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APPLICATION OF ROTATIONAL BEAMFORMING ALGORITHMS ON FAST ROTATING SOUND SOURCES

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ABSTRACT

Aero-acoustic sound sources on fast rotating objects are difficult to be localized using standard beamforming algorithms due to the very limited integration time. As a result both the usable frequency range and source localization suffer. One method to overcome this problem is the application of so called rotational or rotating beamforming algorithms using a virtual array rotation. This paper presents various applications of this kind of beamforming algorithm and first results. It starts with a very simple arrangement of broadband sound sources on a slowly rotating turntable to prove the accuracy and reliability of the algorithm. Then a standard ventilator was tested. In the next step a fan test stand was constructed for the investigation on different impeller designs on single and contra-rotating fans with the aim of acoustic optimization.

1 INTRODUCTION

In [1] Puhle et. al. presented a rotational beamforming algorithm based on a virtual array rotation. As it is realized as a filter it can be applied in both the time- and frequency-domain. Therefore it allows for the usage of all known advanced beamforming algorithms like CLEAN-SC, orthogonal and functional beamforming or acoustic erasers.

Standard beamforming algorithms assume that the microphone array and the measurement object are spatially fixed to each other. This is obviously not the case with rotating sound sources. The rotational beamforming algorithm determines the signals of a virtual microphone array which is fixed in the coordinate system of the fan and virtually rotates with the rotational speed of the source. As a consequence the observed sound field seen from the array can be assumed as quasi-constant under the condition of a constant rotation speed. Hence, integration intervals of any length can be chosen. This not only leads to a much higher averaging and therefore a more reliable and constant signal, but also a higher frequency resolution. The smearing of the aero-acoustic sound sources which can occur with a high integration time without rotational beamforming is avoided.

The first experiment that was conducted was a rather simple arrangement of two smartphones placed on a turntable. Both played back broadband noise and rotated with the rotational speed of the turntable of 45 rpm. Figure 1 shows results without (left) and with (right) rotational beamforming. They were obtained from the time-domain and show the broadband result.

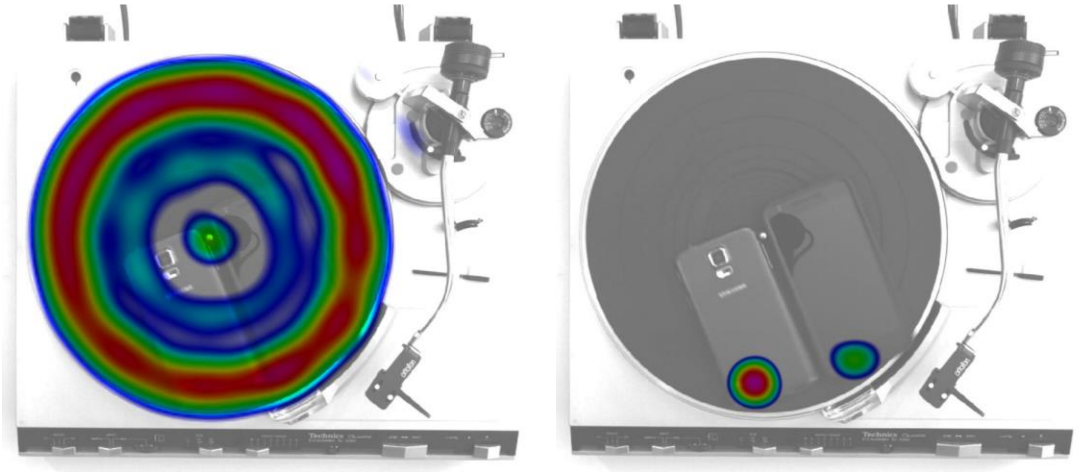


Fig. 1. Two broadband sources rotating on a turntable with 45 rpm; left: without rotation beamforming the typical smearing of the sources occurs; right: with rotational beamforming both sources can be separated and be depicted at the correct position

To obtain proper results with the proposed method a highly precise positioning of the array during the measurements is of importance. The measurement plane with the object under test and the microphone array plane must be in parallel. Furthermore object and array must be aligned concentric. Consequently symmetric sensor arrangements like ring arrays are much more suitable. Before starting the tests one must be assured that both conditions are fulfilled.

