Investigation on the axial thrust and moment coefficient of a centrifugal turbomachine

Long Abstract

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Introduction

Rotor-stator cavities are a common device in centrifugal turbomachines. The flow in such cavities can be either radial inward or radial outward and it impacts the radial pressure distribution acting on the turbomachine rotor in a certain manner. Thrust coefficient C_T and frictional coefficient C_m are two major concerns in a radial turbomachine. The investigations of the flow in those rotor-stator cavities can provide more confidence for calculating the axial thrust and frictional resistance in radial pumps and turbines. The above mentioned coefficients are greatly influenced by four parameters: through-flow coefficient $C_D{}'$, dimensionless axial gap width *G*, circumferential Reynolds number *Re* and surface roughness. This investigation is focused on the impact of C_D, *G* and *Re* on C_T and C_m. The surface roughness R_z of the disk in this study is around 1 μm. The values of R_z on all the other surfaces of the test rig are below 1.6 μm. To close the existing knowledge gap, a test rig is built up at University of Duisburg-Essen [1], shown in Figure 1. The test rig is supplied with water by a pump system. The transducers in the test rig include two pressure transducers (36 pressure tubes), a torque transducer and three tension compression transducers. A thrust plate is fixed by a ball bearing and a nut from both sides to convey the axial thrust to the tension compression transducers. A linear bearing is used to minimize the frictional resistance. During the measurements of axial thrust and frictional resistance, the values when the shaft without the disk is rotating at different speeds of rotation are subtracted. The error of the pressure transducers is 1% (*FS*). The error of the torque transducer is 0.1% (*FS*). The error of the axial thrust transducers is 0.5% (*FS*). All the experimental results are ensemble averages of 1000 samples. The scope of this study are the following parameter ranges: -5050≤ $C_D{}'$ ≤0 (negative for centrifugal through-flow), 0.38×10^6 ≤ Re ≤3.17×10^7 and *G*=0.018, 0.036, 0.054, 0.072.

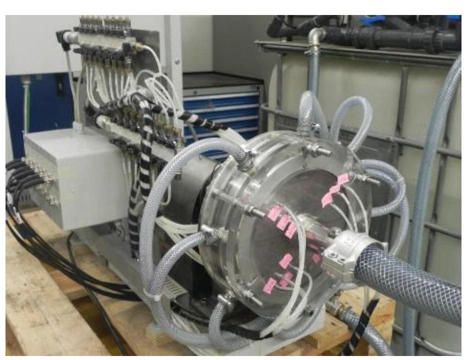


Figure 1. Test rig

1. Axial thrust

Based on the measurements, Bo Hu et al. [1] put forward an empirical equation for the thrust coefficient in a rotor-stator cavity with centripetal through-flow. Although it is organized based on the experimental results for centripetal through-flow, compared with the experimental results, it is also valid for centrifugal through-flow where $C_D{}'$ is negative. It is written as:

$$C_T = [0.0065 \cdot \ln(Re) - 0.113] \cdot e^{(0.00016 \cdot C_D{}')} \cdot [0.67 - 0.122 \cdot \ln(G)] \quad (1)$$

The comparison of the results of C_T for different *G* and $C_D{}'$ are shown in Figure 2. Eq. (p) represents the calculated thrust coefficient based on the measured pressure distribution along the radius of the disk. The experimental results of C_T are in very good agreement with those from Eq. (p) and Eq. (1). The values of C_T increase with increasing $|C_D{}'|$. The values of C_T are larger for wider axial gap in general.

