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[Extended Abstract]

Structure and Kinematics of the Tip Vortex in Axial Turbomachines

Peter F. Pelz, Chair of Fluid Systems, TU Darmstadt, Darmstadt, Germany
Paul Taubert, Chair of Fluid Systems, TU Darmstadt, Darmstadt, Germany

Introduction

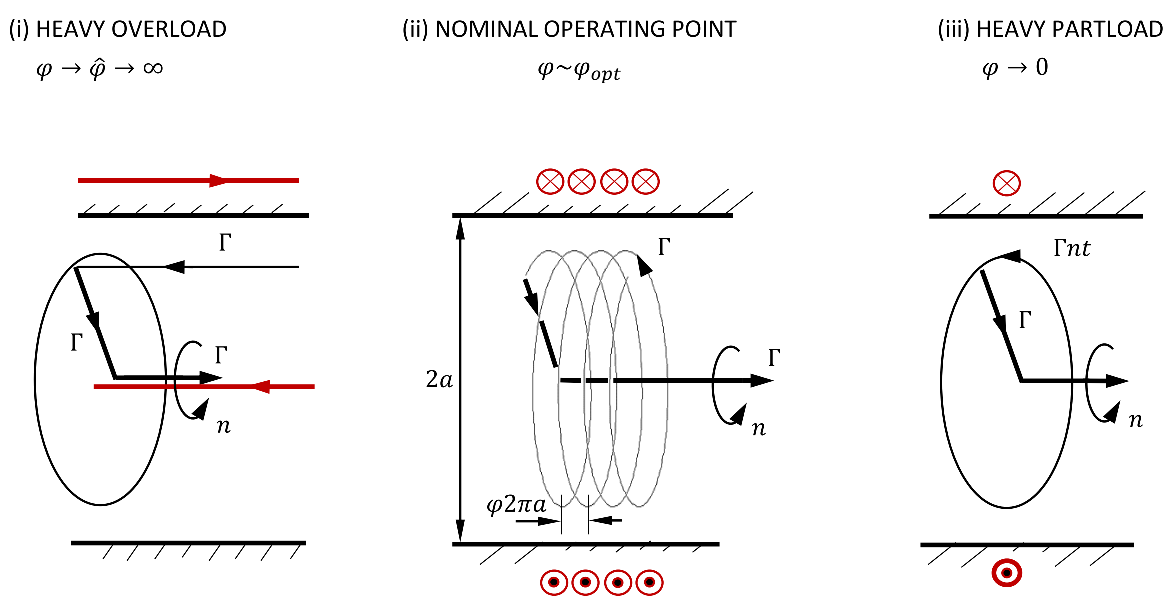

Figure 1. Vortex systems of an axial turbomachine including the boss vortex, the tip vortices and the mirrored vortices in the housing, depending on the load: (i) heavy overload, (ii) nominal operating point and (iii) heavy partload.

This investigation models the kinematics of the vortex system of an axial turbomachine at overload and discusses the influence of the induction. By doing so, the physical understanding of compressor stall at the housing, surge, spill forward and noise generation is enlarged. The total change in circulation along the plane of the machine is linked to the flow number $\varphi := U/(2\pi a n)$ by Euler's turbine equation, with U the axial free-stream velocity and a the radius of the housing. Depending on the operating point, the vortex system of an axial turbomachine changes as figure 1 illustrates. For overload $\varphi \to \infty$, the boss, the bound and the tip vortex form a horseshoe. Both, boss and tip vortex are semi-infinite, straight vortex filaments. The analysis shows an induced movement of the gap vortex against the rotating direction of the turbomachine at overload. For this case, the rotating speed of the tip vortex is half the rotating speed of the turbomachine yielding $f_{\text{ind}} = n/2$. For the nominal operating point $\varphi \approx \varphi_{\text{opt}}$ and negligible induction, the tip vortex transforms into a screw with a pitch of $2\pi\varphi a$. For partload operation $\varphi \to 0$, the tip vortices wind up to a ring vortex which is responsible for kinematic part load recirculation. Cloos et al. [1] investigate dynamic part load recirculation caused by centrifugal force.

For pumps, compressors and ventilators, the sonic emission, losses and flow separation at the housing as well as at the impeller strongly depend on the gap $s := (a - b)/a$ between the housing and the tip of the impeller at radius b [2], [3], [4], [5]. For increasing gap and lower flow number $\varphi < \varphi_{\text{opt}}$, the noise and losses increase.

1. Methods

To investigate the vortex kinematics of an axial turbomachine at overload, a planar potential flow is assumed and described using complex analysis. Helmholtz's theorems are applied to describe the circulation of the vortices. The circulation characterizes the vortex strength. For the three cases (i), (ii) and (iii), mirrored vortices are necessary to fulfill the kinematic boundary condition at the tube wall. The vortices induce a velocity on the flow, which is modeled by the Biot-Savart law. By doing so, the influence of the vortex system to the axial flow is analyzed.

References

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