Another challenge is the frame rate of standard optic cameras, which is much lower than the rotation speed of most observed sources. This also leads to a smeared optic picture even at low integration intervals. Before starting the analysis the video channel of the data stream is replaced by a still picture of the arrangement which is taken with the fan standing still. Figure 2 shows the blurred picture from the video stream when using a reasonable integration time on the left and on the right the still picture it was replaced by. They were taken from a measurement of a ventilator.

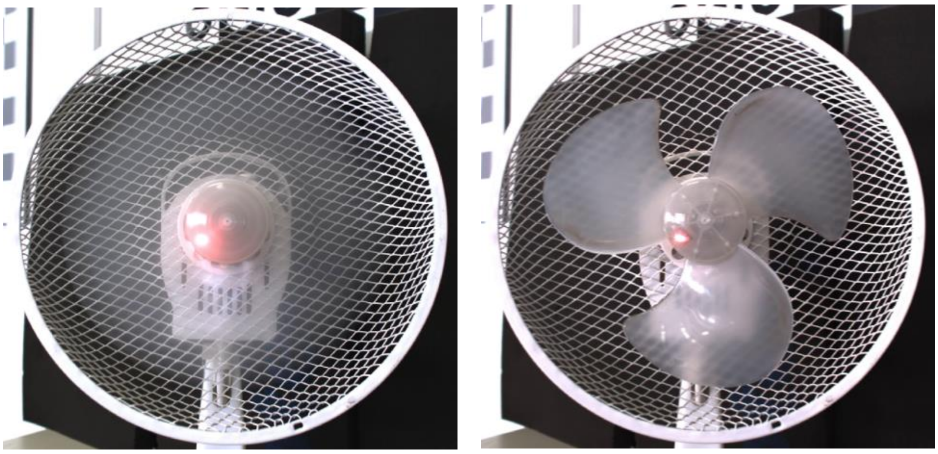


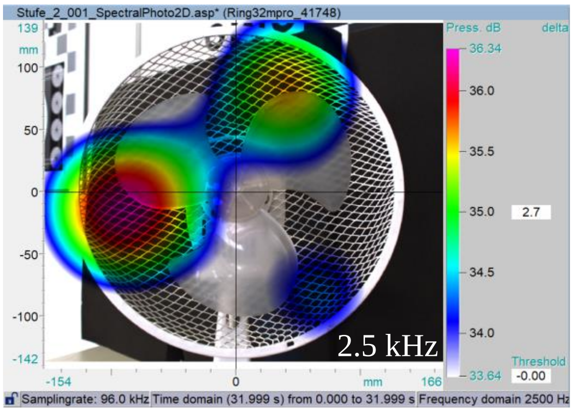
Fig. 2. Left: blurred picture resulted from the overlap of the video frames within the used integration time, the blades cannot be localized; right: still picture of the arrangement which was used as replacement

The rotation speed must be determined, for example with a digital laser rpm-meter. The laser is periodically reflected from a reflective foil on the fan and the starting position can be chosen when the laser hits the centre of the reflective foil. This position then is chosen for taking the still picture.

2 APPLICATIONS

2.1 Ventilator

The described method was now applied on a standard household ventilator with three blades. The following figures show results in various third octave bands.



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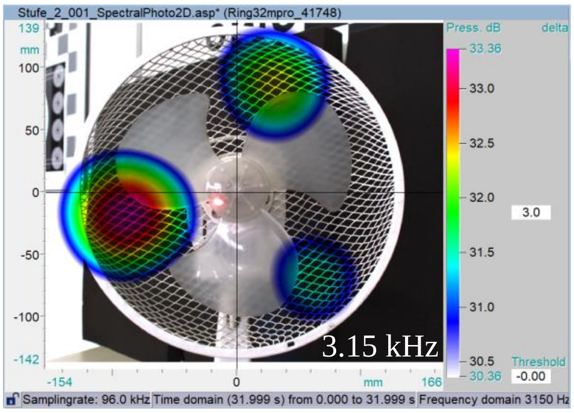

