EXPERIMENTAL INVESTIGATION OF ACTIVE CONTROL OF THE TONAL NOISE COMPONENTS OF AXIAL TURBOMACHINERY WITH FLOW CONTROL

Jan Schulz[1], Wolfgang Neise[2], Michael Möser[3]

[1] **Sonderforschungsbereich 557 „Beeinflussung komplexer turbulenter Scherströmungen“**, Technische Universität Berlin
Müller-Breslau-Str. 8, 10623 Berlin, Germany

[2] **Deutsches Zentrum für Luft- und Raumfahrt e.V.**, Institut für Antriebstechnik, Abteilung Turbulenzforschung Berlin
Müller-Breslau-Str. 8, 10623 Berlin, Germany

[3] **Institut für Anlagentechnik, Prozesstechnik und Technische Akustik**, Technische Universität Berlin
Einsteinufer 25, 10587 Berlin, Germany

1. INTRODUCTION

The aim of the project is to reduce the tonal noise components of axial turbomachines by using active noise control. While conventional methods use loudspeakers, the secondary sound field is generated by flow control in this study. The flow conditions near the blade tips are disturbed i.e. by blowing air into the blade tip region through nozzles (vortex generator jets), which are installed in the fan casing wall. They can be controlled such that a noise reduction of the tonal components is achieved.

2. EXPERIMENTAL FACILITY

The experiments were performed with a low-speed high-pressure axial fan with outlet guide vanes in a ducted inlet/ducted outlet configuration. A schematic presentation of the experimental set-up along with its major dimensions is given in Figure 1.

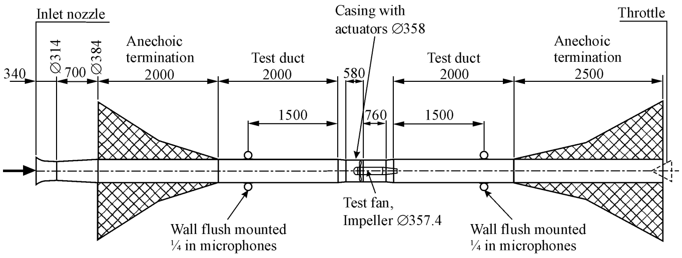

Figure 1: Experimental set-up.

The principal properties of the impeller are: diameter $D = 357.4$ mm, hub-to-tip ratio $\varepsilon = 0.62$, NACA 5-63 blade profile, blade chord length at the tip $c = 53.6$ mm, maximum blade thickness 3 mm, blade stagger angle at the tip $\sigma = 27°$. The tip clearance gap width is $s = 0.3$ mm which corresponds to a tip clearance ratio of $\zeta = s/c = 0.0056$. An impeller with $Z = 18$ blades was used for the experiments. The stator row consists of $V = 16$ stator vanes. This results in a dominant duct mode of azimuthal order $m = 2$ at the blade passage frequency (BPF); compare Tyler and Sofrin [1]. The axial distance between rotor and stator at the impeller blade tips is $\Delta x/c = 0.7$.

On both fan sides, 16 wall-flush mounted 1/4-inch microphones, equally spaced circumferentially, were used to monitor the sound fields in the anechoic fan ducts. The circumferential sound pressure distribution was then resolved into azimuthal duct modes.

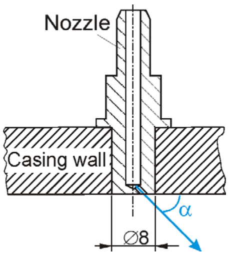

Figure 2: Sketch of the injection nozzles mounted in the casing wall.

To influence the flow conditions near the blade tips, small jets of compressed air are blown into the blade tip region through different types of nozzles. A sketch of the nozzles mounted flush with the inner duct wall is depicted in Figure 2. The axial and circumferential positions of the nozzles as well as the angle α between the jet axes and the fan casing wall were varied in the experiments.

3. RESULTS

The general possibility of reducing the blade passage frequency level (BPF-level) by means of active flow control by up to 20.5 dB was shown e.g. by [2] and [3]. The principle of operation of this active noise reduction method is that the blowing air jets cause longitudinal vortices in the flow (compare Schulz *et al.* [4]) which in turn set up unsteady forces on the rotor blade tips. The interference pattern produced by the interaction of the air jets with the rotor blades is superimposed on the primary noise generation process of rotor/stator interaction as described by Tyler and Sofrin [1].

The rotor/flow-distortion interaction can be used to produce a secondary sound field which can be controlled in both amplitude and phase. The amplitude of the secondary sound field is mainly determined by the mass flow or the momentum of the injected air jets, and its phase relation relative to the primary sound field is governed by the axial and circumferential position of the nozzles. For a fixed axial location, the circumferential position determines the phase shift between the primary and secondary flow induced sound field, see the illustration in Figure 3.