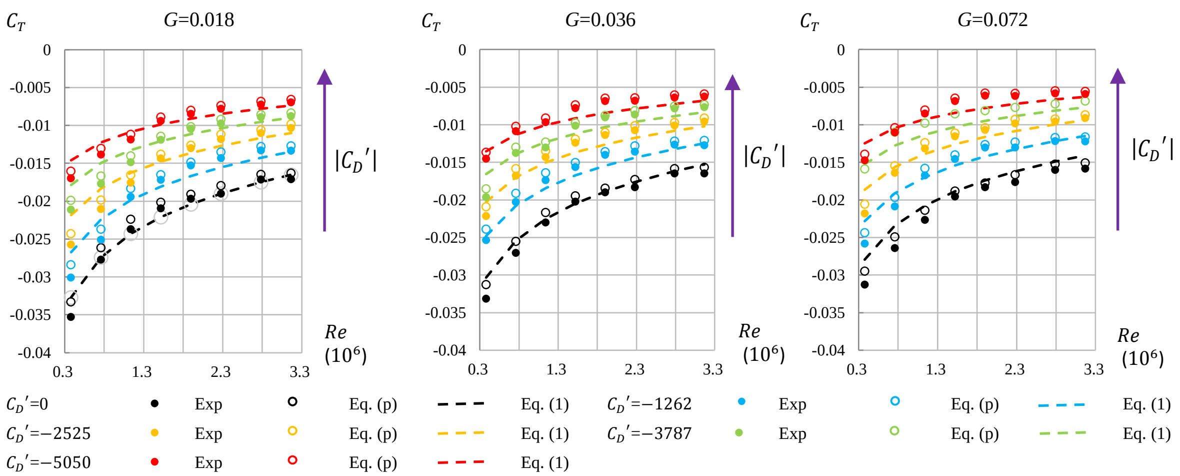
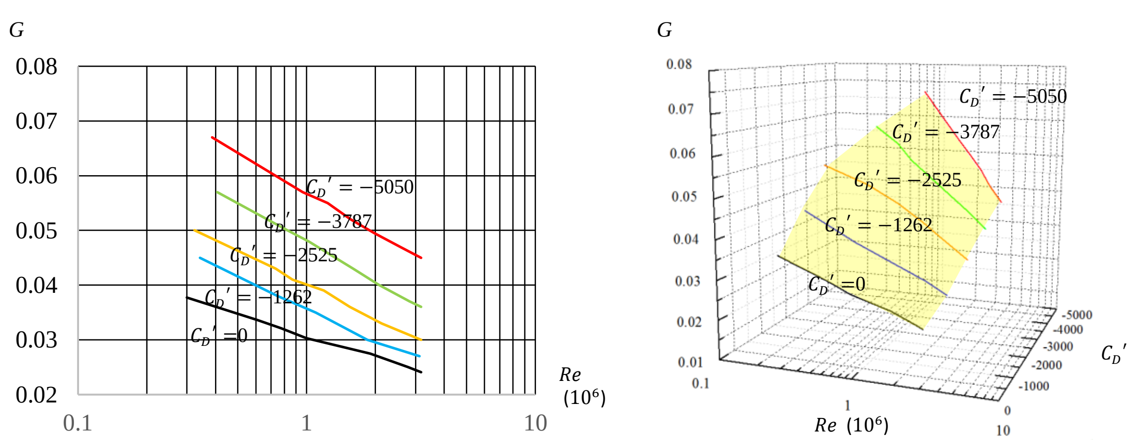


Figure 2. Mean C_{Tf} (Re)-curves

2. 3D Daily&Nece Diagram

Part of the 2D Daily&Nece diagram where the flow is categorized into four flow regimes is extended into 3D by classifying the tangential velocity profiles at *R*=0.945, *R*=0.79 and *R*=0.57 based on the results of numerical simulation (with *SST* k-ω turbulence model, $y^+ \leq 11.4$), depicted in Figure 3. Below and above the distinguishing lines are regime III (small axial gap, turbulent flow, merged boundary layers) and regime IV (large axial gap, turbulent flow, separated boundary layers), respectively. Near the distinguishing surface, there is a transition zone, where regime III and regime IV coexist in the cavity.



(a). Distinguishing lines (b). Distinguishing surface

Figure 3. Part of the 3D DailyNece diagram

3. Moment coefficient

Comparing the torque measurements by the authors with the results from Daily and Nece [2] and Dorfman [3] [4], two correlations are put forward to predict the influence of surface roughness on the moment coefficient (for a single surface of the disk), given in Eq. (2) and Eq. (3).

Regime III $$C_{m3} = 0.32 \cdot G^{-\frac{1}{6}} \cdot Re^{-\frac{1}{4}} \cdot [e^{(-10^{-4} \cdot C_D')}] \cdot \left(\frac{k_s}{b}\right)^{0.272} \qquad (2)$$

Regime IV $$C_{m4} = 0.41 \cdot \mathrm{G}^{\frac{1}{10}} \cdot \mathrm{Re}^{-\frac{1}{5}} \cdot [e^{(-0.6 \cdot 10^{-4} \cdot C_D')}] \cdot \left(\frac{k_s}{b}\right)^{0.272} \qquad (3)$$

On the distinguishing lines (see Figure 3), the results from Eq. (2) should be equal to those from Eq. (3). The results of C_{m3}/C_{m4} for a non-dimensioned gap width *G* at the distinguishing lines are presented in Figure 4. The differences, may be attributed to the existence of the transition zone, are very small in general and cover an amount less than 5%.