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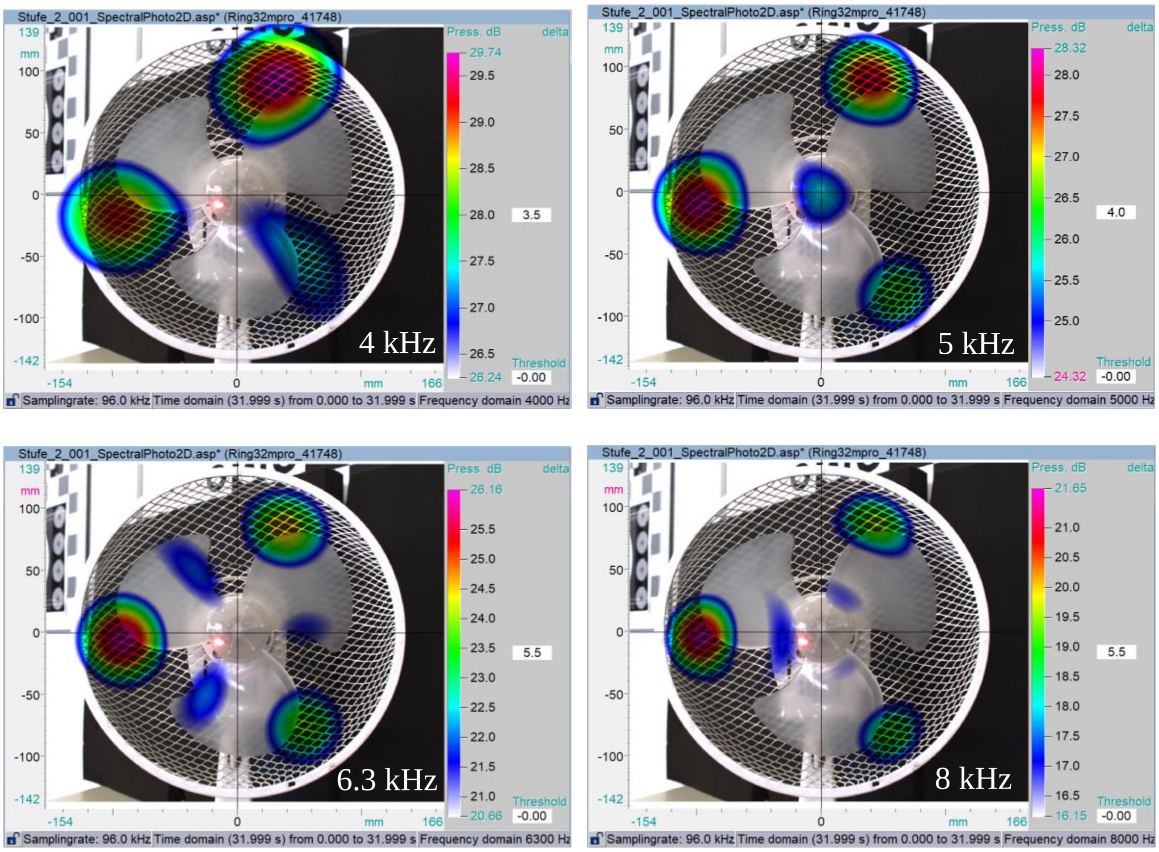

Fig. 3. Acoustic images of the investigated ventilator in various third octave bands using phase-shift beamforming after the rotational beamforming filter was applied

Figure 4 focuses on the 6.3 kHz third octave band. It shows acoustic pictures without and with the application of orthogonal and functional beamforming.