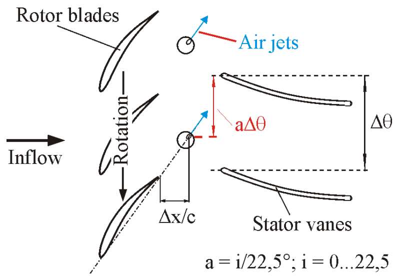

Figure 3: Sketch of the variation of circumferential position of the nozzles.

Figure 4 shows the reduction of the BPF-level ($\Delta L_{p,BPF}$) at BPF = 900 Hz, when the circumferential positions of the nozzles were varied for a fixed axial position. Fan speed, operation condition and radial jet angle α remained unchanged too. Circumferentially, the jet angle is in the direction of the rotor blade chords, see Figure 3. Only BPF-level reductions are shown in Figure 4, increases are suppressed.

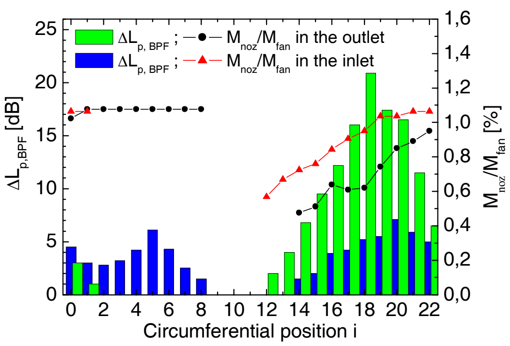

Figure 4: Reduction of BPF-level as function of the circumferential nozzle position; $\Delta x/c = 0.22$; $\varphi = \varphi_{opt}$, $n = 3000$/min, $\alpha = 45°$.

For each position i, an individual optimum mass flow was sought which is also plotted in Figure 4. The maximum BPF-level reduction was obtained at the circumferential position $i = 18$. For the positions $i = 12$ to 17, the optimum injected mass flow is smaller than the one for $i = 18$ which can be explained by the fact that at those positions the momentum of the jet flow is smaller and hence the jets are deflected more by the main flow than in case of the higher mass flow at $i = 18$. In other words, the smaller injected mass flow corrects for the not quite optimum circumferential position. Conversely, at the positions $i = 19$ to 22 and 0 to 8, the optimum injected mass flow is larger than the one at $i = 18$ and the air jets are deflected less.

When the injected mass flow is kept constant at the optimum rate for the position $i = 18$, the BPF-level reductions obtained at the other circumferential positions are lower than shown in Figure 4.

When the axial nozzle position, fan speed, or other parameters are varied, the optimum circumferential position and/or the decrease in BPF-level may change somewhat, but the trends discussed above remain the same.

The influence of the radial angle α relative to the casing wall is shown in Figure 5. Here, only BPF-level reductions in the outlet are depicted. The highest reductions are achieved for $\alpha = 45°$ and 60°. The probable reason for this finding is, that larger longitudinal vortex structures are produced than in case of the other two angles. Hence, the rotor/flow distortion interaction is more effective and results in a better reproduction of the amplitude of the primary sound field by the secondary aeroacoustic sources.

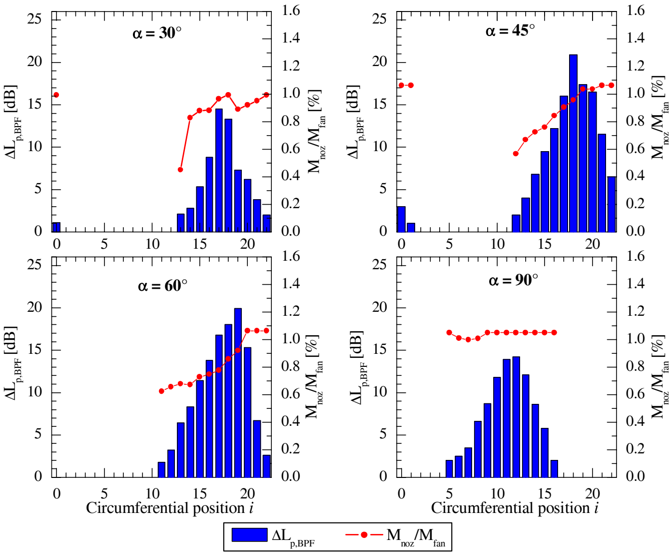

Figure 5: Influence of different radial angles α on the BPF-level reduction.