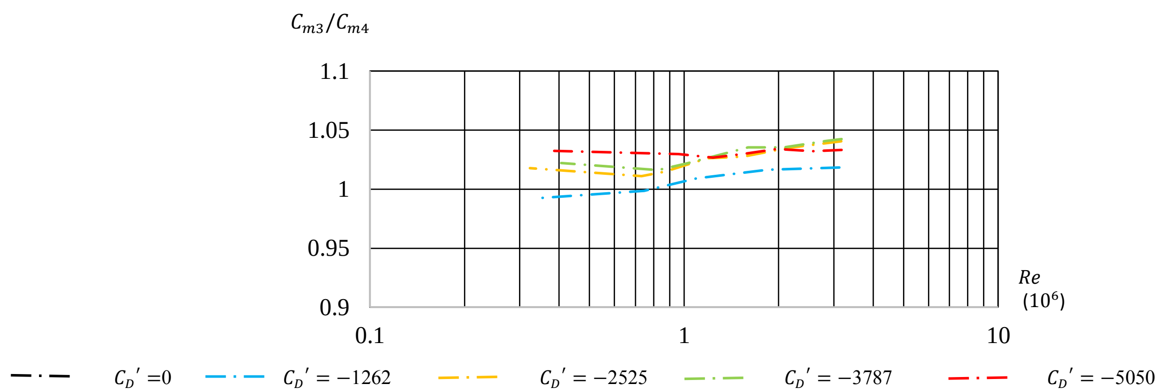


Figure 4. Results of C_{m3}/C_{m4} at the distinguishing lines

The experimental results of C_m are compared with those from Eq. (2) and Eq. (3), depicted in Figure 5. For *G*=0.018, all the flow regime is regime III (see Figure 3) and experimental results of C_m are in a very good accordance with those from Eq. (2). When *G* increase to 0.036, the flow regime changes from regime III to regime IV with the increase of *Re* for $|C_D{}'|$=0, 1262 and 2525, which can also be found based on the experimental results of C_m.When $|C_D{}'|$ further increase to 3787 and 5050, the flow regime is regime III. For *G*=0.072, most of the flow regime is regime IV. The results of C_m from experiments are in a very good agreement with those from Eq. (2) and Eq. (3) according to the flow regimes in Figure 3. The amounts of C_m increase with the increase of $|C_D{}'|$. The values of C_m drop faster with the increase of *Re* for smaller values of *G*.

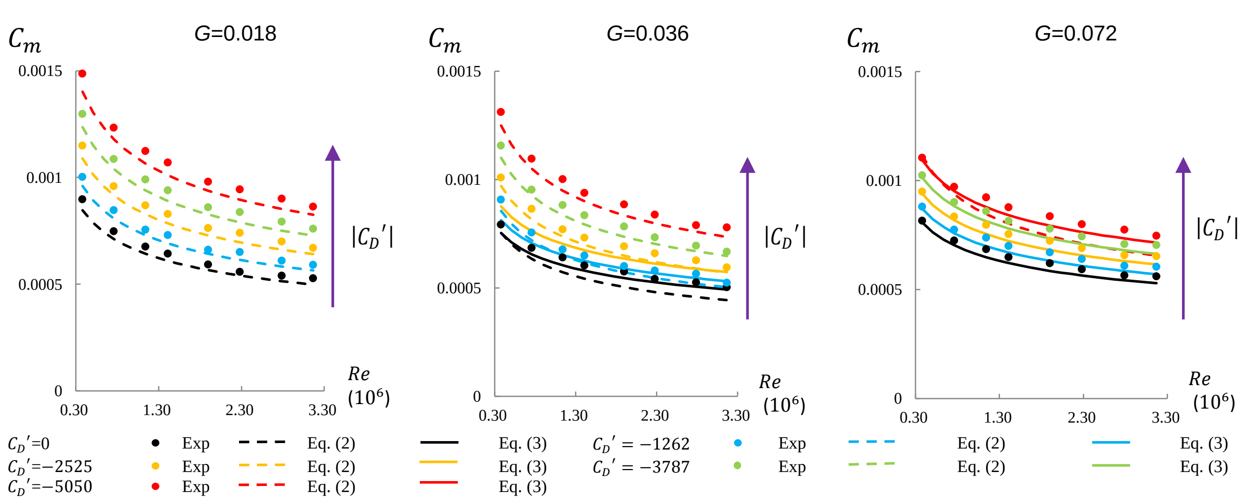


Figure 5. Main C_m (*Re*)-curves in dependence of *G*

Keywords: rotor-stator cavity, centrifugal through-flow, axial thrust, frictional torque

References

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