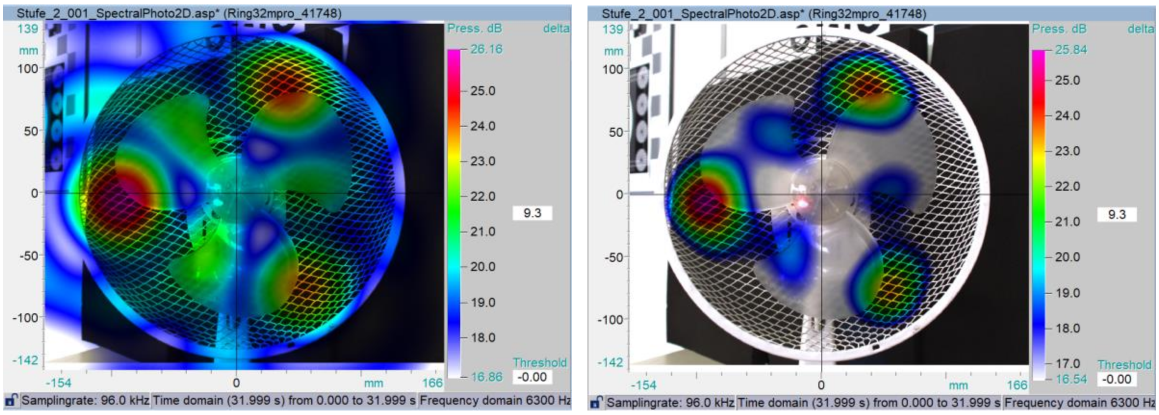

Fig. 4. Acoustic images of the investigated ventilator in the 6.3 kHz third octave band; left: standard phase-shift beamforming; right: applying both orthogonal and functional beamforming; both pictures use the same dynamic of 9.3 dB

2.2 Fan Test Stand

Rotational Beamforming is an obligatory tool for the evaluation of rotating sound sources. To be able to evaluate the influence of different fan designs on the efficiency and noise emission a fan test stand was constructed. Details on its specifications can be found in [1] and [2]. First acoustic tests were performed on the single fan outside the test stand. Unfortunately there was no still image captured, thus the optic picture is blurred. Figure 5 shows results in various third octave bands.