Further, the radial angle α influences the phase relation of the secondary field, too. This can be seen clearly for the case of $\alpha = 90°$, where the injection of the air jets does not cause an axial component. Hence, the vortex structures are located further in direction of the rotation (compare Figure 3) and need to be positioned further against the direction of the rotation, i.e. lower values of $a\Delta\theta$ and i, and a higher mass flow is required to obtain level reductions.

4. RESULTS WITH CLOSED LOOP CONTROL

Since the generating mechanisms of the primary sound field due to rotor/stator interaction and the secondary field due to rotor/flow distortion interaction are aerodynamically coupled, typical feed-forward algorithms or adaptive filters can not be applied. Therefore an extremum-seeking controller was used to determine the optimum mass flow for the vortex generator jets, which controls the amplitude of the secondary sound field. Detailed information on these investigations is given in [5], only the results of the acoustic measurements are presented here.

The phase of the secondary sound field was adjusted by the nozzle position and radial jet angle. The control concept can be applied successfully because the rotor/flow distortion interaction produces the required modal order of the secondary field due to the number of vortex generator jets chosen. The beneficial consequence is that the number of control variables of the controller is reduced.

Figure 6 depicts sound pressure spectra measured in the outlet duct of the fan, when nozzles with the radial angle $\alpha = 60°$ were used. A general result is that the extremum-seeking controller is effective in minimising the level of the tonal components. While with open loop control the BPF-level reduction is 1 dB higher, the reduction of the overall noise level is 1.5 dB larger in the case of closed loop control. This is due to the fact, that it is the overall noise level that is used as the input signal of the controller.

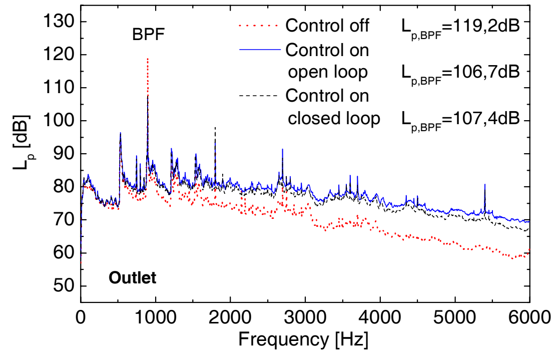

Figure 6: Sound pressure spectra in the outlet duct with ANC using open loop and closed loop control.

In Figure 7 the azimuthal mode spectrum at BPF is shown. Clearly, the BPF-level reduction is due to the reduction of the dominant azimuthal mode of the order $m = 2$.

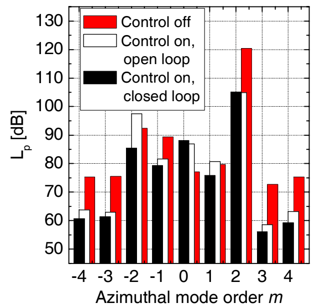

Figure 7: Decomposition of the sound field at BPF with ANC using open and closed loop control.

5. SUMMARY AND OUTLOOK

Different parameters were investigated which are relevant to active control of the tonal noise components of an axial fan by means of flow control. Using vortex generator jets to create the superimposed rotor/flow distortion interaction, the influence of the injected mass flow and geometrical position as well as the blowing angle of the nozzles was discussed. It was also shown, that a closed loop control using an extremum seeking algorithm could be implemented successfully. Future work will focus on extending the method to reduce radial modes and apply the closed loop control to both amplitude and phase of the flow induced secondary sound field.

6. REFERENCES

[1] TYLER, J.M.; SOFRIN, T.G.: Axial flow compressor noise studies. *Transact. of the Soc. of Automotive Engineers* **70**, pp. 309-332.

[2] SCHULZ, J.; NEISE, W.; MÖSER, M.: Active Noise Control in Axial Turbomachines by Flow Induced Secondary Sources. AIAA-2002-2493 8th *AIAA/CEAS-Aeroacoustics Conf.*, 17.-19. June, Breckenridge, CA, USA, 2002.

[3] SCHULZ, J.; MÖSER, M.; NEISE, W.: Aktive Beeinflussung des Drehklangs axialer Turbomaschinen. 28. Deutsche Jahrestagung für Akustik, DAGA 2002, 04. - 07. März, Bochum, 2002.

[4] SCHULZ, J.; FUCHS, M.; NEISE, W.; MÖSER, M.: Active Flow Control to Reduce the Tonal Noise Components of Axial Turbomachinery. AIAA-2002-2949. 1st Flow Control Conf., 24.-27. June, St. Louis, Missouri, USA (2002).

[5] GARWON, M.; SCHULZ, J.; SATRIADARMA, B.; KING, R.; MÖSER, M.; NEISE, W.: Adaptive and Robust Control for the Reduction of Tonal Noise Components of Axial Turbomachinery with Flow Control. CFA/DAGA04, Strasbourg, March, 2004.