides the numerical analysis also experiments within a water model of the vaneless diffuser will be performed for comparison with the numerical model. When more research data become available the analysis will be also extended with the identification of the physical phenomena and mechanisms that can be responsible for the vaneless diffuser rotating instability.

ACKNOWLEDGMENTS

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