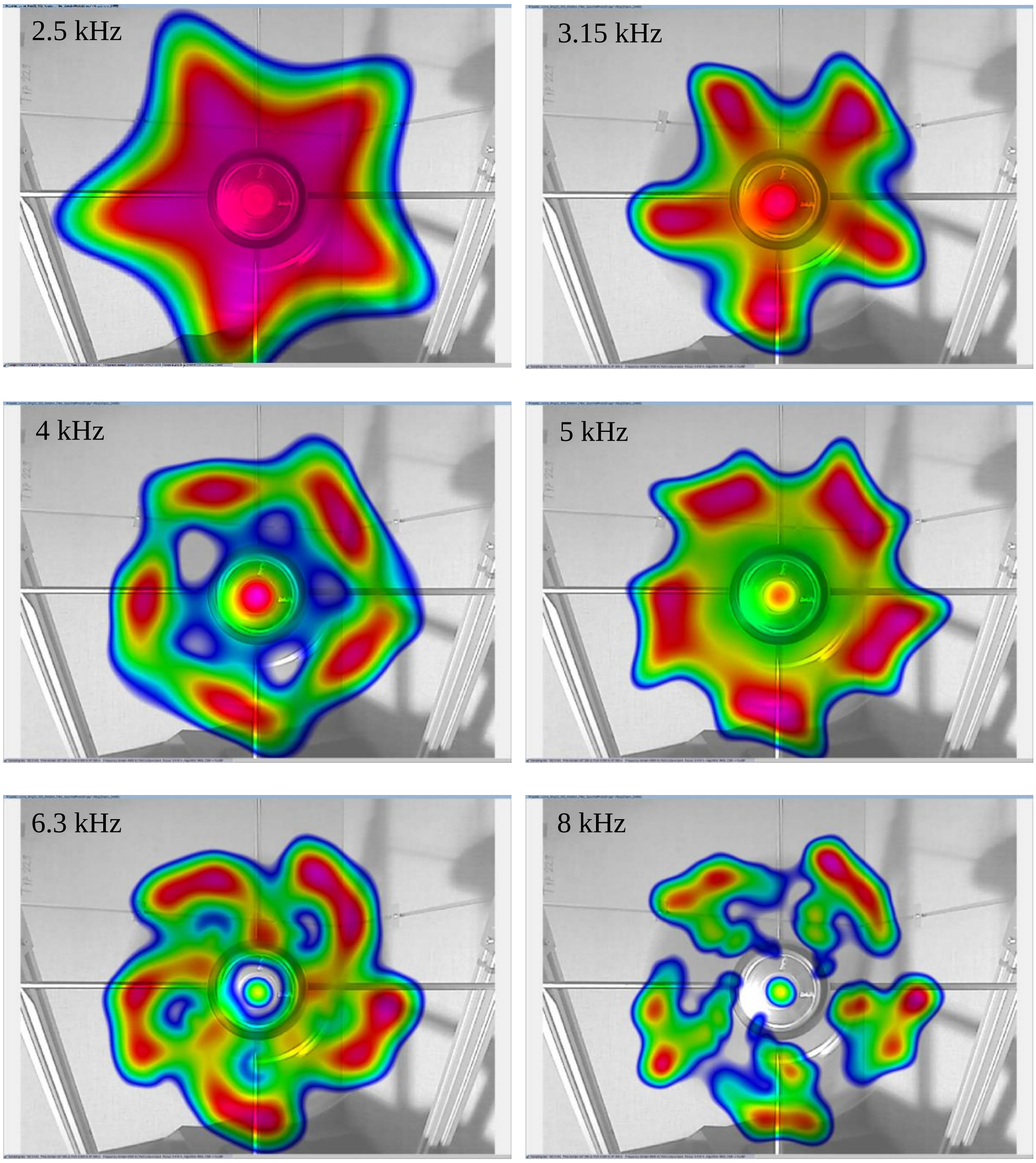

Fig. 5. Acoustic images of the first fan sample of the test stand in various third octave bands; all use orthogonal and functional beamforming and show a dynamic of 20 dB

In the next step the fan was mounted into the fan test stand which allows for the adjustment of flow and pressure parameters and therefore the efficiency.

