New Proposal to the TAMU Turbomachinery Research Consortium

MAKING BETTER SWIRL BRAKES USING CFD PERFORMANCE ASSESSMENT AND GEOMETRY OPTIMIZATION

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May 2019

SIGNIFICANCE

A swirl brake comprises a series of vanes upstream a seal inlet plane to redirect the fluid entering the seal, as shown in Fig. 1. Early in 1980, Benckert and Wachter [1] demonstrate that reducing the inlet circumferential velocity aids to enhance the stability of a labyrinth seal, hence then a swirl brake to effectively minimize the circumferential flow velocity. Since then, implementing swirl brakes in seals is a common industrial practice.

In 2014, Baldassarre et al. [2] perform a geometry optimization of a swirl brake with the aid of the computation fluid dynamics (CFD). The variables include the brake radial vane length, height, and vanes' pitch, all shown in the Figure. Surprisingly, the CFD results show the swirl brake, with a change in variable to ± 50% of the nominal value, produce a lesser percent wise change on the inlet swirl velocity.

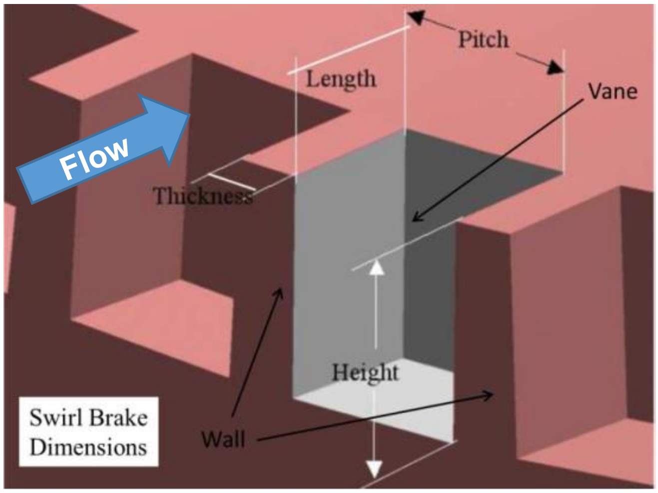

Figure 1. Schematic diagram of a swirl brake. Figure from Ref. [2].

In 2018, Venkataraman et al. [3] design a short length swirl brake for a (tooth on rotor) labyrinth seal and evaluate the influence of the swirl brake to reduce the inlet circumferential velocity. A follow up field application installs the seal on the neck rings of a six-stage centrifugal compressor and demonstrates the swirl brakes extend the compressor stable operating speed range, though at the expense of a small drop in compressor aerodynamic efficiency. The paper shows a meaningful way of combining CFD and experimental procedures to improve the stability range of a compressor via the better design of swirl brakes.

Recently, Najeeb and Childs [4] compile a large test data base for the performance of uniform clearance, smooth surface seal lubricated with a mineral oil, see Fig. 2. The experiments assess the effect of inlet pre-swirl injection speed on the performance of seals with distinct radial clearances (nominal c=0.127 mm). All seals have a swirl brake with radial vanes just upstream of the seal inlet plane. For laminar flow seals with small clearance (1×c and 2×c), the swirl brakes do not offer any substantial change on the test seals stability; that is, the test data shows similar cross-coupled stiffness. A seal with the largest clearance (3×c), however, does show the swirl brake aids to decrease the cross-coupled stiffness for the test seal.

Figure 2. A swirl brake for an annular seal. Photograph from Ref. [3].

There are plenty of successful case studies showing swirl brakes aid to enhance rotor system stability [1-3]. Alas to date there are no engineering recipes on how to design a swirl brake as per its geometry and number of vanes, except that whatever design chosen must be simple and cheap. There are no guidelines on applicability as per pressure ranges and shaft surfaces, worse yet for inlet pre-swirl conditions.

Rather than extensive experimentation, a CFD analysis is presently a rather effective virtual tool to quickly quantify the performance of a swirl brake for wide ranges of seal geometry variations and operating conditions.

PROPOSED WORK 2019-2020

This proposal will conduct CFD modeling to analyze and optimize the geometry of swirl brake for annular seals, handling liquids in particular, as in [4]. The optimization variables include the vanes length, height, wall thickness, vane number, etc. Specific tasks include:

1. Produce the geometry models and meshes for the three smooth surface annular seals with and without a swirl brake, validate the CFD predictions against the test data [4].
2. Investigate the performance of the swirl brake for various seal geometries (± 50% change in seal diameter, clearance and length) and operating conditions (± 50% change in supply pressure, rotor speed, etc.).
3. Change the optimization variables of the swirl brake, produce the meshes and employ CFD to evaluate their influence accordingly.

The CFD predictions and test data will further enable the engineered design and selection of swirl brakes for compressor applications.

Incidentally, note that the advent of additive manufacturing opens the field to produce swirl brakes with unique features that would promote further vortical structures with a larger inlet pressure drop ahead of the seal inlet to both reduce leakage and inlet circumferential fluid flow speed.

BUDGET FROM TRC FOR 2019-2020

Support for research associate (40 h/week) x $ 5,000 x 50% effort during 12 months	$ 30,000
Fringe benefits (16.8%) and medical insurance ($747/month)	$ 9,522
Support for a undergraduate student $2,500 x 50% effort of 10 months	$ 6,250
High performance research center computing fees and personal computer upgrade	$ 1,728
Travel & registration to technical conference	$ 2,500
Total Cost:	**$ 50,000**

REFERENCES

[1] Benckert, H., and Wachter, J., 1980, "Flow Induced Spring Coefficients of Labyrinth Seal for Applications in Rotordynamics," Rotordynamic Instability Problems in High-Performance Turbomachinery Workshop, Texas A&M University, College Station, TX, May 12–14, pp. 189–212, Paper No. NASA CP-2133.

[2] Baldassarre, L., Guglielmo, A., Bernocchi, A., Masi, G., and Fontana, M., 2014, "Optimization of Swirl Brake Design and Assessment of its Stabilizing Effect on Compressor Rotordynamic Performance," Proc. of 43rd Turbomachinery & 30th Pump Symposia, Houston, TX, September 23-25. DOI: https://doi.org/10.21423/R15P94.

[3] Venkataraman, B., Moulton, D., Cave, M., Clarke, C., Wilkes, J., Moore, J., and Eldridge, T., 2018, "Design and Implementation of Swirl Brakes for Enhanced Rotordynamic Stability in an Off-shore Centrifugal Compressor," Proc. of Asia Turbomachinery & Pump Symposium, Singapore, March 12-15. URI: http://hdl.handle.net/1969.1/172529. (DOI will be available on the website soon.)

[4] Najeeb, O., Childs, D. W., 2019, "Static and Rotordynamic Analysis of a Plan Annular (Liquid) Seal in the Laminar Regime with a Swirl Brake for Three Clearances," ASME J. Eng. Gas Turb. Power, **141**(8), pp. 081002.