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[Extended Abstract]

Effects of uncertainty and quasi-chaotic geometry on the leakage of brush seals

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Introduction

To fulfill the goal of improving the overall efficiency of thermal turbomachinery, the development and improvement of the secondary flow system of this machinery is a crucial task. The usage of advanced sealing technologies for this demanding assignment, has been shown to be very beneficial [1]. Brush seals are one of these advanced seals [2]. Because of the great number of individual wires, which deform reversibly under the attack of external forces, this sealing is challenging to build, apply, and even more to model theoretically due to the interaction of the flow and the flow geometry.

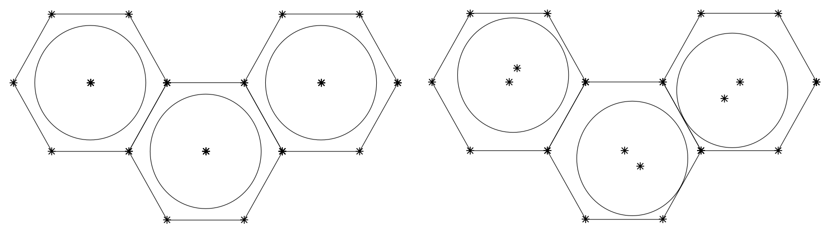
To lay the foundation for a deeper understanding of brush seals, a bottom-up strategy, gaining an empirical validated numerical fluid-structure interaction model, is required. The first cornerstone of this strategy – the generation of a sub-system model of the bristle package – is to be accomplished by creating a parameterized computational fluid dynamic (CFD) model and analyzing the flow through the bristle package without its movement.

1. Methods and modeling

The geometrical structure is gained by a MathWorks® MATLAB® tool which has been developed for this purpose. This tool allows to configure the number of axial and quasi-circumferential bristle rows, the diameter D of the bristles and the dimension e of their circumscribing hexagonal shaped probability ranges. Furthermore a probability density function P within the probability range can be applied. Depending on the variance σ^2 of the probability density function P the geometrical structure can be altered from a regular arrangement with $\sigma^2 = 0$ (figure 1 (a)) to quasi-chaotic arrangement with $\sigma^2 > 0$ (figure 1 (b)). The output of the tool is a JavaScript™ with ANSYS® DesignModler™commands.

The JavaScript™is processed within ANSYS® DesignModler™ to gain a 3D computer aided design (CAD) model. Using ANSYS® Workbench™ the 3D CAD model is interconnected with ANSYS® ICEM CFD™ where, based on user generated templates, a structured multi-block mesh is generated automatically. This methodology is used to perform a grid convergence study where the meshes are applied to a ANSYS® CFD™ solver, either ANSYS® Fluent® or ANSYS® CFX®, for the purpose of solving the governing Reynolds averaged Navier-Stokes (RANS) equation of the flow field.

Post-processing is carried out to obtain the flow field variables (mainly pressure p and velocity $\boldsymbol{u}$ distribution) as well as the leakage mass flow rate $\dot{m}$.



(a) Regular arrangement. (b) Quasi-chaotic arrangement.

Figure 1. Example of bristle pack arrangements (flow direction from left to right).

2. Validation

Validating the CFD flow model of brush seals is rather demanding. From the experimental point of view it's complex to measure the pressure p and velocity $\boldsymbol{u}$ fields within the bristle pack with sufficient accuracy due to the small dimensions of the bristle pack and the bristles itself. The only recorded measurements, regarding the flow domain, mostly are the pressure upstream p_{up} and downstream p_{do} of the bristle pack and the therefore adjusted leakage mass flow rate $\dot{m}$ [3]. Accordingly only these variables are available and used validating the numerical model with experimental data.

Another option to validate the generated CFD model is the use of semi-empiric flow models based on porous media approaches to model the brush seal [4][5].

Both above-mentioned validation methods are used in this paper.

3. Content

The final paper will present multiple modeling approaches for the complex texture of a bristle package and their corresponding CFD analyses. The influence of different fluid domain settings, regular as well as quasi-chaotic bristle pack arrangements and boundary conditions are discussed regarding their influence on the leakage behavior of brush seals.

The effect of different two-equation turbulence models on the solution are discussed briefly. Furthermore, a parameter study for each modeling approach is performed, varying the pressure differential Δp, bristle diameter D and spacing δ, and number of considered axial and circumferential bristles.

The numerical solutions and validating data will be compared and discussed by correlating the leakage mass flow rate $\dot{m}$, pressure drop and geometrical scale of the system and their dependency of the pressure differential Δp.

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