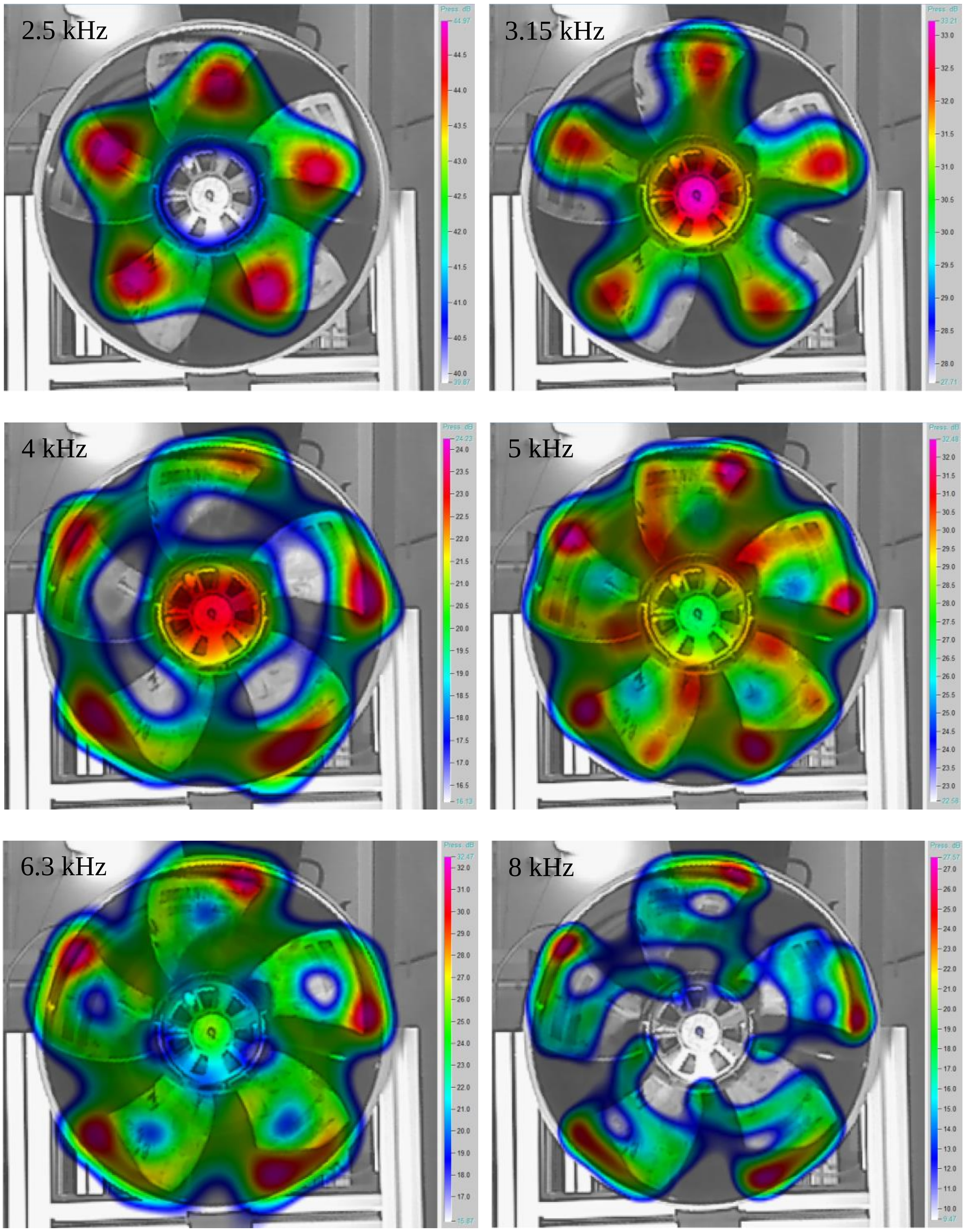

Fig. 6. Acoustic images of fan sample mounted in the test stand in various third octave bands; all use orthogonal and functional beamforming [1]

2.3 Fan Test Stand with Contra-Rotating Fans and Variations

It has be proven, that the rotational beamformer can localize aero-acoustic noise sources on single axial fans in the free-field, like the ventilator, or in the tube or the test stand respectively. In many fields of application a design with two contra-rotating fans can be advantageous and increase the efficiency. However, they suffer from a higher noise emission. In the next step of the project the usage of the rotational filter on such arrangements is investigated with the aim of finding a fan design with a decreased noise level while still having a high efficiency. [2] provides an overview on the tested fans, the design parameters and the testing environment, figure 7 shows first results.

One has to note, that there are two rotational speeds of two impellers here. Thus, the rotational filter can be fed with two different rpm-signals and the corresponding direction of rotation which leads to different results.

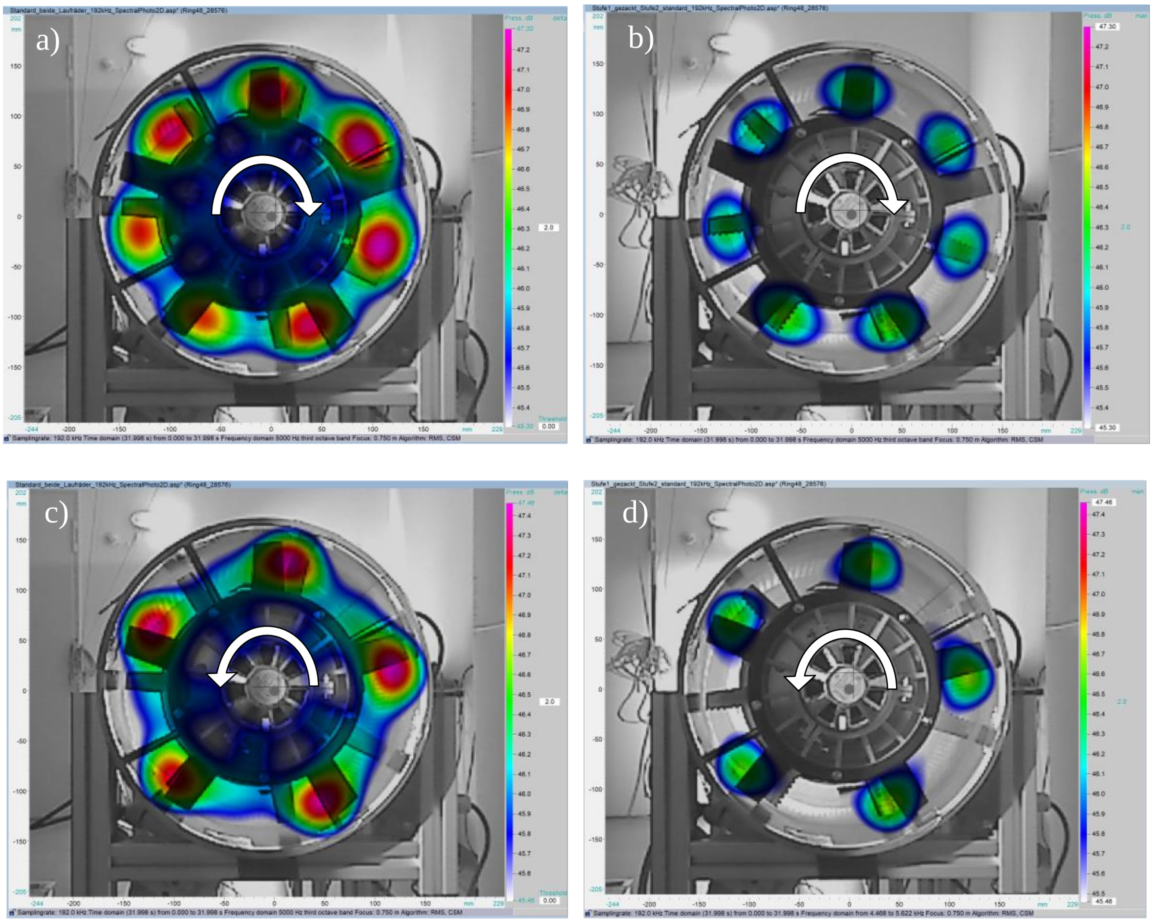

Fig. 7. Acoustic image of the 5 kHz third octave band on a contra-rotating fan; all use standard phase-shift beamforming [2]

First row a) and b): rotational filter using the rpm-signal of the clockwise rotating inner impeller A; a) both impellers with standard vanes; b) impeller A with serrations

Second row c) and d): rotational filter using the rpm-signal of the counter-clockwise rotating outer impeller B; c) both impellers with standard vanes; d) impeller A with serrations

Figure 7 shows clearly the 7 blades of impeller A, when applying the rotational filter using its corresponding rpm-speed and the 5 blades of impeller B, when using the rpm-speed of impeller B. Furthermore it proves, that the noise level in the depicted frequency band could be reduced by approx. 1 dB with the implemented serrations.

3 CONCLUSIONS AND OUTLOOK

Various applications of a rotational beamforming algorithm on rotating sound sources are presented in this paper. They prove the accuracy and reliability of the method and its capability of localizing various aero-acoustic noise sources in several frequency bands. Thus it is a useful tool for the evaluation of different fan and impeller designs and therefore the starting point and reference tool for optimization, noise reduction and sound design on fans etc.

One project on which the method is applied is the presented fan test stand. It was shown, that the filter even performs well on contra-rotating fans. Further comprehensive investigations are on-going to profoundly understand the influence of design variations on the impellers and the mutual interference from the sound fields of both impellers.

Current work uses the filter to assess the impact of proplets on the noise emission of propellers on drones. The results will be presented in a future paper.

Drawback of the presented method is the required accurate positioning of the array in respect to the measurement object. Consequently it is not yet usable for measurements from an oblique position. This is the case when measuring wind power plants from a remote position for example. The adaption of the algorithm for such scenarios should be part of future work.

ACKNOWLEDGEMENT

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